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Optimization of Electric Vehicles Charging Stations in Urban Areas: A Huff Model and Genetic Algorithm Study of Chandigarh, India

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Abstract
With the rapid adoption of electric vehicles (EVs) in India, a coherent approach in developing public charging infrastructure is essential. In this paper, we propose a hybrid framework integrating the Huff Model with a Genetic Algorithm (GA) to determine the optimal locations of EV charging stations in Chandigarh city. Chandigarh is the best choice for study because of its highest charger-to-vehicle ratio in the country. The Huff Model approximates the probability of individual demand nodes (residential and commercial) to select specific charging facilities in view of site attractiveness and location decay. The GA optimization process is iterative in search of the most efficient station configuration with the aim of maximizing aggregated accessibility and minimizing energy deficiency given the constraints of solar energy and battery storage based on Chandigarh 500 kWp photovoltaic (PV) chargers. A synthetic demand of 10 destinations in Chandigarh is used to simulate the demand of urban traffic with the load variation, solar production, and grid reliance. Computational evidence shows that the convergence of the GA fitness score between 0.45 and 0.95 with respect to multiple generations, indicating a satisfactory equilibrium in charging demand versus solar energy utilisation. With the inclusion of the PV capacity and battery state of charge in the algorithm we can reduce grid dependence by about 28 per cent compared to non-solar optimization runs. The resultant spatial distribution outlines the strategically ideal areas within the Sector 17, Sector 35, and the Industrial Phase I and the IT Park in respect to technical efficiency and enhanced consumer experience with a provision of accessibility, shorter wait time and greater dependability of the charging services delivery. This is the first study to offer a hybrid and scalable model of an EV charging infrastructure. In future, testing the model with real-time data can be insightful to develop the sustainable charging infrastructure across diverse cultures.
Keywords: Electric Vehicle, Huff Model, Genetic Algorithm, Solar Integration, Charging station Optimization, Chandigarh, Experience

1. Introduction
Transportation emerged as a major contributor to global greenhouse gas emissions realising an estimated 37.4 gigatonnes (Gt) of CO_2 in 2023. Road transport alone accounts for approximately 16% of these emissions (IEA, 2024). Electric and hybrid vehicles provide a new and sustainable approach to a low-carbon mobility model to reduce these high emissions (Gnanavendan et al., 2024). Electric vehicles (EVs) are a key indicator of a fundamental transformation in urban mobility, contributing to significant reductions in greenhouse gas emissions and reliance on fossil fuels. India has been encouraging the adoption of EVs as a strategy to reduce air pollution and sustainable development under the National Electric Mobility Mission Plan (NEMMP 2025) (Ministry of Heavy Industries, 2024). Chandigarh has become one of the first Indian cities to lead in electric mobility. In the financial year 2024–25, the city reported an approximate 14.8% share in EV mobility (Yadav, 2025) and the highest charger-vehicle ratio (IANS, 2024).

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To mobilize the EV ecosystem, locational convenience and ease of availability needs to address from the users' perspective (EV Mechanica, 2025; Kore and Kaul, 2022). Cost, technology, and structured approach to place the EV stations as per users' mobility patterns are essential to achieve long-term sustainability objectives (Hildermeier et al., 2019; Narasipuram and Mopidevi, 2021; Kore and Kaul, 2022; NITI, 2023). Therefore, the placement of EV charging stations should be based on users' demand in specific areas, their preference for certain retail formats, and the accessibility of the underlying electrical grid. Traditional models often fail to understand the users' preferences for visiting charging stations and the influence of onsite renewable generation on service availability. Hence, a probabilistic and optimization approach is required to build a scalable, user-focused charging system that can support the current EV development in Chandigarh.

The present paper offers a novel approach of integrating the Huff Model-a spatial interaction model (commonly used in retail site selection) (Huff, 1963) with a Genetic Algorithm (GA) optimization framework that considers the opportunities of solar photovoltaic (PV) energy generation and battery storage options, which reflect the innovative solar-powered EV charging centers of Chandigarh (CREST Chandigarh, 2025; Sagar, 2025; Sarker et al., 2025). Applying Huff Model to the service sector is a quantitative technique of explaining the users' preference to a particular location (Huff, 1963; Li and Lu, 2012). In the present study, the Huff Model is employed to estimate the probability of EV users choosing a given charging point based on site attractiveness and distance-decay effects. It will point out the heterogeneity of the spatial demands. Simultaneously, the GA-an iterative algorithm is used to explore the solution space and determine the optimal combination of charging station locations. The objective is to maximize system accessibility while promoting renewable energy utilization, minimizing dependence on grid electricity, and reducing overall costs.

The study is conducted in Chandigarh, which is the region where EV demand is distributed spatially in commercial, residential, and industrial locations, including Sector 17, Sector 35, and IT Park (Pulse Energy, 2024). Empirical study of distributed PV generation incorporating storage based on four operational solar-powered hubs and this could be applied to model the changing demand. The research executes the simulation of the GA convergence with the artificially created data of load and solar capacity, and it may be observed that the optimal network utility and grid decrease potential have been enhanced considerably in 100 generations. The key objectives of the research are:

1. Developing a spatially explicit demand model in the Huff probability framework.
2. Optimize the GA based algorithm using a combination of spatial probabilities of choices, solar energy supply forecasting and battery storage capacity limits;
3. Learning how to apply the spatial model using estimations of EV demand and solar profiles.
4. Prioritizing urban locations in EV Charging stations to enhance sustainable urban mobility infrastructure.
5. Improving the customer experience through the smart placement of EV charging stations to increase customer access and convenience.

This paper is structured as follows. Following the introduction regarding the occurring issues in EV charging infrastructure in urban settings, the study objectives and suggested approaches are discussed in detail. Next, the literature on the proposed hybrid approach integrating the Huff

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model and GA is presented for a detailed view. The research methodology section presents the formulations and algorithmic perspective of the hybrid approach. Next, an illustrative dataset in an artificial setting is generated, incorporating demand, solar energy potential, and other key variables necessary for spatial planning. Thereafter, findings have been presented in a discussion about infrastructure planning to perform the spatial demand in Chandigarh city, followed by policy recommendations. Finally, the conclusion summarizes the findings, reflects on their generalizability, and suggests directions for future research, including dynamic adjustments based on real-time data.
Overall, the research will offer a replicable, integrated, and expanded model EV charging stations, which can be broadened to other cities in India and other nations, to speed up the process of transforming the urban transport infrastructure to a cleaner one. The framework will also facilitate the platform where user experience will be enhanced with the introduction of the latest technologies that will provide the ability to charge in an accessible, convenient, and reliable manner.

2. Literature Review

2.1 Huff Model for Spatial Interaction and Location Analysis

Proposed by David Huff in 1963, the Huff Model has been extensively used in retail location planning to model consumer probabilistic preference between conflicting facilities in the way of attractiveness and distance decay (Huff, 1963). The model estimates the probability P_{ij}that a consumer at location i will select facility j and is formulated as follows:

P_ij=(A_j^α D_ij^(-β))/(∑_(k=1)^n A_k^α D_ik^(-β))

A j is the attractiveness of site j, D ij is the distance between consumer i and site j, and 2 and 3 are sensitivity parameters (Huff, 1964; ArcGIS Pro Documentation, 2025). This model can accommodate the spatial heterogeneity of consumer behaviour and has been applied to a wide range of other fields, such as access to healthcare (Subal et al., 2021), retail services (Berman and Evans, 2024; Singla and Rai, 2018; Liang et al., 2020), and, more recently, to urban infrastructure (EV charging stations).
The search of EV charging stations will involve the interpretation of Huff model in the search of attractiveness depending on the density of the location, the power level (AC/DC) and solar integration, and range decay with the urban travel impedance and range anxiety. Furthermore, time-varying variants also cover time-varying changes in demand, which enhances the fidelity of the model to the real-world usage patterns (Ma et al., 2024). These adaptations provide practical information on trends in the spatial demand which will be applied in the most important Indian smart cities.

2.2 Genetic Algorithms in Location-Allocation Optimization

Genetic Algorithms (GAs) are a form of metaheuristic optimization techniques that are based on natural selection, and that can be successfully implemented to solve high-dimensionality, nonlinear combinatorial and spatial facility location problems (Holland, 1975; Mitchell, 1996;Goldberg, 1989). The GAs begin with sets of candidate solutions represented as chromosomes and then are evolved by repeated application of selection crossover and mutation to achieve the most optimal solutions as the fitness is assessed (Deb, 2001).

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To put it simply, one of the most popular techniques of solving complex optimization problems with multiple parameters is the Genetic Algorithm. In numerous technical processes, it is not always required to find the absolute best option but only to have the result that is close to the best or an improvement over the previous results (Koza, 1992; Forest, 1992). GAs are effective in these cases as they have the ability to experiment and manipulate numerous variables simultaneously in a high-performing search. This flexibility has seen its application in various applications like aircraft design, signal processing and stability analysis of nonlinear systems.
In infrastructure planning, GAs have been applied in power plants, waste facility location (Yu et al., 2022) and to a growing extent, in the placement of EV charging stations (Efthymiou et al., 2017). Genetic Algorithms (GAs) are useful in the optimization of electric vehicle charging stations (EVCS). Akbari et al. (2018) demonstrated that optimization of charging station locations with the help of a GA makes the travel distances substantially shorter, such as the overall distance between settlements and the closest station can decrease by more than 55 km to approximately 14 km. Continuing on the same theme, Rene and Fokui (2024) suggested a hybrid GA-PSO (Particle Swarm Optimization) algorithm that does not only acknowledge the travel efficiency but also such factors as load voltage deviations, line losses, and incorporation Their results show that the combined strategy is better than applying GA or PSO, in particular, and reveal how evolutionary algorithms combined with the consideration of renewable energy can enable smarter and more sustainable EV charging networks.

2.3 EV Charging with Solar Energy

Sustainable development and the expansion of EV adoption need to promote with regenerative energy options. Adoption of onsite renewable energy resources helps in relieving the grid load, lowering carbon footprints and increase resiliency (IRENA, 2024). The study conducted by Benayad et al. (2025) in the field of solar/photovoltaic (PV) energy highlights the importance of shifting to renewable energy sources to promote EV mobility. The use of solar grids in EV infrastructure is a crucial step in infrastructure planning from a sustainability point of view (Haque et al., 2019).
Recently, Chandigarh city has installed four of such solar-powered EV charging stations with a roof covered in PV arrays and battery energy storage systems (EV Mechanica, 2025). These dedicated solar plants generate approximately 500 kWp and they have the capacity of supplying up to 30 to 40 per cent of the daily electricity demands in the stations and reducing grid dependency and operation costs by a very large margin (CREST Chandigarh, 2025; EV Mechanica, 2025).
Solar integration is a major factor influencing the attractiveness of a charging station in user choice modeling, as locations with renewable energy facilities can attract eco-conscious consumers. Additionally, when solar generation profiles are incorporated into the GA optimization, the balancing of loads and minimization of peak grid demand are enhanced, making the system more robust. Despite these advancements, there is very little information on the integration of consumer demand models like the Huff Model with solar-aware GA optimization in the context of rapidly developing Indian urban centers. This gap is directly addressed in the present study.
Although the application of Huff-based spatial interaction models and GA optimization have been widely studied as independent tools in facility location literature, a combination of both remains

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an emerging research topic. The present paper takes this theme to the next stage of integrating consumer probabilistic choice models and complex heuristic optimization to the particularity of the solar PV generation and battery-storage as the subjects of the urban location-allocation work. When the study was conducted in a unique urban ecosystem Chandigarh that boasts of high EV adoption and emphasis in implementing renewable infrastructure, the findings have a practical and methodological implication in the discourse of sustainable energy and transportation planning in India and the world in general. This integrated approach is based on the technical structure and empirical simulation that are described in the following paragraphs.

3. Methodology

3.1 Huff Model Formulation for Spatial Demand Probability

The Huff Model uses a gravity-based spatial interaction model to make the probability P ij that an EV user originating at demand node chooses a charging station at candidate site j. This probabilistic decision model will include the appeal of charging points as well as the resistance of the distance travelled:

$$P_{ij}=\frac{A_j^\alpha D_{ij}^{-\beta}}{\sum_{k=1}^n A_k^\alpha D_{ik}^{-\beta}}$$

where:

P i j t is the probability of selection;

A j is the attractiveness of station j, where the charging speed, amenities, and the availability of renewable energy are included;

D ij is the distance between demand sector i to station j in kilometres;

The parameters α and 2 are sensitivity parameters which scale the effect of attractiveness and travel distance, respectively, which are tuned in this case with Chandigarh-specific travel survey data;

n is the number of candidate sites taken into account.

Attractiveness A_j is modeled as a weighted function of multiple site attributes:

A j=w speed S j +w solar R j +w amenity M j.

where:

S j represents normalized charging power capacity (kW);

R j is the fraction of the solar energy capacity that is normalized;

M_j captures amenity score (parking, position to commercial areas);

weights w reflects relative importance based on stakeholder survey in Chandigarh.

3.2 Optimization with Genetic Algorithm in view of Regenerative Energy

GA algorithm approach is designed to find an optimal solution for EV charging stations, including a subset of $n$stations $S \subseteq \{1, \dots, n\}$and an appropriate energy mix of solar and grid power.

Each candidate solution chromosome encodes:

- Binary genes representing station inclusion (1 = selected, 0 = not selected);
- Continuous genes for proportional allocations of solar $p_j^{\text{solar}}$and grid energy $p_j^{\text{grid}}$for each station j.

The optimization objective fitness function Fbalances competing goals:

$$F = \sum_{i=1}^m \sum_{j \in S} P_{ij} \times D_i \times \left(\left(p_j^{\text{solar}} E_j^{\text{solar}}\right)/D_i\right) - \lambda \sum_{j \in S} \left(p_j^{\text{grid}} E_j^{\text{grid}}\right)^2 - \gamma \sum_{j \in S} C_j$$

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where:

- D_i is the daily EV charging demand at sector i;
- E_j^{solar} and E_j^{grid} denote energy supplied by solar and grid respectively at station j;
- λ, γ are penalty factors for grid energy use and installation cost C_j;
- m represents the number of demand sectors.

Energy balance constraints per station are:

$$E\_j\text{^"}solar\text{"} + E\_j\text{^"}battery\text{"} + E\_j\text{^"}grid\text{"} \geq \sum\_i P\_ij\ D\_i$$

with battery state-of-charge (SOC) dynamics modeled as:

$$SOC\_j\ (t+1) = SOC\_j\ (t) + \eta\_c\ E\_j\text{^"}solar\text{"}\ (t) - 1/\eta\_d\ \ E\_j\text{^"}battery\text{"}\ (t)$$

where η_c, η_d are charging and discharging efficiencies, and storage is bounded by battery capacity.

3.3 Pseudocode of annotated Genetic Algorithm

```
Algorithm GA_Solar_Huff_Optimization
Input:
 Candidate_Sites = {S1, S2, ..., Sn}
 Demand_Data = {D1, D2, ... Dm}  # EV demand at each sector
 Distances = D ij matrix            # Distance sector i to site j
 SolarCapacity = E solar j= solar s max PV energy per site
 Battery_Capacity = BESS_j= {BESS previously listed battery storage capacity}
 Parameters: α, β (Huff), λ, γ (penalties), Population_Size, Max_Generations
1. Initialize Population:
  For each chromosome:
   - Matrix of site selection.
   - vectors of solar/grid energy allocation.
   - Initialize battery SOC to 50%
2. Assess the Fitness of every chromosome:
  For each site j:
   - Find out Huff probability P ij of all sectors i.
   - Estimate load: Load_j = Σ_i (P_ij × D_i)
   - Calculate solar energy consumed: Solar used: Solar used j =min (Load j, E solar j).
   - Set voltage at the solar cells: Solar_used_j and Load_j.
   - Determine grid energy requirement: Gridj = Loadj - Solarusedj - Battery discharge j.
  - Minimize fitness through objective function F.
3. Selection:
  Select the best chromosomes by performing tournament selection.
4. Crossover:
  Parents Exchange genes (site selection and solar/grid ratios) between parents.
5. Mutation:
  Randomly choose bits of the selection of site or distort ratios of energy.
6. The update subroutine on energy storage is as follows:
  For each site j:
  If excess solar > 0:
```


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Fill charge battery up to capacity BESS_j
If deficit:
Release of battery when SOC<|human|>release of battery when SOC> threshold
Update SOC state

7. Termination:
Repeat steps 2-6 until Max Generations or fitness convergence.
Output best chromosome: optimum sites and combination of energy.

This approach is a strict combination of spatial demand modelling, renewable energy limitations, and heuristic multi-objective optimization that is specific to the urban environment of Chandigarh. The following section gives the results of data-driven simulation that shows the performance of the algorithms and the implementation lessons.

4. Simulation and Results

4.1 Synthetic Data Description

The synthetic data was to reflect realistic EV charging demand and solar production on 10 candidate locations within the primary urban areas of Chandigarh (Sector 17, Sector 22, Sector 35, Industrial Area Phase I, IT Park, Manimajra, Botanical Garden Parking, New Lake Parking, Grain Market and Zirakpur Road corridor reflecting an actual node with existing EV infrastructure or high urban density, Table 1.

Table 1: Summary of candidate sites with demand and renewable energy parameters

Site	Daily EV Demand (kWh)	Solar Capacity (kWh)	Battery Capacity (kWh)	Distance-weighted Attractiveness Score (A_j)
Sector 17	850	340	200	0.88
Sector 22	640	290	160	0.72
Sector 35	1020	410	240	0.95
Industrial Area Phase I	780	350	190	0.80
IT Park	1200	500	270	0.98
Manimajra	560	250	150	0.68
Botanical Garden Parking	700	320	175	0.75
New Lake Parking	750	345	185	0.78
Grain Market	690	310	170	0.74
Zirakpur Road Corridor	1010	430	260	0.92

4.2 Genetic Algorithm Setup

The above formulation was used to create a population of genetic algorithm having 100 chromosomes. The GA was carried out with 100 generations and the cross over probability of 0.8 and mutation probability of 0.05. The Huff model parameters were taken, which are: 1.2, 1.5 which are Chandigarh travel parameters. The battery and solar efficiencies were assumed to be 85 and 90 per cent respectively.

4.3 Fitness Score Convergence

The GA has an average starting fitness of approximately 0.45 that is inconsistent selection in site and unbalanced solar-grid. The generations make the space more accessible and energy efficient to a point where the fitness score comes to approximately 0.95 and this is very optimal location of the stations and integration of solar. The choice of the optimum location and energy combination is optimized.

The best identified chromosome was the stations in the Sector 17, Sector 35, IT Park and Zirakpur road corridor that fulfil greater than 75 per cent of the demand with high contributions of the solar (Table 2). The integrated solar rate is capable of supplying approximately 42 per cent of charging demand loading as well as the battery storage moderates the variations of peak-usage and to a considerable degree has removed grid dependency by approximately 28 per cent vis-a-vis a no-solar constrained environment.

Table 2: Energy utilization distribution under optimal GA solution

Site	Load Served (kWh)	Solar Energy Used (kWh)	Battery Discharge (kWh)	Grid Energy (kWh)
Sector 17	820	320	90	410
Sector 35	980	400	110	470
IT Park	1150	470	140	540
Zirakpur Road Corridor	970	430	130	410

The analysis of the simulation proves that the application of the Huff Model and GA was effective to choose the site that can be used to promote the emerging EV ecosystem in Chandigarh. An optimal balance between the demands and the renewable generation constraint of a network design is the result of maximization of user accessibility and sustainable use of energy. The subroutine of the solar-load balancing in GA renders it applicable to the real world in the urban environment where the conditions are not constant.

5. Discussion

The study supports the integrated approach of Huff Model and a Genetic Algorithm as an effective method for EV charging infrastructure planning in Chandigarh and similar urban hubs. Spatial planning with renewable energy is a significant step in promoting the EV mobility ecosystem in alignment with NEEMP 2025. Sustainable urban development and energy independence need to be facilitated with dependable solutions.

The results indicate heterogeneity in demand distribution and equity in coverage of EV charging stations. Thus, the factors influencing the location of EV charging stations may vary because of several demographic and psychological factors. Locational preferences give high priority to

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attractively advanced urban nodes, including Sector 17, Sector 35, IT Park and other regions along Zirakpur Road in comparison to the rest of the locations. These are high-density commercial, institutional, and transit-oriented developments with great intra-urban travel demand. GA formally accounts for the spatial heterogeneity of the charging behaviour by use of consumer choice probabilities. The optimization process offers fair access and reduces disparities in distance-based heuristic allocation (Zhou et al., 2024; Berman and Evans, 2024). It is important to note that probabilistic assignment does not only focus infrastructure on the most demanded nodes leading to the under-serving of peripheral areas. The model thus assists in achieving the smart city goals of Chandigarh by highlighting accessibility with spatial justice, which is typically underscored in the conventional normative methods of planning.

The fact that the onsite production of solar PV and battery energy storage is directly linked to the GA structure is a pointer that signifies the innovative focus of clean energy programs by Chandigarh towards mobility infrastructure (CREST Chandigarh, 2025). Simulation results show that renewable energy can balance 42% of daily charging demand, while battery drainage effectively manages variability, reducing grid power use by 28% on optimized routes.

The fact that the onsite production of solar PV and battery energy storage is directly linked to the GA structure is a pointer that signifies the innovative focus of clean energy programs by Chandigarh towards mobility infrastructure (CREST Chandigarh, 2025). Simulation results have proved that with renewable energy, 42 per cent of the daily charging power can be balanced and battery drainage is a valid means of dealing with variability, meaning that 28 per cent less grid power can be used on optimized routes.

In order to encourage an EV and regenerative ecosystem, subsidizing the installation of solar panels at the EV charging hubs can be used to reduce carbon emissions and operational costs. Besides, the battery storage can be added to enable more versatile use of the energy on a demand basis, to comply with the Central Electricity Regulatory Commission (CERC) India. All of these can increase the power grid and ensure that the national renewable energy objectives in India are met by the local infrastructure investment (Ministry of Power, 2025).

The Genetic Algorithm validates that the heuristic run to search the complex multi-objective optimization space. The optimization run of Chandigarh demand, energy supply and cost offers converge to a near-optimal solution with 100 generations.

It has a balancing of solar-load subroutines since the real-world feasibility is not normally taken into account in purely spatial models. This generalized computational system can be used to test various assumptions in an urban planning sense including varying EV demand growth rates, solar capacity expansions, or grid tariffs variations, and provide dynamic decision-support tools to policymakers.

The holistic approach to EV charging stations favours both behavioural and environmental concerns. The solar-integrated charge stations boost consumer confidence since it show commitment to clean vehicles, and EV adoption can be rapid (Alrubaie et al., 2023). The accessibility compensates for the range anxiety that causes mobility change. Policymakers can use these insights to develop incentive programs that ensure that socioeconomically different neighbourhoods are considered, which will result in inclusive and carbon-neutral urban transport systems.

Solar-powered and spatially optimized EV charging infrastructure integration will help in directly providing a more convenient, dependable, and user-friendly charging ecosystem. The model will

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ensure that drivers are no longer faced with range anxiety, since conveniently placed chargers will be located in strategic locations around the major activity centers and residential clusters. These improvements lead to more consumer confidence in electric mobility systems, which is a key element in speeding up electric vehicle adoption (Alrubaie et al., 2023).

From a market perspective, strategically placed solar-integrated charging stations increase visibility and consumer involvement. It also concurs with the marketing goals on sustainability leadership and technological innovation. At the policy level, user-centric infrastructure network contributes to the market preparedness by streamlining the use of EV in day-to-day commute and business activities. This, in its turn, may trigger the involvement of the private sector, lure green investments, and increase the number of partnerships between the government and the business. Combining customer experience optimization with the addition of renewable energy, Chandigarh can be an example of economically viable and socially inclusive urban electrification. The study contributes the following policy recommendations for Chandigarh City.

- Encouraging solar PV installations at emerging charging hubs with finance and load options
- Integrate the Huff-GA model into Chandigarh's mobility planning for data-driven siting decisions.
- Implement dynamic pricing to encourage charging during peak solar generation.
- Engage stakeholders to refine EV adoption and charging accessibility insights.

6. **Limitations and Future Research Directions**

Synthetic data enables controlled exploration of model dynamics. However, to enhance model validity, an empirical study using real-time data sets related to demand, solar irradiance measurements, and high-resolution battery performance is necessary. Future studies should also consider the heterogeneity of charging behaviour and the interplay of multi-modal travel demand with machine learning programs. Additionally, investigating model dynamics under external influences, such as real-time traffic information and dynamic energy prices would submit more information towards infrastructure planning. Since the ecosystem has to be reinforced to incorporate renewable energy technologies, the special focus must be given to electric vehicles in order to reach the equilibrium and sustainable transportation system (Narasipuram & Mopidevi, 2021). Chandigarh can be the first city to have genuinely smart and green urban mobility infrastructure by integrating economic, technical and environmental priorities and an example of Indian smart cities to achieve sustainable development and energy security.

7. Conclusion

This paper has contributed a spatial-probabilistic and energy-constrained optimization model comprising Huff Model and Genetic Algorithm to determine the most optimal electric battery charging station locations in Chandigarh, India. With the careful inclusion of solar photovoltaic power generation and battery storage limitations indicative of the innovative renewable energy-based hubs in Chandigarh, the study focused on refined outputs in comparison to additional location-allocation methods. These simulation outcomes were based on synthetic demand and solar capacity data in balancing spatial demand coverage and renewable energy. The annotated GA pseudocode including dynamic solar-load balancing and battery state-of-charge control shows that the framework is flexible enough to apply to real urban energy systems. The unified

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strategy makes it easy to have a just, sustainable, and eco-friendly implementation of charging infrastructure. Future research must include empirical real-time data and multi-modal travel dynamics because of its precision and scalability-based solutions in infrastructure planning. The strategy can be of use in Chandigarh and other smart cities to promote in clean and accessible electric mobility ecosystems.

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