

Article

An Interaction-Aware NI-EA Framework for EV Charging-Station Siting: Source-Conditioned Robust Candidate Sets and Bounded Spatial Evidence in Dubai

Ghassan Malkawi ^{1,*}, Azmi Alazzam ¹, Ahmed Abdelaziz Elsayed ², Asem Omari ¹, Said Badreddine ¹, Bakeel Hussein ³, Mohammed Alhagyan ⁴ and Abdelrahman Altigani ¹

¹ Computer Information Science (CIS), Faculty of Computer Information, Higher Colleges of Technology, Al Ain Campuses, Al Ain P.O. Box 17155, United Arab Emirates; aalazzam@hct.ac.ae (A.A.); aomari@hct.ac.ae (A.O.); sbadreddine@hct.ac.ae (S.B.); aabdelgader@hct.ac.ae (A.A.)

² Department of Computer Engineering and Computational Sciences, Canadian University Dubai, Dubai P.O. Box 117781, United Arab Emirates; ahmed.elsayed@hud.ac.ae

³ Department of Applied Engineering, Sana'a Community College, Sana'a 5695, Yemen; bakeelyem@gmail.com

⁴ Mathematical Science Department, College of Science, United Arab Emirates University, Al Ain P.O. Box 15551, United Arab Emirates; m.alhagyan@uaeu.ac.ae

* Correspondence: gmalkawi@hct.ac.ae

Abstract

Public-data electric-vehicle charging-station siting needs a screening workflow that can use spatial proxies while keeping demand, grid-capacity, and implementation claims separate from the score. This study develops an interaction-aware Nonlinear Interaction–Einstein Aggregation (NI-EA) framework for Dubai and extends it with source-conditioned robust candidate-set diagnostics. From 7410 admitted candidate/amenity records, 5097 inside-boundary candidates are scored using a candidate-derived activity-density proxy, a charger-coverage-gap proxy, and a grid-access proxy. The analysis compares NI-EA with WSM, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Einstein aggregation; reconstructs a 63-scenario interaction/curvature/blending rank matrix; evaluates weighting, road-network, and official-DEWA source sensitivities; and reports necessary and possible top-K candidate sets, family-balanced finite-scenario acceptability, rank-displacement summaries, and bounded spatial-evidence context from official community, transport, parking, DEWA, and OpenStreetMap-derived sources. The baseline leader is S1421/Boonmax, while official-DEWA coordinate-source reconciliation changes the leader to S3473. Across the reconstructed interaction, weighting, road-network, and official-DEWA scenario families, the top-15 necessary core contains 12 candidates, and the top-15 possible envelope contains 18 candidates. Activity-radius and charger-count coverage alternatives are reported separately as proxy-definition sensitivities. TOPSIS has 0/15 top-15 overlap with NI-EA because it favors a different profile with much higher coverage-gap scores but low activity density. The reported output is therefore a source-conditioned planning shortlist and robustness audit, not an observed-demand map, feeder-capacity validation, financial feasibility assessment, or construction recommendation.



Academic Editor: Michael Fowler

Received: 27 May 2026

Revised: 27 June 2026

Accepted: 1 July 2026

Published: 6 August 2026

Copyright: © 2026 by the authors.

Published by MDPI on behalf of the

World Electric Vehicle Association.

Licensee MDPI, Basel, Switzerland.

This article is an open access article

distributed under the terms and

conditions of the [Creative Commons](#)

[Attribution \(CC BY\)](#) license.

Keywords: electric-vehicle charging stations; NI-EA; robust candidate sets; CRITIC weighting; multi-criteria decision-making; GIS; Dubai; public data; sensitivity auditing; source-conditioned screening; implementation evidence gate

1. Introduction

The expansion of electric-vehicle (EV) charging infrastructure is a central requirement for smart-city mobility, energy transition, and urban decarbonization. Siting EV charging stations requires spatially grounded assessment of candidate context, existing charging coverage, proximity to electrical-infrastructure proxies, and traceable candidate/amenity screening evidence [1–6]. The Dubai Electricity and Water Authority (DEWA), OpenStreetMap (OSM), Geographic Information System (GIS), and Multi-Criteria Decision-Making (MCDM) terminology used below is defined at first substantive use to keep source and method roles explicit.

Classical multi-criteria decision-making (MCDM) methods such as the weighted-sum model (WSM) and TOPSIS are useful because they are transparent and reproducible. However, additive methods can understate interactions among criteria. In the present framework, candidate-derived local amenity/activity-density and grid-access proxies may reinforce each other because a site that combines high local activity density with near-grid access can score differently from a site that excels in only one dimension. The proposed Nonlinear Interaction–Einstein Aggregation (NI-EA) model uses this interaction as a bounded planning-level diagnostic rather than as proof of engineering feasibility [7,8].

This study moves beyond an illustrative candidate example by applying the framework to a public-data Dubai workflow with candidate admission, boundary filtering, charger integration, benchmark comparison, and full-candidate sensitivity checks. Its contribution is an auditable candidate-level screening workflow, beginning from a retained candidate-metric matrix, that separates admitted public-data proxies from unavailable engineering variables such as traffic counts, parcel feasibility, cost, and feeder capacity. The present study adds a source-conditioned robustness layer: rather than treating one rank-one candidate as a construction decision, it identifies necessary and possible top-*K* candidate sets, family-balanced finite-scenario acceptability, and bounded spatial/context evidence from official community, transport, parking, DEWA, and OpenStreetMap-derived sources. These additions do not introduce a new scoring criterion or replace the baseline NI-EA ranking. The Dubai interpretation remains conditional: the study reports a baseline score field and tested upper-tier continuity or change, not a source-invariant citywide construction ranking.

The principal contribution is a source-conditioned public-data screening workflow that distinguishes a baseline leading candidate from a robust upper-tier candidate set under explicitly reconstructed model and source scenarios. The analysis does not replace the baseline NI-EA ranking; it identifies which candidates remain within the upper tier in the stated scenario families and where that stability fails.

2. Related Work and Research Gap

EV charging-station planning has been studied through facility-location models, transportation-demand models, grid-constrained planning, GIS-MCDA methods, and fuzzy decision frameworks [4–6,9,10]. GIS-MCDA studies show that spatial layers such as accessibility, demand proxies, land-use context, and proximity to infrastructure can support early-stage screening of charging locations. Objective weighting methods such as CRITIC and entropy are widely used to avoid author-opinion weights, while equal weights provide a neutral baseline for sensitivity analysis [11–14]. TOPSIS remains a common benchmark because it compares alternatives against ideal and anti-ideal solutions [15,16]. Einstein aggregation provides a bounded nonlinear aggregation alternative for normalized criteria, but it should not be interpreted as a physical grid model unless coupled with engineering data [8]. The admitted interaction is interpreted through the standard mathematical idea

of complementarity or increasing differences, rather than through an unreported fuzzy capacity or hidden interaction matrix [17,18].

Recent city-scale EV charging studies also show that siting is commonly addressed through GIS-based suitability mapping, stakeholder or objective weighting, traffic-aware planning, grid-capacity assessment, and optimization. GIS-AHP and fuzzy-AHP have been used for fast-charging site selection, GIS-multi-influencing-factor (MIF)-TOPSIS has been used to map suitability zones, and fuzzy TOPSIS has been coupled with substation-capacity assessment [19–21]. Other studies incorporate traffic load, activity–travel patterns, demand and economic scenarios, spatial equity, or MILP-based deployment under capacity constraints [22–26]. Compared with these studies, the present Dubai case does not claim demand calibration, feeder-capacity validation, financial feasibility, or deployment optimization. Its contribution is focused: it audits whether candidate-level screening conclusions survive changes in charger-coordinate source, activity-density scale, coverage definition, road-network distance, weighting scheme, candidate representation, and interaction settings.

The gap addressed here is the need for an interaction-aware, claim-bounded, and candidate-level decision-support framework that can be applied to a real public-data EV charging-siting case without inventing unavailable engineering variables. The present evidence supports auditable reported-output verification; a separate regeneration step from the retained raw source layers remains necessary before the workflow can be described as fully reproducible from those raw source layers.

3. Materials and Methods

3.1. Study Design and Data Admission

Public candidate/amenity screening records were collected and screened spatially. A Dubai boundary proxy was used to retain inside-boundary candidate points. DEWA location-list and device-coordinate exports were treated as official charger evidence, while OpenStreetMap, Nominatim, and Google Maps Platform outputs were treated as public coordinate, boundary, and geocoding evidence rather than as official engineering measurements [1,2,27–29]. Candidate/amenity records were admitted as screening points rather than as engineering site parcels. Duplicate handling, source timestamps, and layer roles are documented in the supplementary source registry; distance calculations are reported as proxy calculations derived from the retained coordinate fields and are not interpreted as travel-time, parking-access, cable-length, or feeder-capacity measurements. Dynamic charger status and occupancy labels were not treated as time-stable availability measurements. A conservative status-snapshot sensitivity is supplied in the Supplementary Materials, but it is not an available-only network reconstruction. A 15-site inspection subset was selected before NI-EA scoring using neutral inspection priority and spatial/type diversity, not final model rank. Archived API-assisted checks and a post hoc desk audit are retained for this subset; they do not represent a field visit, property-level feasibility review, or proof of pre-score manual verification.

The first criterion is a candidate-derived local amenity/activity-density baseline. For each retained candidate, it is the self-excluded count of other admitted records from the same 7410-record candidate/amenity source set within the selected radius. It is not an independent spatial-demand layer, an observed charging-demand measure, an exposure layer, or validation evidence.

Table 1 summarizes the admitted indicators, sensitivity-only proxies, and variables held outside the reported calculation.

Table 1. Indicator admission status and held variables. Held variables are not used in the main calculation.

Factor	Variable or Proxy	Use	Admission Decision
Candidate-derived local amenity/activity-density baseline	Self-excluded count of admitted candidate/amenity records within radius	Main criterion	Retained only as a candidate-derived spatial-density proxy; 0.5, 1, and 2 km radii are tested as sensitivity. It is not an independent demand or exposure layer.
Coverage gap	Distance to nearest charger; charger-count alternatives	Main criterion and sensitivity	Nearest distance is the baseline definition; count-gap definitions and official-DEWA coordinate-source reconciliation are tested as sensitivities.
Grid-access proxy	Inverse distance to nearest substation proxy	Main criterion	Kept as a proxy only; it does not measure feeder capacity.
Traffic flow	Traffic counts or mobility intensity	Not used	Held because no admitted reproducible dataset is included in the reported analysis.
Land and parking feasibility	Parcel, zoning, or parking capacity	Not used	Held because no admitted dataset is available.
Road-network distance	Candidate-to-nearest-charger driving-network route	Sensitivity only	Tested as a matched OSM-network sensitivity; not a main criterion and not a substation or cable proxy.
Temporal validation	Historical charger-coordinate snapshots	Not used	Held because official dated spatial station snapshots are unavailable; OSM mapping snapshots are not commissioning evidence.

Dubai interpretation convention. Each reported score and rank is conditional on the study's admitted Dubai boundary proxy, candidate/amenity source set, activity-density radius, charger layer, substation-proxy layer, and NI-EA parameterization. "Baseline leader" means the highest-ranked candidate for that specified baseline configuration only. It does not denote an observed charging-demand location, a source-invariant winner, a feasibility-screened site, or an implementation recommendation. Sensitivity results are interpreted as evidence of continuity or change within the explicitly tested scenarios, rather than as validation of unobserved demand or engineering suitability.

3.2. Normalization, Objective Weighting, and NI-EA Aggregation

Let x_{ij} denote the raw value of candidate i on admitted criterion j , where $j \in \{A, C, G\}$, and let r index candidates in the active calculation population for the scenario being evaluated. In the present application, $x_{iA} = a_i$ is the candidate-derived activity-density count, $x_{iC} = c_i$ is the charger-coverage-gap proxy, and $x_{iG} = g_i$ is the raw grid-distance proxy. The activity-density and coverage-gap variables are benefit-type criteria after admission. They are normalized as

$$X_{ij} = \frac{x_{ij} - \min_r(x_{rj})}{\max_r(x_{rj}) - \min_r(x_{rj})}, \quad (1)$$

Because lower grid-distance is preferable in this planning proxy, the grid-distance variable is transformed from a cost-type distance to a benefit-type grid-access score as

$$G_i = \frac{\max_r(g_r) - g_i}{\max_r(g_r) - \min_r(g_r)}. \quad (2)$$

The normalized activity-density and coverage-gap scores are denoted A_i and C_i , and the transformed grid-access score is denoted G_i .

The baseline objective weights are obtained using CRITIC. For criterion j , the information content is

$$q_j = \sigma_j \sum_{k=1}^m (1 - r_{jk}), \quad (3)$$

where σ_j is the standard deviation of criterion j , r_{jk} is the Pearson correlation between criteria j and k , and m is the number of admitted criteria. The CRITIC weight is

$$w_j = \frac{q_j}{\sum_{\ell=1}^m q_\ell}. \quad (4)$$

Equal and entropy weights are used only as sensitivity checks.

For candidate i , the linear component is

$$L_i = w_A A_i + w_C C_i + w_G G_i. \quad (5)$$

The admitted interaction is the activity-density-grid reinforcement term

$$I_i = A_i G_i. \quad (6)$$

Because the applied model contains only one admitted interaction, the interaction coefficient ρ and interaction-scaling coefficient λ enter the implemented score only through their product. The applied interaction-strength parameter is therefore

$$\kappa = \lambda \rho. \quad (7)$$

No fuzzy measure, joint density, capacity function, or expert-elicited interaction matrix is estimated in the applied Dubai configuration; the single admitted interaction is represented only through κ . The interaction-adjusted NI-EA kernel is

$$Z_i = L_i + \kappa I_i = w_A A_i + w_C C_i + w_G G_i + \kappa A_i G_i. \quad (8)$$

Proposition 1 (Differential complementarity of the NI-EA kernel). *For the admitted Dubai specification in Equation (8), the marginal effects of activity density, coverage gap, and grid access are*

$$\frac{\partial Z_i}{\partial A_i} = w_A + \kappa G_i, \quad \frac{\partial Z_i}{\partial C_i} = w_C, \quad \frac{\partial Z_i}{\partial G_i} = w_G + \kappa A_i. \quad (9)$$

The cross-partial derivative between activity density and grid access is

$$\frac{\partial^2 Z_i}{\partial A_i \partial G_i} = \kappa. \quad (10)$$

Hence, for the baseline value $\kappa = 0.12$, the admitted activity-density and grid-access criteria are complementary in the NI-EA kernel because $\frac{\partial^2 Z_i}{\partial A_i \partial G_i} = \kappa = 0.12 > 0$. This is a local increasing-differences statement: increasing G_i raises the marginal contribution of A_i , and increasing A_i raises the marginal contribution of G_i .

Proof. Differentiating Equation (8) with respect to A_i , C_i , and G_i gives Equation (9). Differentiating $\partial Z_i / \partial A_i = w_A + \kappa G_i$ with respect to G_i gives Equation (10). Therefore, if $\kappa > 0$, activity density and grid access are complementary in the interaction-adjusted kernel. $\square$

Using the baseline weights in Table 2, the marginal activity-density effect lies in $[0.4814, 0.6014]$ as G_i ranges from 0 to 1, and the marginal grid-access effect lies in $[0.2338, 0.3538]$ as A_i ranges from 0 to 1. Figure 1 visualizes this difference for a purely additive WSM kernel, whose corresponding cross-partial derivative is zero.

Table 2. Baseline weights and sensitivity parameters used in the 5097-candidate analysis.

Test Group	w_A	w_C	w_G	Parameter Set
CRITIC	0.4814	0.2849	0.2338	Baseline objective weights
Equal weights	0.3333	0.3333	0.3333	Weight-sensitivity comparator
Entropy weights	0.5180	0.4757	0.0064	Weight-sensitivity comparator; grid-access receives negligible weight
Interaction strength	–	–	–	$\kappa \in \{0, 0.03, 0.06, 0.09, 0.12, 0.18, 0.27\}$; $\gamma \in \{0.5, 1, 2\}$; $\alpha \in \{0.25, 0.5, 0.75\}$

Weights are rounded to four decimal places; totals may differ from 1.0000 because of rounding.

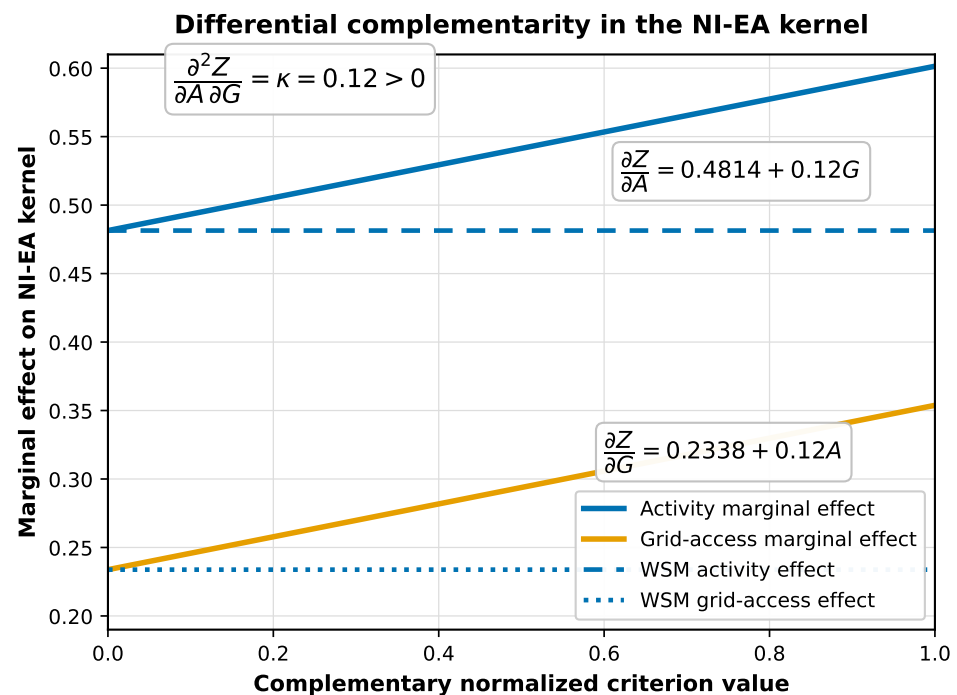


Figure 1. Differential complementarity of the NI-EA kernel for the baseline Dubai settings. The positive cross-partial derivative $\frac{\partial^2 Z}{\partial A \partial G} = \kappa = 0.12$ shows that activity density and grid access are complementary in the admitted interaction term. The dashed and dotted horizontal lines show the corresponding WSM marginal effects, where the cross-partial derivative is zero.

The nonlinear response is

$$\Psi_i = \exp(\gamma Z_i), \quad (11)$$

where γ controls response curvature. The nonlinear response is then normalized over the active calculation population as

$$N_i = \frac{\Psi_i - \min_r(\Psi_r)}{\max_r(\Psi_r) - \min_r(\Psi_r)}. \quad (12)$$

The Einstein component is computed from bounded weighted contributions

$$u_{ij} = w_j X_{ij}, \quad (13)$$

using the Einstein sum

$$a \oplus_E b = \frac{a + b}{1 + ab}. \quad (14)$$

For $a, b \in [0, 1]$, the Einstein sum in Equation (14) also lies in $[0, 1]$; therefore, the recursive Einstein component remains bounded. This is an aggregation property, not a physical model of EV-grid constraints. For the ordered set of admitted criteria, the recursive component is

$$E_i^{(1)} = u_{i1}, \quad (15)$$

$$E_i^{(j)} = E_i^{(j-1)} \oplus_E u_{ij}, \quad j = 2, \dots, m, \quad (16)$$

$$E_i = E_i^{(m)}. \quad (17)$$

The final NI-EA score is

$$S_i = \alpha N_i + (1 - \alpha)E_i. \quad (18)$$

Proposition 2 (Pareto-monotonicity under fixed-scenario normalization conditions). For a fixed sensitivity scenario, fixed active candidate population, and fixed population-specific normalization bounds with positive denominators in Equations (1), (2), and (12), let $w_A, w_C, w_G \geq 0$, $\kappa \geq 0$, $\gamma > 0$, and $\alpha \in [0, 1]$. Then the applied NI-EA score preserves coordinatewise dominance over the admitted benefit-type criteria. Specifically, if candidate p weakly dominates candidate q such that

$$A_p \geq A_q, \quad C_p \geq C_q, \quad G_p \geq G_q,$$

then the kernel in Equation (8) satisfies $Z_p \geq Z_q$. This follows because

$$\frac{\partial Z_i}{\partial A_i} = w_A + \kappa G_i \geq 0, \quad \frac{\partial Z_i}{\partial C_i} = w_C \geq 0, \quad \frac{\partial Z_i}{\partial G_i} = w_G + \kappa A_i \geq 0,$$

and

$$A_p G_p - A_q G_q = A_p (G_p - G_q) + G_q (A_p - A_q) \geq 0.$$

The exponential response is monotone for $\gamma > 0$, and the Einstein aggregation component is monotone in its bounded inputs. Therefore, under the stated fixed-scenario conditions, a candidate that is no worse in all three admitted criteria is not assigned a lower NI-EA score by the applied aggregation structure. This proposition is an internal ranking-coherence property; it is not an engineering-feasibility or demand-validation claim.

For every reported active calculation population, each criterion and the nonlinear response had a positive observed range. The reported calculations therefore use the direct denominators in Equations (1), (2), and (12); no epsilon perturbation was applied. A future zero-range criterion would require a separately declared handling rule before scoring.

TOPSIS comparator. For the TOPSIS comparator, the three already benefit-oriented min–max criteria are vector-normalized and weighted using the same CRITIC weights:

$$r_{ij}^T = \frac{X_{ij}}{\sqrt{\sum_{r=1}^n X_{rj}^2}}, \quad v_{ij} = w_j r_{ij}^T, \quad (19)$$

$$v_j^+ = \max_i(v_{ij}), \quad v_j^- = \min_i(v_{ij}), \quad (20)$$

$$D_i^+ = \sqrt{\sum_j (v_{ij} - v_j^+)^2}, \quad D_i^- = \sqrt{\sum_j (v_{ij} - v_j^-)^2}, \quad (21)$$

$$C_i^* = \frac{D_i^-}{D_i^+ + D_i^-}. \quad (22)$$

Equations (19)–(22) define the TOPSIS comparator used in the benchmark analysis, where n is the active candidate population for the comparator. The reported TOPSIS ordering

ranks candidates by decreasing C_i^* . All reported candidate orderings use a descending stable sort; exact score ties retain the predefined candidate-row order.

The baseline parameter setting is $\kappa = 0.12$, $\gamma = 1$, and $\alpha = 0.5$. These are reference-scenario aggregation parameters used for the sensitivity grid; they are not calibrated estimates from feeder-capacity measurements, load-flow data, or revealed charging-user behavior. This formulation is used as a planning-level aggregation model; it is not a feeder-capacity model or load-flow validation.

3.3. Three-Level Ranking-Stability Certificate

The reported sensitivity checks are interpreted through a rank-based certificate that separates three different properties: retention of the upper screening tier, retention of the leading candidate, and retention of the full ordering. Let r_i^0 denote the baseline rank of candidate i , and let r_i^s denote the rank of the same candidate in sensitivity scenario s . For a fixed top-tier size K , define

$$T_K^0 = \{i : r_i^0 \leq K\}, \quad T_K^s = \{i : r_i^s \leq K\}. \quad (23)$$

The top-tier retention score is

$$\Omega_K(s) = \frac{|T_K^0 \cap T_K^s|}{K}. \quad (24)$$

Let the baseline and scenario leaders be

$$\ell^0 = \arg \min_i r_i^0, \quad \ell^s = \arg \min_i r_i^s. \quad (25)$$

The leader-retention score is

$$L(s) = \begin{cases} 1, & \ell^s = \ell^0, \\ 0, & \ell^s \neq \ell^0. \end{cases} \quad (26)$$

For n_s shared candidates, define the full-order change rate and full-order retention score as

$$\Gamma(s) = \frac{|\{i : r_i^s \neq r_i^0\}|}{n_s}, \quad F(s) = 1 - \Gamma(s). \quad (27)$$

The three-level certificate is

$$C_K(s) = (\Omega_K(s), L(s), F(s)). \quad (28)$$

Definition 1 (Three-level ranking-stability certificate). For any tested sensitivity scenario s , $\Omega_K(s)$ certifies the retained fraction of the baseline top- K set, $L(s)$ certifies whether the baseline leader is retained, and $F(s)$ certifies the retained fraction of exact ranks over the shared candidate set. Hence, $\Omega_K(s) = 1$ certifies full top- K retention, $0 < \Omega_K(s) < 1$ certifies partial top-tier retention, $L(s) = 0$ rejects leader invariance, and $F(s) < 1$ rejects full-order invariance. High $\Omega_K(s)$ with low $F(s)$ therefore supports top-tier screening stability only; it does not support full-ranking invariance.

Explanation. By construction, $T_K^0 \cap T_K^s$ contains exactly the baseline top- K candidates that remain in the scenario top- K set; dividing by K gives $\Omega_K(s)$. The definition of $L(s)$ compares the rank-one candidates in the two rankings, so $L(s) = 0$ is exactly a leader switch. The set $\{i : r_i^s \neq r_i^0\}$ contains exactly the candidates whose exact rank changes; normalizing by n_s gives $\Gamma(s)$, and $F(s) = 1 - \Gamma(s)$ is the retained exact-rank fraction. The stated interpretations follow directly from these definitions.

This certificate is only a classification device for reported rankings in tested scenarios. It is not a new siting criterion, weight, validation test, demand measure, or implementation decision.

3.4. Matched Road-Network Coverage Sensitivity

The baseline coverage gap is a straight-line candidate-to-nearest-charger proxy. A matched subsequent sensitivity replaced only this coverage distance with a directed OSM vehicular-road route to the nearest of the same 279 baseline combined charger points. The road graph was extracted from the dated GCC OpenStreetMap snapshot of 19 June 2026 [2,30]. It retained common vehicle-road classes, preserved one-way tags, and excluded pedestrian, cycle, construction, proposed, and explicitly vehicle-prohibited links. Service, private/destination, and track edges were retained for service/parking topology but do not establish legal access. Candidates and chargers were snapped to charger-reachable graph nodes. A transparent 250 m routable-snap quality gate excluded seven of the 5097 candidates, leaving a matched population of 5090. No routes to substations were calculated. The road test recomputed coverage normalization, CRITIC weights, and the NI-EA score in the matched population. It is a route-proxy sensitivity only; it does not model cable length, feeder capacity, charger availability, legal access, parking/gate access, real-time travel, or construction feasibility.

3.5. Official DEWA Coordinate-Source Reconciliation Sensitivity

After completion of the baseline analysis, a supplied DEWA *Electric Vehicles Green Charger Points* CSV provided 335 device records with a common load timestamp of 8 May 2026 [1]. The source export is documented in the supplementary source registry and retained by the authors subject to source terms. Exact duplicate latitude/longitude pairs were collapsed without any arbitrary spatial-clustering threshold, yielding 304 official exact-coordinate points. The 48 baseline OSM EV points were retained unchanged, so the audit replaced only the DEWA coordinate component of the coverage layer. Bidirectional nearest-coordinate crosswalks quantified agreement between the 231 baseline DEWA/Google points and the 304 official points. A source-sensitivity scenario then recomputed nearest straight-line coverage distance, CRITIC weights, and NI-EA scores over all 5097 candidates. Because the official snapshot was obtained after the baseline analysis and differs in date and record granularity, it is treated as a reconciliation sensitivity rather than a retroactive replacement of the baseline. A supplementary mechanism audit separated the coverage-geometry effect from CRITIC re-estimation by evaluating official-source coverage with fixed baseline weights and baseline coverage with official-source weights. These diagnostic configurations do not replace either reported scenario. The export has no commissioning-date, dynamic-availability, or occupancy field; it therefore does not resolve temporal validation or operational availability.

3.6. Candidate-Representation Sensitivity

A separate fixed-source sensitivity analysis tested whether the reported spatial priority pattern depends only on the original point-candidate representation. The original 7410 admitted candidate/amenity records, with that identical 7410-record set reused as the activity-density reference layer, 279 baseline combined charger points, 527 OSM substation proxy points, and the selected OSM/Nominatim Dubai boundary polygon were recovered from the pre-NI-EA source record. Regular centroid grids at 500 m, 1 km, and 2 km spacing were generated inside the same boundary polygon, each with four half-cell origin offsets. At each grid point, the three admitted raw proxies were recomputed from the fixed layers: candidate-derived self-excluded activity-density count within 1 km, nearest combined-charger distance, and nearest substation-proxy distance. The exact NI-EA form

and parameters ($\kappa = 0.12$, $\gamma = 1$, and $\alpha = 0.5$) were retained, while normalization and CRITIC weights were recomputed within each grid population. Grid points are a spatial-support test only: they are not asserted to be feasible sites, and no grid point is promoted as a construction recommendation. The audit compared nearest-grid score association with the reported 5097-candidate score field and spatial co-location between the reported top-50 and each grid's top-1% grid-score field. A supplementary descriptive enrichment audit also compared the top-50 with the remaining 5047 candidates at top-field thresholds of 0.5%, 1%, and 2%, using nearest-field distance and shares within 1 and 2 km; it did not use inferential tests or provide demand or implementation validation.

3.7. Source-Conditioned Robust Candidate-Set Diagnostics

The robustness extension keeps the reported baseline NI-EA score unchanged and uses additional diagnostics only to interpret candidate stability under tested source and model perturbation conditions. Let $\mathcal{S}$ denote the finite set of candidate-level sensitivity scenarios for which complete ranks can be reconstructed, including the 63 interaction/curvature/blending scenarios, the equal- and entropy-weighting scenarios, the matched road-network scenario, and the official-DEWA source scenario. Let $\mathcal{S}^+ = \{0\} \cup \mathcal{S}$ denote the baseline column together with those reconstructed sensitivity scenarios. The necessary and possible candidate sets are calculated across the reconstructed interaction, weighting, road-network, and official-DEWA scenario families. Activity-density-radius and charger-count coverage alternatives are reported separately as proxy-definition sensitivities and are not included in the robust-set calculation. For each scenario $s \in \mathcal{S}^+$, let $T_K^{(s)}$ be the top- K set defined in Equation (23). The necessary and possible top- K candidate sets are

$$\mathcal{N}_K = \bigcap_{s \in \mathcal{S}^+} T_K^{(s)}, \quad \mathcal{P}_K = \bigcup_{s \in \mathcal{S}^+} T_K^{(s)}. \quad (29)$$

The set $\mathcal{N}_K$ contains candidates that remain in the top- K tier in the baseline and every reconstructed sensitivity scenario, whereas $\mathcal{P}_K$ contains all candidates that enter the top- K tier at least once. These are descriptive robust-candidate sets for the tested reconstructed scenarios only; they are not probabilities, construction approvals, or official recommendations. For full-order retention, the road-network comparison uses the 5090 matched candidates. For reconstructed top- K robust-set and acceptability calculations, the seven excluded candidates retain an out-of-top-tier sentinel road rank of 5098 in the released 5097-row rank matrix and therefore contribute zero to $\mathbf{1}\{r_i^{(s)} \leq K\}$ for the road-network scenario.

To avoid allowing the 63 interaction scenarios to dominate all other evidence, a family-balanced finite-scenario top- K acceptability score is also reported. If $\mathcal{F}$ is the set of scenario families and $\mathcal{S}_f$ is the set of scenarios in family f , then

$$a_i^{(K)} = \frac{1}{|\mathcal{F}|} \sum_{f \in \mathcal{F}} \frac{1}{|\mathcal{S}_f|} \sum_{s \in \mathcal{S}_f} \mathbf{1}\{r_i^{(s)} \leq K\}. \quad (30)$$

Here, $\mathbf{1}\{\cdot\}$ equals 1 when the enclosed condition is true and 0 otherwise. The value $a_i^{(K)}$ is a finite-scenario descriptive score, not a stochastic probability or SMAA analysis. Rank-displacement summaries report the median, 90th percentile, 95th percentile, and maximum absolute movement $|r_i^{(s)} - r_i^0|$ within each family.

3.8. Bounded Spatial, Regulatory, and Source-Evidence Layer

A bounded spatial-evidence layer was added only after the reported score was computed. It links retained candidates to official Dubai community polygons, population tables, RTA public-transport and parking datasets, the raw official DEWA EV Green

Charger export, and the Geofabrik GCC OpenStreetMap snapshot. DEWA's EV Charging Infrastructure Regulation defines the distribution system as DEWA's electrical network at 33 kV and below and states that public charging operation requires a charge-point operator (CPO) license and required approvals for deployment and connection to the distribution system [31]. DEWA's EV Charging Technical Regulations specify definitions for electric-vehicle supply equipment (EVSE), electric-vehicle charging stations (EVCS), public/private EVSE, CPOs, connector types, ambient design conditions, and installation requirements [32]. DEWA's annual statistics provide system-wide transmission/distribution and capacity context, but not candidate-level feeder headroom [33]. Digital Dubai's data-roles guidance is used only to frame data-owner, data-stewardship, source-date, and reuse responsibilities for the multi-source public-data workflow [34].

The spatial-evidence layer is used only as post-screening context. It is not included in the reported NI-EA score or rank and does not validate observed charging demand, traffic flow, parking occupancy, parcel rights, utility connection approval, feeder capacity, or financial feasibility.

4. Results

4.1. Boundary Screening and 15-Site Inspection Subset

The boundary screening retained 5097 of 7410 candidate records and held 2313 records outside the Dubai boundary proxy. This step reduced the risk that bounding-box retrieval could include records outside the intended study area. The boundary is an OSM/Nominatim public boundary proxy and should not be described as an official government boundary.

Table 3 reports the five highest-scoring entries in the separately specified 15-site inspection subset.

Table 3. Top five calculation entries from the separate 15-site pre-score inspection subset. Post hoc desk-audit status is shown; the full 15-site list and full-candidate ranks are provided in Supplementary Table S1 (root file Table_S1.csv) and Supplementary Ledger S1 (root file Ledger_S1.csv).

Rank	Site ID	Standardized Label	Subset NI-EA Score	Desk-Audit Status
1	S208	Prime Medical Centre	0.8093	Conditional
2	S4464	Al Muraqqabat parking candidate (22C Street, Deira)	0.7561	Conditional
3	S6468	Downtown Dubai parking candidate (near Sheikh Mohammed bin Rashid Boulevard P2)	0.5708	Conditional
4	S6166	Henna Park - JVC	0.5477	Keep
5	S5486	Al Thanyah Fourth parking candidate (Street 2)	0.5338	Conditional

Scores document the previously specified 15-site calculation subset and do not constitute site approval. The subset was selected before NI-EA scoring under neutral inspection-priority and spatial/type-diversity rules. Its post hoc desk-audit evidence is reported in Supplementary Ledger S1 (root file Ledger_S1.csv). The status "Conditional" indicates post hoc facility-level or coordinate/address-level support only and does not establish pre-score manual verification. It is not a field-verified construction shortlist.

Evidence resolution note. A targeted post hoc review found facility-level public evidence for S208 in the Deira/Reef Mall area and coordinate/address evidence for S5486 at 34 Street 2, Al Thanyah Fourth. These findings change their desk-audit status from Hold to Conditional but do not retroactively establish pre-score manual verification. S6584 remains an anonymous OSM leisure record with unresolved facility identity in Supplementary Ledger S1 (root file Ledger_S1.csv).

4.2. Full-Candidate Sensitivity and Ablation

The complete 15-site inspection subset is provided in Supplementary Table S1 (root file Table_S1.csv) to keep the article table readable. The 5097-candidate analysis was

conducted over all inside-boundary candidate records. The purpose was not to replace the separate inspection subset but to test scoring behavior and ranking behavior over the entire candidate universe. The analysis shows that the pre-score 15-site inspection subset is not identical to the 5097-candidate top-15. With the defined baseline configuration, the highest-ranked full-candidate points form a compact Deira/Al Rigga proxy-score hotspot, with S1421/Boonmax ranked first. This is a Dubai-specific baseline score pattern, not a citywide portfolio of independent construction recommendations, an observed charging-demand map, or a claim that the baseline leader remains first for every plausible source or proxy definition.

The high agreement between NI-EA and WSM indicates that the Dubai baseline top tier is not driven by nonlinear aggregation alone. The contribution of NI-EA in this case is therefore not rank reversal for its own sake but an interaction-aware and bounded diagnostic structure combined with source- and proxy-sensitivity auditing.

Table 4 reports the full-candidate ablation and comparator results.

Table 4. Ablation and benchmark comparison over the 5097-candidate universe. Overlap is measured relative to the NI-EA baseline.

Method	Spearman	Kendall	Top-15 Overlap	Top-25 Overlap
WSM	0.9995	0.9831	15/15	25/25
Einstein aggregation	0.9995	0.9824	14/15	25/25
TOPSIS	0.8358	0.7083	0/15	1/25
NI-EA without interaction ($\kappa = 0$)	0.9995	0.9830	15/15	25/25

The TOPSIS diagnostic indicates that the 0/15 top-15 overlap should not be interpreted as a computational error. It reflects a different criterion profile: TOPSIS favors candidates with stronger coverage-gap performance and weaker activity-density performance than the NI-EA upper tier. The full intermediate TOPSIS quantities and criterion profiles are reported in the Supplementary Materials. Therefore, TOPSIS is interpreted as a benchmark revealing profile sensitivity, not as evidence that either ordering is an implementation recommendation.

Interaction-effect audit. The released coordinate-free metric matrix was used to quantify the contribution of the admitted interaction term without changing any score definition or ranking rule. The direct kernel contribution is $\Delta Z_i^{\text{int}} = \kappa A_i G_i$, and its share in the interaction-adjusted kernel is

$$ICR_i = \frac{\kappa A_i G_i}{w_A A_i + w_C C_i + w_G G_i + \kappa A_i G_i}.$$

At the baseline value $\kappa = 0.12$, the median ICR_i was 0.1355 for the baseline top-15, 0.1349 for the baseline top-25, 0.1333 for the baseline top-50, and 0.0497 for the remaining 5047 candidates. Recomputing the score with $\kappa = 0$ left the baseline top-15 and top-25 unchanged, changed 10 of the top-50 by at most one rank, and changed 4890 of all 5097 ranks with a maximum movement of 314 positions. The interaction term is therefore quantitatively present and structurally interpretable, but it does not create the reported Dubai top-15 by itself.

4.3. Interaction and Weight Sensitivity

The $\kappa/\gamma/\alpha$ sensitivity grid contains 63 scenarios. Across these scenarios, the leading candidate remains S1421/Boonmax, top-10 overlap is 10/10, top-15 overlap ranges from 14/15 to 15/15, and top-25 overlap is 25/25. The minimum Spearman correlation is 0.99857,

and the minimum Kendall correlation is 0.97156. However, the full middle-rank ordering changes in some scenarios, with maximum absolute rank movement of 545 positions. Therefore, the appropriate claim is that the leading candidate and top-tier membership are stable across the tested interaction-strength and blending scenarios, not that the full ranking is invariant.

Weight sensitivity shows that substantial top-15 overlap was retained across the tested weighting schemes. However, the leading candidate changed with equal weights, and entropy weighting assigned negligible weight to the grid-access proxy. Therefore, weight sensitivity is interpreted as top-tier membership stability only, not leading-candidate invariance across all weight schemes.

Figure 2 displays the complete 63-scenario distribution underlying Table 5 and confirms that the reported variation is limited to the stated 14–15 top-15 range.

Table 5. Summary of top-15 overlap across interaction-strength settings. Values are summarized across the tested γ and α combinations.

κ	Minimum Overlap	Median Overlap	Maximum Overlap
0.00	15	15	15
0.03	14	15	15
0.06	14	15	15
0.09	14	15	15
0.12	14	15	15
0.18	14	14	15
0.27	14	14	14

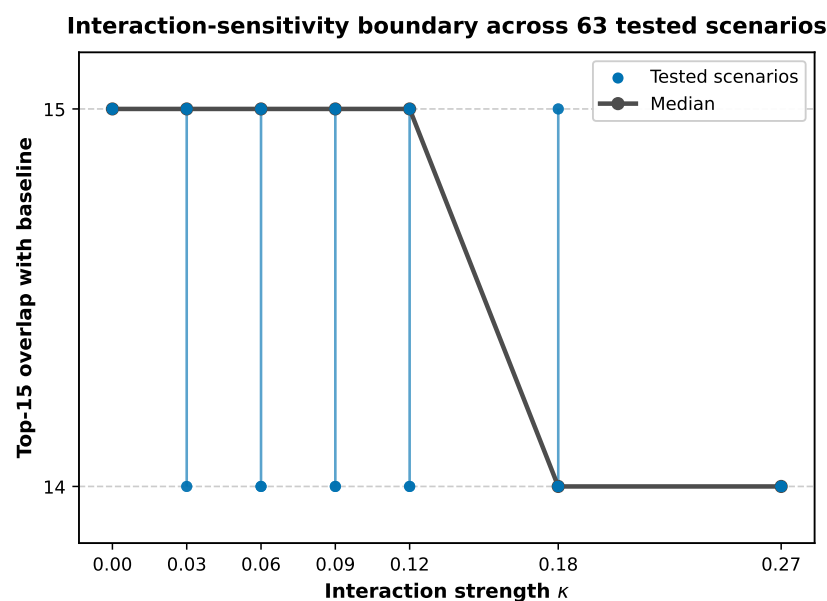


Figure 2. Top-15 overlap with the baseline across all 63 tested $\kappa/\gamma/\alpha$ scenarios. Points denote individual scenarios; vertical segments show the scenario-specific minimum–maximum range and the line shows the median at each κ . The figure supports top-tier stability only; full-ranking invariance is not claimed.

Figure 3 summarizes the weight-sensitivity boundary across CRITIC, equal, and entropy weighting.

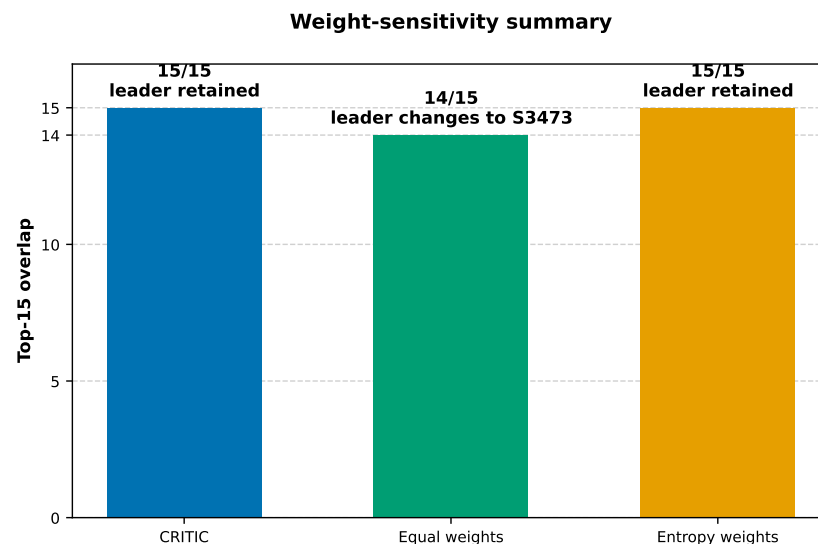


Figure 3. Weight-sensitivity summary across CRITIC, equal, and entropy weighting. Substantial top-tier overlap is retained, but the leading candidate changes with equal weights; neither leading-candidate invariance nor full-ordering invariance is claimed.

4.4. Proxy-Definition Sensitivity and Pareto Check

Activity-density-radius sensitivity tests confirm that the selected activity-density radius is a material modeling choice. Relative to the 1 km baseline, the 0.5 km radius preserves only 1 of the baseline top-15 candidates, while the 2 km radius preserves none of the baseline top-15. The purpose of this test is not to select a universal radius but to show that candidate-derived activity-density proxies must be treated as spatial assumptions rather than independent demand measures. Table 6 reports the activity-density-radius sensitivity results.

Table 6. Candidate-derived activity-density-radius sensitivity relative to the 1 km baseline. Overlap columns report overlap with the baseline NI-EA ordering.

Activity-Density Radius	Top Candidate	Spearman	Kendall	Top-10	Top-15	Top-25
0.5 km	S3453	0.9149	0.7513	1/10	1/15	7/25
1 km baseline	S1421/Boonmax	1.0000	1.0000	10/10	15/15	25/25
2 km	S324	0.9027	0.7419	0/10	0/15	0/25

Coverage-definition sensitivity also shows material dependence when nearest-charger distance is replaced by charger-count gap definitions over increasing radii. The nearest-distance baseline and the 1 km count-gap definition keep the same leading candidate, but wider count-gap definitions change the leading candidate and reduce top-tier overlap. These results are reported as proxy-definition sensitivity, not as evidence of construction feasibility or failure. Table 7 reports the coverage-definition sensitivity results.

Figure 4 combines the activity-radius and coverage-definition tests into a distance-related proxy sensitivity envelope. The shaded zones are descriptive guide regions only: they distinguish severe disruption, partial retention, and high retention of the baseline top-15 set, and they are not statistical significance thresholds. The figure supports the claim that distance-related proxy definitions materially affect the screening output and must not be interpreted as observed demand or feasibility evidence.

Table 7. Coverage-definition sensitivity relative to the nearest-distance baseline.

Coverage Definition	Top Candidate	Spearman	Kendall	Top-10	Top-15	Top-25
Nearest distance	S1421/Boonmax	1.0000	1.0000	10/10	15/15	25/25
Count-gap 1 km	S1421/Boonmax	0.7460	0.6213	10/10	13/15	24/25
Count-gap 2 km	S3498	0.6430	0.5116	7/10	12/15	17/25
Count-gap 3 km	S3457	0.5484	0.4067	6/10	9/15	13/25
Count-gap 5 km	S3495	0.2104	0.1504	0/10	0/15	2/25

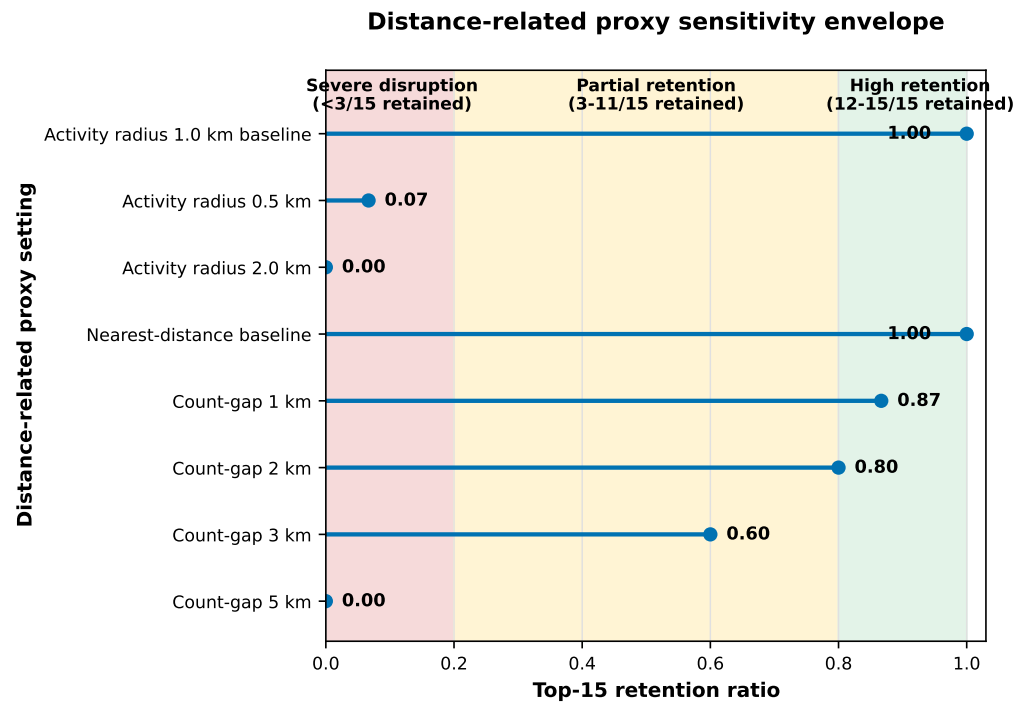


Figure 4. Distance-related proxy sensitivity envelope for the Dubai screening output. The horizontal scale is the retained share of the baseline top-15 candidates in each distance-related proxy setting. Shaded guide zones indicate severe disruption (<3/15 retained), partial retention (3–11/15 retained), and high retention (12–15/15 retained). These zones are descriptive aids only and do not constitute statistical thresholds, demand validation, or feasibility evidence.

The Pareto dominance check examined the top-50 full-candidate alternatives using the three admitted normalized criteria. It found 16 nondominated candidates and 34 candidates dominated by higher-ranked alternatives, with 0 dominance-rank violations. A supplementary full-candidate audit over the 5097-candidate universe found 142 nondominated candidates, 4955 dominated candidates, 3,509,658 dominance pairs, and 0 dominance-rank violations. These results are consistent with Proposition 2: within a fixed active population and fixed normalization bounds, the applied NI-EA score preserves coordinate-wise dominance. This remains an internal coherence audit, not engineering validation or city-wide optimality.

4.5. Candidate-Representation Sensitivity

The fixed-source recovery reproduced the 5097 polygon-retained candidates, 279 combined charger points, and 527 substation proxy points. Reapplying the exact NI-EA formula to the fixed candidate metrics reproduced the reported baseline scores with a maximum absolute difference of 1.84×10^{-15} . Across the 12 regular-grid constructions, association between each reported candidate score and the score of its nearest grid point remained high, with Spearman correlation from 0.8678 to 0.9848 and Kendall correlation from 0.6909 to 0.9002. The reported top-50 candidates remained within 2 km of the top-1%

grid-score field in every construction; at 500 m and 1 km grid spacing, all 50 were within 1 km, as summarized in Table 8.

Table 8. Candidate-representation sensitivity using fixed source layers. Each spacing uses four half-cell origin offsets. The top grid field is the top-1% grid-score field.

Grid Spacing	Grid Points per Offset	Nearest-Grid Score Spearman	Nearest-Grid Score Kendall	Baseline Top-50 Within 1 km of Top-1% Grid-Score Field	Baseline Top-50 Within 2 km of Top-1% Grid-Score Field
500 m	23,784–23,802	0.9825–0.9848	0.8924–0.9002	50/50	50/50
1 km	5943–5952	0.9604–0.9639	0.8364–0.8456	50/50	50/50
2 km	1485–1492	0.8678–0.8748	0.6909–0.7048	18/50–50/50	50/50

Grid NI-EA calculations recompute normalization and CRITIC weights within each grid population. The results therefore test spatial-pattern continuity with alternative candidate representation, not invariance of weights, exact grid ranks, or construction feasibility.

Across all 12 fixed-source grid constructions, every baseline top-50 candidate lay within 2 km of the corresponding top-1% grid-score field. Across the supplementary top-field thresholds of 0.5%, 1%, and 2%, the reported top-50 also remained within 2 km of every grid high-score field. Their median nearest-field distances ranged from 0.18 to 1.06 km across the 12 constructions, compared with 2.71 to 13.50 km for the remaining 5047 candidates. The corresponding 2 km capture shares were 100% for the top-50 and 17.5–40.1% for the remaining candidates. This supports continuity of the upper-score spatial pattern with alternative candidate representations, while not implying exact-rank invariance, observed demand, parcel feasibility, feeder capacity, or construction readiness.

The grid population produced different CRITIC weights from the baseline point-candidate population: across the four 1 km grids, activity-density weight ranged from 0.0849 to 0.0987, coverage-gap weight from 0.4803 to 0.4875, and grid-access weight from 0.4209 to 0.4276, compared with baseline weights of 0.4814, 0.2849, and 0.2338. The appropriate conclusion is therefore spatial-pattern continuity for an alternative candidate representation, not invariance of CRITIC weights, exact ranks, or feasible-site status.

4.6. Road-Network Coverage Sensitivity

The matched road-network test uses the same baseline combined charger layer and replaces only the straight-line coverage distance. Raw route distance and Euclidean distance are related but not interchangeable (Spearman = 0.7885, Kendall = 0.6187). After recalculating weights and scores over the 5090 matched candidates, the road-network and Euclidean-coverage NI-EA rankings have Spearman = 0.9294 and Kendall = 0.8053. S1421/Boonmax remains the leader, and top-10, top-15, top-25, and top-50 overlaps are 10/10, 14/15, 24/25, and 46/50. Because 5064 of 5090 ranks still change, the result supports upper-tier continuity for this substitution, not full-ranking invariance, observed accessibility, or site feasibility. Table 9 summarizes the matched road-network coverage sensitivity.

Table 9. Matched road-network coverage sensitivity using the same 279 baseline combined charger points.

Metric	Result
Matched candidates	5090 (7 excluded by 250 m routable-snap quality gate)
Raw road-vs.-Euclidean coverage Spearman/Kendall	0.7885/0.6187
NI-EA rank Spearman/Kendall	0.9294/0.8053
Leading candidate	S1421/Boonmax in both analyses
Top-10/top-15/top-25/top-50 overlap	10/10/14/15/24/25/46/50
Changed ranks/maximum absolute movement	5064/4089

4.7. Official DEWA Coordinate-Source Reconciliation Sensitivity

The supplied DEWA coordinate export contains 335 device records and 304 exact-coordinate points, compared with 231 baseline DEWA/Google points. The two layers have asymmetric spatial coverage: 170 of the baseline DEWA points are within 100 m of an official point, whereas only 115 official points are within 100 m of a baseline DEWA point. Their median nearest distances are 20.6 m in the baseline-to-official direction and 256.9 m in the official-to-baseline direction. This pattern is consistent with a combination of changed network coverage, device-versus-location granularity, and geocoding differences; it is not treated as evidence that either layer is universally correct.

When the baseline DEWA component is replaced by the official exact-coordinate points and the 48 baseline OSM points are retained, raw coverage distance has Spearman = 0.8237 and Kendall = 0.7005 relative to the baseline. The resulting NI-EA rankings have Spearman = 0.9355 and Kendall = 0.8183. The leading candidate changes from S1421/Boonmax to S3473, while top-10, top-15, top-25, and top-50 overlap are 8/10, 13/15, 24/25, and 45/50. This limits the baseline-leader claim to the baseline charger layer and supports substantial but incomplete top-tier continuity with a plausible charger-layer substitution. The mechanism audit shows that replacing charger geometry while holding baseline weights fixed already changes the leader to S3473, whereas applying official-source weights to baseline geometry retains S1421. Thus, the coverage-geometry change is sufficient for the observed leader switch; the audit does not identify whether the coordinate differences arise from mapping, device-versus-site granularity, or network evolution. Table 10 summarizes the official-DEWA coordinate-source reconciliation outcomes.

Table 10. Official DEWA coordinate-source reconciliation sensitivity. The official CSV is not used to overwrite the baseline.

Metric	Result
Official DEWA device records/exact-coordinate points	335/304
Baseline DEWA/OSM EV points	231/48
Baseline DEWA points within 25/100/250 m of official points	129/170/196
Official points within 25/100/250 m of baseline DEWA points	65/115/149
Raw coverage distance Spearman/Kendall	0.8237/0.7005
NI-EA rank Spearman/Kendall	0.9355/0.8183
Leading candidate, baseline/official-source scenario	S1421/Boonmax/S3473
Top-10/top-15/top-25/top-50 overlap	8/10/13/15/24/25/45/50
Changed ranks/maximum absolute movement	5078/3898

Figure 5 visualizes the rank relationship for all 5097 candidates in the baseline and official-DEWA source-sensitivity scenarios. It shows substantial overall rank association alongside the leader switch reported above.

Figure 6 separates the coverage-geometry substitution from CRITIC re-estimation in the four diagnostic configurations. The four-configuration mechanism audit establishes a rank-sign source-regime result: across both tested CRITIC-weight regimes, replacing the charger geometry reverses the S1421–S3473 leader ordering, whereas CRITIC-weight re-estimation with the baseline geometry does not. The result is a diagnostic property of the tested source configurations, not a causal claim about the physical charging network.

Figure 7 visualizes the corresponding S3473-minus-S1421 score-margin components.

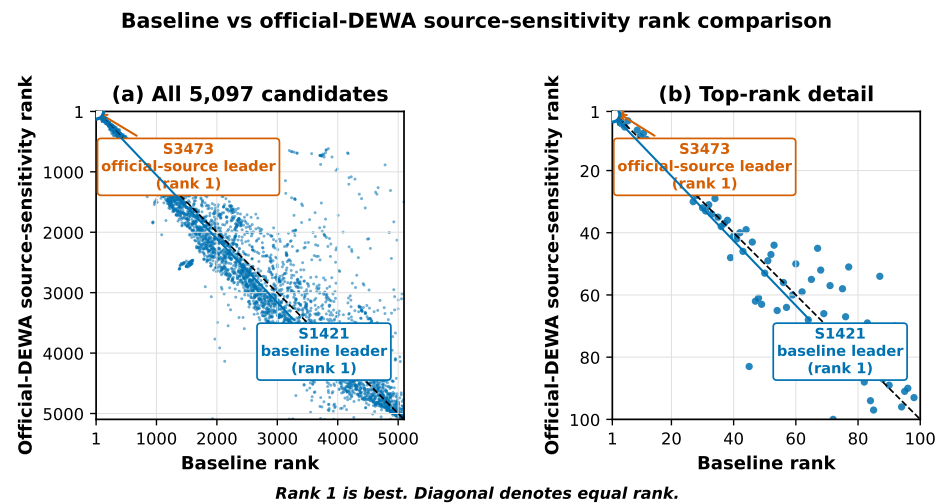


Figure 5. Candidate-level rank comparison between the baseline and official-DEWA source-sensitivity scenarios. Rank 1 is best, and the diagonal denotes rank equality. The labeled candidates S1421 and S3473 are the baseline and official-source leaders, respectively.

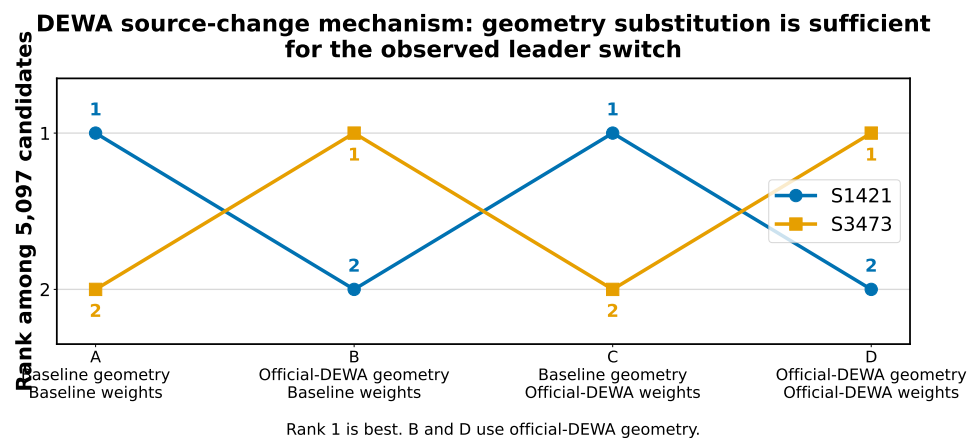


Figure 6. DEWA source-change mechanism decomposition for the two leading candidates. Configurations A–D combine baseline or official charger geometry with baseline or recomputed CRITIC weights. Rank 1 is best. The four configurations show that charger-geometry substitution is sufficient, within the tested configurations, for the observed leader switch between S1421 and S3473. The analysis does not establish a definitive charger layer.

Table 11 reports the corresponding two-by-two score-margin decomposition for S3473 minus S1421.

Table 11. Two-by-two source-regime margin decomposition for S3473 minus S1421. Average geometry and weight effects summarize the two-way source regime; the interaction term is reported as a separate diagnostic, and the bars in Figure 7 should not be read as a simple additive waterfall.

Component	Score-Margin Value
Baseline margin (D_{BB})	−0.001219
Geometry effect, average	0.002043
Weight effect, average	0.000271
Geometry–weight interaction	0.000563
Official-source margin (D_{OO})	0.001095

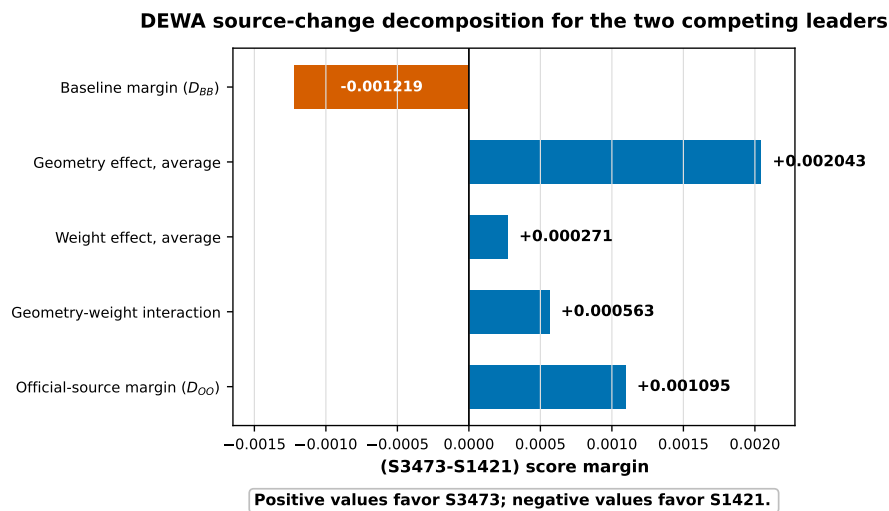


Figure 7. Two-by-two decomposition of the S3473-minus-S1421 score margin across baseline/official charger geometry and baseline/official CRITIC weights. Positive values favor S3473 and negative values favor S1421; the bars are diagnostic and should not be read as a simple additive waterfall or as a construction-feasibility claim.

4.8. Ranking-Stability Certificate for Reported Sensitivity Scenarios

Table 12 applies the certificate in Equation (28) with $K = 15$ to the sensitivity scenarios that provide candidate-level or full-order change counts in the released outputs. The certificate does not alter any score or rank; it classifies the reported rankings.

Table 12. Three-level ranking-stability certificate for reported sensitivity scenarios. Ω_{15} is top-15 retention, L is leader retention, and F is exact full-order retention.

Scenario	n_s	Top-15 Overlap	Ω_{15}	Top-15 Loss ($1 - \Omega_{15}$)	L	F	Certificate Interpretation
Interaction grid: componentwise conservative envelope across 63 settings	5097	14/15	0.9333	0.0667	1	0.0361	Strong top-tier retention and leader retention; exact full-order invariance is rejected.
Equal weights	5097	14/15	0.9333	0.0667	0	0.0086	Top-tier membership is mostly retained, but the leader changes; leader invariance is rejected.
Entropy weights	5097	15/15	1.0000	0.0000	1	0.0086	No top-15 loss is observed, but exact full-order invariance is still rejected.
Matched road-network coverage	5090	14/15	0.9333	0.0667	1	0.0051	Leader and most top-tier candidates are retained; the full ordering is not retained.
Official-DEWA coordinate-source sensitivity	5097	13/15	0.8667	0.1333	0	0.0037	Substantial but incomplete top-tier retention; the leader changes from S1421/Boonmax to S3473.

For the interaction grid, Ω_{15} , L , and F are componentwise conservative summaries across the 63 tested $\kappa/\gamma/\alpha$ settings and are not asserted to arise from one common scenario. For road-network and official-DEWA scenarios, F uses the reported changed-rank counts in Tables 9 and 10.

The certificate clarifies the main Dubai result. The road-network scenario gives $\mathcal{C}_{15} = (0.9333, 1, 0.0051)$, so it retains the baseline leader and most of the top tier while rejecting exact full-order invariance. The official-DEWA scenario gives $\mathcal{C}_{15} = (0.8667, 0, 0.0037)$, so it retains substantial top-tier overlap but rejects a source-invariant leading candidate. The complement of top-15 retention, $1 - \Omega_{15}$, is reported as a descriptive top-tier loss measure rather than as a new ranking index. It shows low top-tier loss under interaction, equal-weight, entropy-weight, and road-network substitution conditions, and a larger but still partial loss with the official-DEWA source substitution. The activity-density-radius and coverage-definition summaries reinforce a stronger proxy-definition fragility: the 0.5 km activity-density radius retains only 1/15 of the baseline top-15, the 2 km radius retains

0/15, and the 5 km count-gap coverage definition retains 0/15. These calculations support source- and proxy-conditioned screening, not a final construction ranking.

Figure 8 visualizes the two most decision-relevant certificate outcomes. The road-network substitution retains the baseline leader and most of the top-15 while showing low full-order retention. The official-DEWA coordinate-source substitution retains substantial top-15 overlap but changes the leading candidate; therefore, it rejects a source-invariant leader claim.

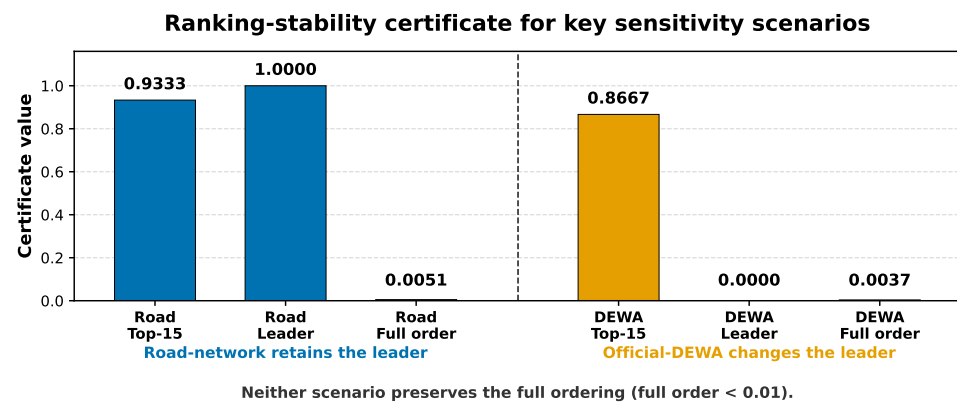


Figure 8. Ranking-stability certificate for the two key source/proxy substitutions. Road-network coverage retains the leader and most of the top-15 but not the full ordering. Official-DEWA coordinate-source sensitivity retains substantial top-15 overlap but changes the leader, so a source-invariant leading-candidate claim is rejected.

4.9. Source-Conditioned Candidate-Set Robustness

The reconstructed candidate-level scenario matrix extends the certificate in Table 12 from summary-level overlap to 67 sensitivity-scenario rank columns, in addition to the baseline rank column: 63 interaction/curvature/blending scenarios, two alternative weighting scenarios, the matched road-network scenario, and the official-DEWA source scenario. Table 13 shows that interaction-grid scenarios retain the upper tier strongly across K , while weighting, road-network, and official-DEWA scenarios are more disruptive at small K than at wider tiers. Figure 9 extends the tabulated K -stability summary by plotting additional K values reported in the Supplementary Materials.

Table 13. Source-conditioned K -stability profile for reconstructed candidate-level scenario families. Values are top- K retention rates relative to the baseline ordering.

Scenario Family	K	Min. Ω_K	Median Ω_K	Max. Ω_K	Scenarios
Interaction grid	15	0.9333	1.0000	1.0000	63
Interaction grid	25	1.0000	1.0000	1.0000	63
Interaction grid	50	0.9600	1.0000	1.0000	63
Weighting	15	0.9333	0.9667	1.0000	2
Weighting	25	0.9600	0.9600	0.9600	2
Weighting	50	0.9200	0.9400	0.9600	2
Road network	15	0.9333	0.9333	0.9333	1
Road network	25	0.9600	0.9600	0.9600	1
Road network	50	0.9200	0.9200	0.9200	1
Official-DEWA source	15	0.8667	0.8667	0.8667	1
Official-DEWA source	25	0.9600	0.9600	0.9600	1
Official-DEWA source	50	0.9000	0.9000	0.9000	1

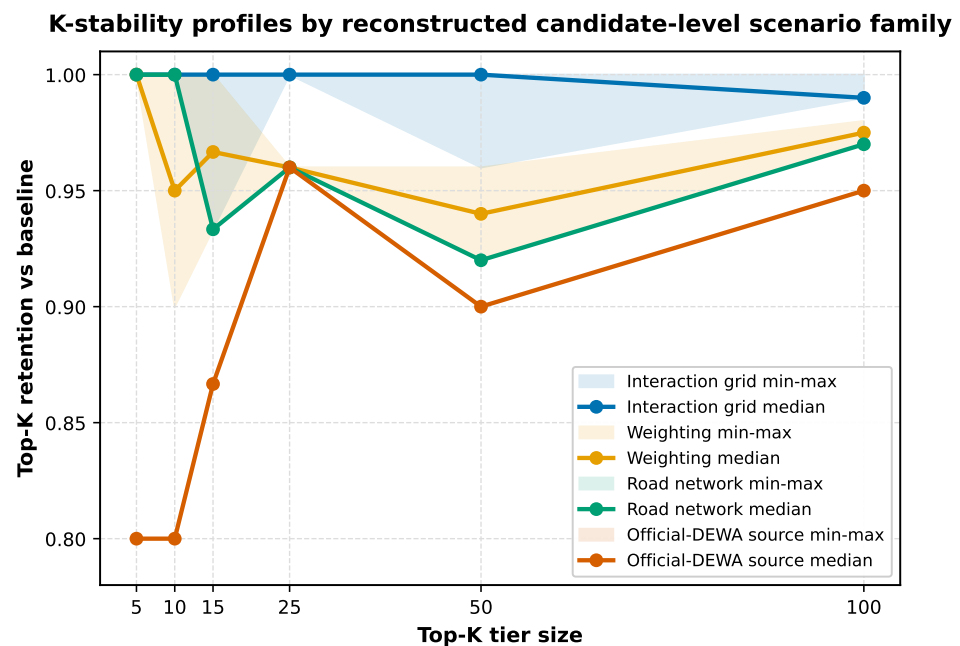


Figure 9. K-stability profiles by reconstructed candidate-level scenario family. Solid lines show median top-K retention and shaded bands show family minimum–maximum envelopes. Only reconstructed interaction, weighting, road-network, and official-DEWA families are included.

Table 14 reports the necessary and possible candidate sets. The top-15 necessary core contains 12 candidates and the top-15 possible envelope contains 18 candidates. The present analysis therefore interprets the output as a bounded robust-candidate set under the tested perturbation conditions, not a single construction recommendation.

Table 14. Necessary and possible top-K candidate sets across the baseline and reconstructed sensitivity-scenario families. Complete sets are in the Supplementary Materials.

K	$ \mathcal{N}_K $	$ \mathcal{P}_K $	Necessary-Core Site IDs Shown
5	4	6	S493; S1421; S3473; S3498
15	12	18	S281; S282; S283; S493; S1421; S3451; S3457; S3472; S3473; S3474; S3496; S3498
25	23	28	S246; S281; S282; S283; S493; S1120; S1421; S3451; S3452; S3457; S3472; S3473; ...
50	45	59	S010; S208; S229; S246; S247; S281; S282; S283; S284; S285; S488; S493; ...

Necessary-core site IDs shown are complete for $K = 5$ and $K = 15$ and truncated for $K = 25$ and $K = 50$; complete lists are provided in the Supplementary Materials. Robust sets are calculated across the baseline and reconstructed interaction, weighting, road-network, and official-DEWA scenario families only. Activity-density-radius and charger-count coverage alternatives are reported separately as proxy-definition sensitivities and are not included in this calculation.

Table 15 reports the leading family-balanced acceptability results. S1421, S3473, and the other leading baseline candidates remain high-acceptability candidates, but their median and worst sensitivity ranks show that the baseline ordering should not be read as an implementation order.

Table 15. Highest family-balanced finite-scenario acceptability candidates. Top-10 candidates are shown. Acceptability is descriptive and is not a probability.

Site ID	Baseline Rank	$a_i^{(15)}$	$a_i^{(25)}$	Best Rank	Median Rank	Worst Rank
S1421	1	1.000	1.000	1	1.0	2
S3473	2	1.000	1.000	1	2.0	3
S493	3	1.000	1.000	2	3.0	3
S3498	4	1.000	1.000	4	4.0	5
S3457	5	1.000	1.000	4	5.0	6
S3472	6	1.000	1.000	4	6.0	8

Table 15. Cont.

Site ID	Baseline Rank	$a_i^{(15)}$	$a_i^{(25)}$	Best Rank	Median Rank	Worst Rank
S3451	7	1.000	1.000	6	7.0	11
S3496	8	1.000	1.000	7	8.0	12
S282	9	1.000	1.000	7	9.0	9
S283	10	1.000	1.000	9	10.0	11

Figure 10 provides a representative heat-map view of rank movement for the baseline top-25 in selected sensitivity scenarios; it is descriptive and does not replace the full rank matrix reported in the Supplementary Materials.

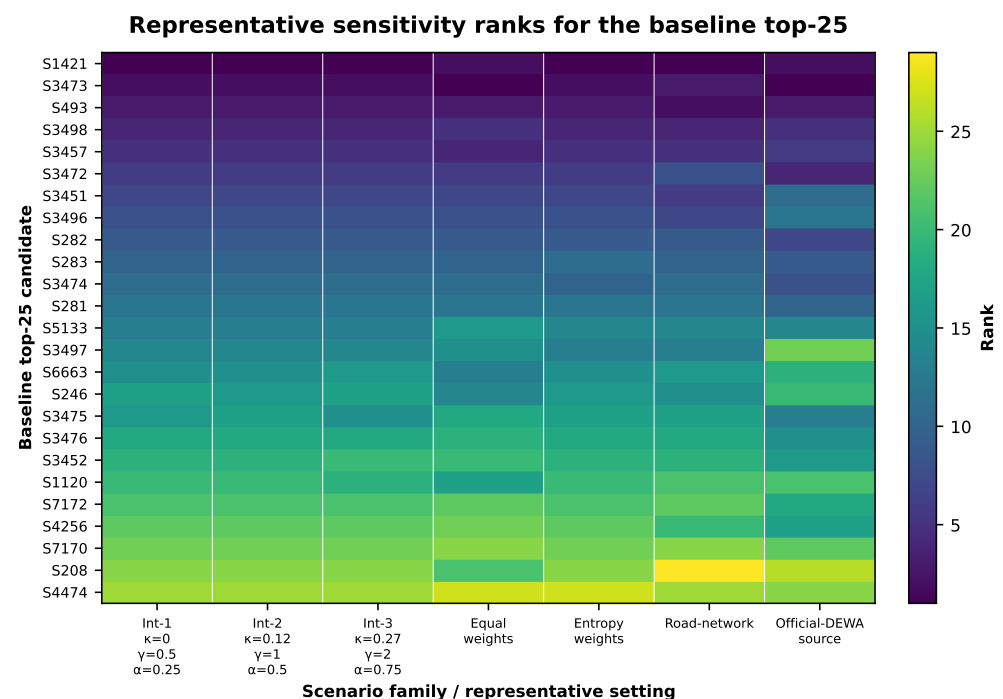


Figure 10. Representative sensitivity ranks for the baseline top-25 candidates in selected interaction, weighting, road-network, and official-DEWA source scenarios. The heat map is descriptive and does not replace the full reconstructed rank matrix reported in the Supplementary Materials.

4.10. Dubai-Specific Spatial Pattern Interpretation

Figure 11 maps the baseline citywide source-layer context and enlarges the Deira/Al Rigga hotspot used for the spatial-pattern interpretation.

The GIS overlay in Figure 11 shows that the highest-ranked full-candidate points cluster in the Deira/Al Rigga baseline field. Together with the grid analysis, this supports a cautious spatial-pattern interpretation: the area is a representation-supported proxy-score hotspot for the admitted public-data configuration. It is not a spatially independent demand surface, a construction-ready zone, or evidence that every candidate remains top-ranked with different charger sources or proxy definitions. The separate 15-site list remains a pre-score inspection subset with post hoc desk-audit evidence reported separately.

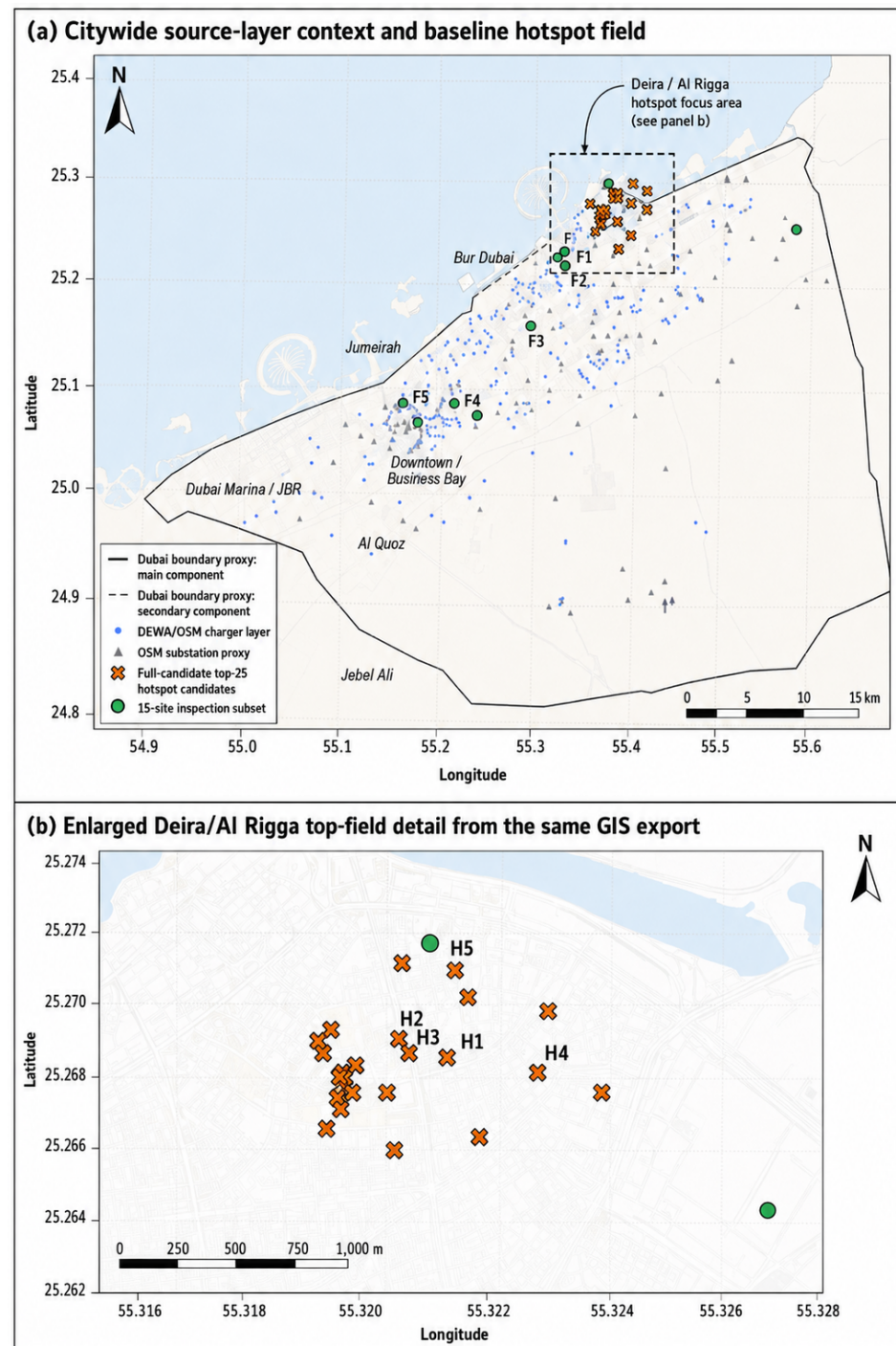


Figure 11. Dubai-wide GIS context and enlarged Deira/Ai Rigga hotspot detail for the baseline screening output. Panel (a) locates the Dubai boundary proxy, DEWA/OSM charger layer, substation-proxy layer, baseline top-25 hotspot candidates, and the pre-score 15-site inspection subset, with area labels added only for geographic orientation; labels H1–H5 denote selected hotspot candidates and F1–F5 denote selected pre-score inspection-subset points shown for readability. Panel (b) enlarges the Deira/Ai Rigga top-field detail based on the same GIS export to show the local hotspot concentration and inspection-subset points. The hotspot denotes a Dubai-specific proxy-score concentration for the 5097-candidate baseline configuration; it is not an observed charging-demand surface, a construction-ready zone, or an independent deployment recommendation. Panel (b) is a readability crop only; no new spatial layer, score, rank, or candidate decision is introduced. Source layers: DEWA EV Green Charger locations [1]; OpenStreetMap data [2]; Nominatim boundary/geocoding [27]. © OpenStreetMap contributors.

4.11. Bounded Spatial and Regulatory Evidence Layer

Table 16 documents how source, date, and unit differences were handled in the present workflow. The official DEWA raw export contains 335 device records, 335 unique device IDs, 304 unique exact coordinates, and 633 total connectors at a common 8 May 2026 load timestamp; therefore, device, connector, and coordinate counts are not interchangeable. The Geofabrik GCC Protocolbuffer Binary Format (PBF) MD5 checksum was verified before use. These source checks support reproducibility boundaries but do not change the reported baseline score.

Table 16. Source, date, and unit ontology for the multi-source workflow. The complete machine-readable ontology and scenario registry are provided in the Supplementary Materials.

Layer Group	Unit Handled in the Workflow	Role in This Study	Score Use
Candidate records	Candidate/amenity records retained as screening candidate points	Baseline activity, coverage, grid-access, and interaction calculations	Yes
Charger layers	Station, device, connector, and coordinate records kept distinct	Baseline coverage proxy and official-source reconciliation	Baseline/sensitivity
OSM/Geofabrik snapshot	OSM nodes, ways, relations, roads, and substation-proxy features	Road-network sensitivity, substation-proxy QA, and spatial-source documentation	Sensitivity/proxy only
Community/population layers	Community polygons and community-year records	Descriptive spatial context after ranking	No
Transport/parking layers	Station, stop, route-time, and parking-zone records	Descriptive urban-accessibility and implementation context after ranking	No
DEWA regulatory documents	Regulatory and technical evidence	Claim-boundary support for the post-screening evidence gate	No

4.12. Descriptive Post-Screening Urban-Context Comparison

To assess whether the upper-tier candidates also align with urban-context evidence not used in NI-EA scoring, a descriptive post-screening comparison was conducted after all scores and ranks had been finalized. The comparison contrasts the baseline top-50 candidates with the remaining 5047 retained candidates using post-screening layers only, including public-transport proximity, deduplicated bus-stop proximity, parking-zone context, and community-level attributes. These variables were not included in the NI-EA score, CRITIC weighting, TOPSIS comparison, road-network coverage test, or official-DEWA source-reconciliation score. Therefore, the comparison is interpreted only as descriptive urban-context support for the reported spatial pattern, not as demand validation, utilization validation, financial feasibility, feeder-capacity evidence, or construction approval.

Straight-line proximity values were computed from retained candidate coordinates to the nearest public-transport station and deduplicated bus-stop coordinate; the bus-stop layer was deduplicated by stop identifier and coordinate after excluding records without coordinates. Parking-space context was assigned at the community/zone level from the 2026 parking-space dataset rather than as site-level occupancy. All baseline top-15 candidates fall within Al Muraqqabat in the community-join layer, and all top-15 candidates are within 1 km of both a public-transport station and a deduplicated bus stop. These findings support an urban-context interpretation of the Deira/Al Rigga hotspot only. Table 17 reports the corresponding descriptive post-screening urban-context comparison.

The baseline top-50 candidates show smaller descriptive distances to the reported public-transport and bus-stop layers, together with higher observed shares within the selected distance bands, than the remaining retained candidates. Because these post-screening context variables were not included in NI-EA scoring and were not assessed through inferential validation, the comparison provides descriptive urban-context support for the reported spatial pattern only. It does not independently validate charging demand, utilization, parking availability, feeder capacity, financial feasibility, or construction suit-

ability. RTA public-transport station and bus-stop layers are used only as descriptive urban-accessibility context [35].

Table 17. Descriptive post-screening urban-context comparison between the baseline top-50 and the remaining retained candidates. These variables are not included in the NI-EA score or rank.

Indicator	Top-50	Remaining 5047	Interpretation
Median distance to public-transport station (km)	0.311	1.063	Closer urban-accessibility context
Share within 500 m of public-transport station	0.900	0.295	Post-screening context only
Share within 1 km of public-transport station	1.000	0.485	Post-screening context only
Median distance to deduplicated bus stop (km)	0.156	0.200	Closer local transit context
Share within 500 m of deduplicated bus stop	1.000	0.778	Post-screening context only
Share within 1 km of deduplicated bus stop	1.000	0.879	Post-screening context only
Parking-zone match share	1.000	0.521	Zone-level context only
Median matched community parking-space count	3848	2056	Zone-level context only
Dominant community concentration	Al Muraqqabat (0.80)	Al Thanyah Fifth (0.04)	Spatial concentration only

5. Discussion

The Dubai case is best interpreted as a layered screening analysis. The 5097-candidate analysis prevents overinterpretation of the separate 15-site inspection subset, and the ranking-stability certificate separates three claims that should not be conflated: upper-tier retention, leader retention, and full-order retention.

Methodologically, the applied model uses $\kappa = \lambda\rho$ for one admitted activity-density-grid interaction. Treating ρ and λ as independently interpretable would be incorrect in this implementation because only their product affects the score. Proposition 1 shows the local role of this term: the cross-partial derivative of the NI-EA kernel with respect to activity density and grid access equals κ , so the baseline value $\kappa = 0.12$ creates a positive complementarity in the screening kernel. The sensitivity analysis therefore tests interaction strength through κ , while γ and α vary the nonlinear response and blending.

The results do not show universal NI-EA superiority over WSM. They show that NI-EA provides an interaction-aware score whose upper-tier behavior is stable across the tested interaction scenarios, while TOPSIS and the proxy-definition tests reveal method and source dependence. The road-network substitution preserves the baseline leader and most upper-tier membership but changes many middle ranks. The official-DEWA source scenario changes the top candidate from S1421/Boonmax to S3473. The added diagnostics clarify this evidence boundary: Pareto-monotonicity supports internal ranking coherence under fixed-scenario normalization conditions; the top-15 loss column distinguishes low parameter/road loss from stronger proxy-definition fragility, and, within the four tested configurations, charger-geometry replacement is sufficient for the observed S1421/S3473 leader switch, whereas CRITIC-weight re-estimation alone under baseline geometry conditions is not. The resulting contribution is therefore a transparent, source-conditioned Dubai screening pattern, not a single definitive location, an observed-demand map, or a construction decision.

The fixed-source candidate-representation sensitivity audit further shows that the spatial priority pattern remains associated when the same sources are projected onto regular grids, even though CRITIC weights change with the active calculation population. This supports spatial-pattern continuity, not exact-rank, weight, or feasible-site invariance. The necessary and possible candidate sets are also limited to the reconstructed interaction, weighting, road-network, and official-DEWA scenario families; the activity-density-radius and charger-count coverage alternatives remain separate proxy-definition sensitivities

because they change the definition of the screening proxy rather than only perturbing a fixed scenario family.

Post-Screening Implementation Evidence Gate

To make the reported screening outputs usable in a later technical review without extending the NI-EA model, a separate implementation-review register preserves existing candidate identifiers, scores and ranks, and reported road-network and charger-source sensitivity fields. It adds no criterion, weight, equation, recalculation, or construction recommendation. Instead, it records explicit default states—“Not assessed in the current public-data model” and “Pending post-screening technical review”—for planning or parcel review, parking and access, observed traffic or dwell evidence, utility connection, charge-point operator (CPO) or site-owner pathway, and safety review. These fields are not blank omissions; they document evidence that is outside the current model and must not be used to revise the reported NI-EA score or rank. Its GIS-ready version is retained in a restricted reproducibility archive because it contains third-party-derived coordinate and label fields subject to applicable source terms.

Dubai’s published urban-development context emphasizes sustainable urban development and accessible service centers, while DEWA makes EV Green Charger locations available through official digital channels [1,36]. These sources motivate the need to separate the present public-data screening output from the later evidence needed for implementation. They do not calibrate the NI-EA score, establish a project decision, or imply institutional uptake of this study.

Table 18 specifies the evidence boundary for the post-screening technical review.

Table 18. Dubai-specific post-screening implementation evidence gate. The table documents the boundary between the reported screening analysis and evidence needed only for a later technical review.

Dubai Evidence Layer	Reported Role and Explicit Model Status	What Is Not Established; Evidence Required Before Implementation
DEWA EV Green Charger location source [1]	Baseline coverage proxy; used as transparent charger-layer source evidence.	Does not establish availability, charging power, queuing, or feeder capacity; later review needs time-matched device/site, operating-status, and engineering evidence.
Official DEWA coordinate-source reconciliation	Source-sensitivity test; top-tier continuity is substantial, but the leading candidate is not invariant.	Does not establish a definitive charger layer or overwrite the baseline; later review needs versioned reconciliation and decision-specific site evidence.
Planning and parcel evidence	Not assessed in the public-data model; not used in any reported score or rank.	Does not establish parcel control, zoning, land permission, or site availability; later review needs versioned parcel, zoning, permission, and access records.
Parking, access, and traffic/dwell evidence	Not assessed in the public-data model; not used in any reported score or rank.	Does not establish parking capacity, legal access, observed demand, or traffic feasibility; later review needs site, parking, access, and observed traffic/dwell evidence.
Utility/charge-point operator (CPO) and site-owner evidence	Not assessed in the public-data model; not used in any reported score or rank.	Does not establish feeder headroom, load-flow feasibility, connection approval, commercial agreement, or charger design; later review needs utility, charge-point operator (CPO)/site-owner, protection/design, and approval evidence.
Dubai community and population context [37,38]	Spatially joined only as post-screening descriptive context; not used in any NI-EA score or rank.	Does not establish population-adjusted need, observed demand, or community priority; later review needs versioned community boundaries, keyed population records, and a reproducible decision-specific join.

Figure 12 illustrates the operational handoff boundary after Table 18: later implementation evidence is recorded separately and does not alter any reported score, rank, weight, or conclusion.

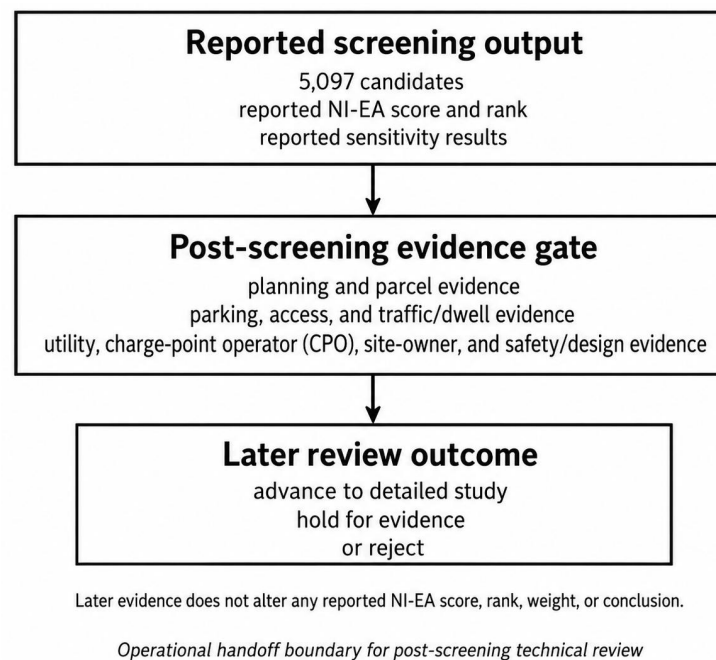


Figure 12. Operational handoff boundary for post-screening technical review. The current study ends with the reported screening output; later planning, utility, charge-point-operator, site-owner, and project-decision records are not used to alter any reported score, rank, weight, or conclusion. Conceptual post-screening workflow only; no authority endorsement, access to non-public authority data, or construction approval is implied.

These international implementation references are used to interpret the implementation boundary of the framework, not to calibrate Dubai scores, compare city performance, or assess regulatory compliance [39–45]. Table 19 lists the international references used solely to contextualize the implementation boundary.

Table 19. International implementation references supporting the Dubai screening boundary. City examples and standards are used only to interpret the boundary between public-data screening and later implementation evidence.

Reference Type	International Reference	Relevant Implementation Lesson	Relation to the Dubai NI-EA Screening Case	Not Claimed in This Study
<i>City implementation examples</i>				
City	Amsterdam [39]	Demand-driven public-charging rollout.	Supports interpretation of activity-density and coverage-gap proxies as planning-level constructs.	No cross-city score comparison.
City	Stockholm [39]	Planning-oriented rollout with grid, operator, and site-actor coordination.	Supports a post-screening implementation evidence gate.	No parcel/grid approval or stakeholder endorsement.
City	London [40]	Citywide delivery barriers and differing user needs.	Supports implementation framing beyond GIS ranking.	No London calibration or Dubai–London performance comparison.
City	Singapore [41]	EVCA safety, type approval, and charger registration logic.	Supports separation of screening from technical approval and operation.	No UAE regulatory equivalence; NI-EA is not an approval or safety tool.

Table 19. Cont.

Reference Type	International Reference	Relevant Implementation Lesson	Relation to the Dubai NI-EA Screening Case	Not Claimed in This Study
<i>Standards and regulatory references</i>				
Standard	ISO 37122 [42]	Smart-city indicator definitions, transparency, and traceability.	Supports clear reporting of indicators and boundaries.	Not a site-approval standard; no Dubai candidate validation.
Regulatory reference	Regulation (EU) 2023/1804 (AFIR) [43]	Public charging access, user information, interoperability, payment, and reporting principles.	Informs later evidence requirements only.	Not a Dubai compliance assessment or binding UAE rule.
Technical standards	IEC 61851-1/ISO 15118-20 [44,45]	Charging equipment, energy transfer, and vehicle-to-charger communication.	Belong to later design, interoperability, and operating evidence.	Not used in siting, NI-EA scoring, or candidate ranking.

These implementation references reinforce the study's central boundary: public-data screening can identify candidate-priority patterns, but implementation requires later planning, utility, operator, safety, and regulatory evidence.

6. Limitations and Future Work

This study is a diagnostic screening framework, not a construction decision. All Dubai result labels are conditional on the admitted source layers and tested proxy definitions. The Dubai boundary is an OSM/Nominatim proxy, not an official government boundary. The candidate-derived activity-density count is sensitive to radius definition and is derived from the same admitted candidate/amenity source set used to define the candidate universe; it therefore does not replace observed charging demand, traffic counts, or an independent exposure layer. Substation proximity is a grid-access proxy and does not measure feeder capacity or load-flow feasibility. Coverage-distance and charger-count definitions also produce different rank behavior, so coverage is interpreted as a proxy-definition result rather than a physical service-quality measurement.

The 15-site subset was not field-verified. Its post hoc desk audit is limited to archived public-data identity, coordinate, and charger-proximity evidence; no parcel access, parking capacity, land permission, utility connection, or construction feasibility assessment was performed. One subset row retains unresolved facility identity evidence in Supplementary Ledger S1 (root file Ledger_S1.csv), and two other rows have only post hoc facility-level or coordinate/address-level support. Road-network distance was tested only as a candidate-to-nearest-charger OSM driving-network sensitivity; it does not determine real-time travel, parking/gate access, station availability, routes to substations, cable length, feeder capacity, or construction feasibility.

The official DEWA coordinate export provides a stronger location source but differs in date and device-level granularity from the baseline charger layer and has no commissioning-date or dynamic-availability field. It therefore serves only as a source-reconciliation sensitivity. Temporal validation remains out of scope: the OSM snapshot audit reflects mapping state rather than commissioning evidence, and the conservative DEWA status-snapshot sensitivity cannot establish systemwide availability because most official coordinate points could not be device-linked to display-status records. Future studies may populate the implementation-review register with documented planning/parcel, parking/access, traffic/dwell, utility, charge-point-operator, site-owner, and safety evidence; such evidence was not used to calculate or revise the reported NI-EA scores or ranks.

7. Conclusions

This study presents a source-conditioned NI-EA screening workflow for EV charging-station siting in Dubai. The baseline full-candidate analysis ranks S1421/Boonmax first, while official-DEWA coordinate-source reconciliation changes the leading candidate to S3473; road-network substitution retains S1421 and most of the upper tier. The added robustness analysis provides robust candidate-set diagnostics: the top-15 necessary core contains 12 candidates and the possible top-15 envelope contains 18 candidates across the reconstructed interaction, weighting, road-network, and official-DEWA scenario families. The TOPSIS audit shows that TOPSIS selects a different criterion profile rather than revealing an implementation error. Bounded community, transit, parking, OSM, and DEWA regulatory evidence is used only to interpret post-screening context. The results support a transparent public-data screening and robustness-auditing workflow, not a demand-calibrated deployment plan, feeder-capacity validation, financial feasibility assessment, or construction-ready shortlist. Future validation requires charger utilization histories, EV registrations, parking and dwell data, parcel/site-owner evidence, and utility connection review for selected candidates.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/wevj17080411/s1>. Supplementary Table S1 is provided as the root file Table_S1.csv, and Supplementary Ledger S1 is provided as the root file Ledger_S1.csv. Exact archive paths for the remaining supplementary items are listed in the root file Supplementary_Item_Map.md. The Supplementary Materials include reuse-safe derived tables for method ablation, TOPSIS intermediate diagnostics, a within-method score-discrimination summary for NI-EA, WSM, TOPSIS, and Einstein aggregation, the reconstructed candidate-level scenario-rank matrix, K-stability profiles, necessary and possible top-K sets, family-balanced acceptability, rank-displacement summaries, interaction, weighting, activity-density-radius, coverage-definition, Pareto, road-network, official-DEWA source-reconciliation, full-candidate Pareto-monotonicity, and interaction-effect audit outputs; fixed-source candidate-representation summaries; source/date/unit ontology and scenario-registry files; bounded community, transport, parking, and DEWA source-context summaries; the 15-site inspection-subset table; conservative status-snapshot and temporal data-suitability notes; reproducibility documentation; and an implementation-review field schema. The schema introduces no new scoring variable or result and is not a construction or engineering-feasibility assessment.

Author Contributions: Conceptualization, G.M.; methodology, G.M. and M.A.; software, G.M.; validation, G.M., A.A. (Azmi Alazzam), A.A.E., A.O., S.B., B.H., M.A. and A.A. (Abdelrahman Altigani); formal analysis, G.M.; investigation, G.M.; resources, G.M. and A.A. (Azmi Alazzam); data curation, G.M.; writing—original draft preparation, G.M.; writing—review and editing, A.A. (Azmi Alazzam), A.A.E., A.O., S.B., B.H., M.A. and A.A. (Abdelrahman Altigani); visualization, G.M.; supervision, A.A. (Azmi Alazzam) and M.A.; project administration, G.M. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by the Higher Colleges of Technology (HCT), United Arab Emirates.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data used in this study are derived from publicly available sources cited in the manuscript. Processed data supporting the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments: The authors acknowledge the institutional support of the Higher Colleges of Technology (HCT), United Arab Emirates.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Dubai Electricity and Water Authority (DEWA). Display EV Green Charger Locations; Electric Vehicles Green Charger Points CSV Export, Load Timestamp 8 May 2026, Source/Export Retained by Authors. Available online: <https://dewa.gov.ae/en/consumer/ev-community/ev-green-charger-stations> (accessed on 20 June 2026).
2. OpenStreetMap Contributors. OpenStreetMap [Data Set]; OpenStreetMap Foundation. 2026. Available online: <https://www.openstreetmap.org> (accessed on 20 June 2026).
3. Haklay, M.; Weber, P. OpenStreetMap: User-generated street maps. *IEEE Pervasive Comput.* **2008**, *7*, 12–18. [\[CrossRef\]](#)
4. He, F.; Wu, D.; Yin, Y.; Guan, Y. Optimal deployment of public charging stations for plug-in hybrid electric vehicles. *Transp. Res. Part B Methodol.* **2013**, *47*, 87–101. [\[CrossRef\]](#)
5. Deb, S.; Tammi, K.; Kalita, K.; Mahanta, P. Review of recent trends in charging infrastructure planning for electric vehicles. *WIREs Energy Environ.* **2018**, *7*, e306. [\[CrossRef\]](#)
6. Erbaş, M.; Kabak, M.; Özceylan, E.; Çetinkaya, C. Optimal siting of electric vehicle charging stations: A GIS-based fuzzy Multi-Criteria Decision Analysis. *Energy* **2018**, *163*, 1017–1031. [\[CrossRef\]](#)
7. Sun, L.; Dong, H.; Liu, A.X. Aggregation functions considering criteria interrelationships in fuzzy multi-criteria decision making: State-of-the-art. *IEEE Access* **2018**, *6*, 68104–68136. [\[CrossRef\]](#)
8. Wang, W.; Liu, X. Intuitionistic fuzzy geometric aggregation operators based on Einstein operations. *Int. J. Intell. Syst.* **2011**, *26*, 1049–1075. [\[CrossRef\]](#)
9. Sadeghi-Barzani, P.; Rajabi-Ghahnavieh, A.; Kazemi-Karegar, H. Optimal fast charging station placing and sizing. *Appl. Energy* **2014**, *125*, 289–299. [\[CrossRef\]](#)
10. Xu, D.; Pei, W.; Zhang, Q. Optimal planning of electric vehicle charging stations considering user satisfaction and charging convenience. *Energies* **2022**, *15*, 5027. [\[CrossRef\]](#)
11. Diakoulaki, D.; Mavrotas, G.; Papayannakis, L. Determining objective weights in multiple criteria problems: The CRITIC method. *Comput. Oper. Res.* **1995**, *22*, 763–770. [\[CrossRef\]](#)
12. Shannon, C.E. A mathematical theory of communication. *Bell Syst. Tech. J.* **1948**, *27*, 379–423. [\[CrossRef\]](#)
13. Siksnyte-Butkiene, I.; Zavadskas, E.K.; Streimikiene, D. Multi-Criteria Decision-Making (MCDM) for the Assessment of Renewable Energy Technologies in a Household: A Review. *Energies* **2020**, *13*, 1164. [\[CrossRef\]](#)
14. Zavadskas, E.K.; Turskis, Z. Multiple criteria decision making (MCDM) methods in economics: An overview. *Technol. Econ. Dev. Econ.* **2011**, *17*, 397–427. [\[CrossRef\]](#)
15. Hwang, C.-L.; Yoon, K. *Multiple Attribute Decision Making: Methods and Applications: A State-of-the-Art Survey*; Lecture Notes in Economics and Mathematical Systems; Springer: Berlin/Heidelberg, Germany, 1981; Volume 186. [\[CrossRef\]](#)
16. Chen, C.-T. Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy Sets Syst.* **2000**, *114*, 1–9. [\[CrossRef\]](#)
17. Topkis, D.M. Minimizing a submodular function on a lattice. *Oper. Res.* **1978**, *26*, 305–321. [\[CrossRef\]](#)
18. Milgrom, P.; Shannon, C. Monotone comparative statics. *Econometrica* **1994**, *62*, 157–180. [\[CrossRef\]](#)
19. Guler, D.; Yomralioglu, T. Suitable location selection for the electric vehicle fast charging station with AHP and fuzzy AHP methods using GIS. *Ann. GIS* **2020**, *26*, 169–189. [\[CrossRef\]](#)
20. Rane, N.L.; Achari, A.; Saha, A.; Poddar, I.; Rane, J.; Pande, C.B.; Roy, R. An integrated GIS, MIF, and TOPSIS approach for appraising electric vehicle charging station suitability zones in Mumbai, India. *Sustain. Cities Soc.* **2023**, *97*, 104717. [\[CrossRef\]](#)
21. Chumbi, W.E.; Martínez-Minga, R.; Zambrano-Asanza, S.; Leite, J.B.; Franco, J.F. Suitable site selection of public charging stations: A fuzzy TOPSIS MCDA framework on capacity substation assessment. *Energies* **2024**, *17*, 3452. [\[CrossRef\]](#)
22. Campaña, M.; Inga, E. Optimal planning of electric vehicle charging stations considering traffic load for smart cities. *World Electr. Veh. J.* **2023**, *14*, 104. [\[CrossRef\]](#)
23. Zhang, Q.; Si, G.; Li, H. Optimization of electric vehicle charging station location distribution based on activity–travel patterns. *ISPRS Int. J. -Geo-Inf.* **2025**, *14*, 373. [\[CrossRef\]](#)
24. Shaat, M.; Oroumchian, F.; Abohaia, Z.; El Barachi, M. A data-driven framework for electric vehicle charging infrastructure planning: Demand estimation, economic feasibility, and spatial equity. *World Electr. Veh. J.* **2026**, *17*, 42. [\[CrossRef\]](#)
25. Perko, J.; Topić, D. GIS-based multi-criteria optimization of EV charging stations integrated into public lighting infrastructure. *World Electr. Veh. J.* **2026**, *17*, 274. [\[CrossRef\]](#)
26. Ouerghi, S.; Elsheikh, R.; Amini, H.; Aldosari, S. An integrated GIS–AHP–sensitivity analysis framework for electric vehicle charging station site suitability in Qatar. *ISPRS Int. J. -Geo-Inf.* **2026**, *15*, 54. [\[CrossRef\]](#)
27. Nominatim. Open-Source Geocoding with OpenStreetMap Data. Available online: <https://nominatim.org/> (accessed on 20 June 2026).
28. Google Maps Platform. Geocoding API Overview. Available online: <https://developers.google.com/maps/documentation/geocoding/guides-v3/overview> (accessed on 20 June 2026).

29. Google Maps Platform. Text Search (New), Places API. Available online: <https://developers.google.com/maps/documentation/places/web-service/text-search> (accessed on 20 June 2026).
30. Geofabrik GmbH. OpenStreetMap Data Extracts: GCC States. Historical Snapshot: Gcc-States-260619.osm.pbf; File Timestamp 2026-06-19 22:33 UTC. Available online: <https://download.geofabrik.de/asia/gcc-states-260619.osm.pbf> (accessed on 20 June 2026).
31. Dubai Electricity and Water Authority (DEWA). *Electric Vehicles Charging Infrastructure Regulation for the Emirate of Dubai*, Version 1.3; DEWA: Dubai, United Arab Emirates, 2025. Available online: <https://www.dewa.gov.ae/en/builder/useful-tools/regulatory-framework-for-ev-charging-infrastructure> (accessed on 21 June 2026).
32. Dubai Electricity and Water Authority (DEWA). *EV Charging Technical Regulations: Technical Specifications and Installation Requirements for Private and Public Electric Vehicle Supply Equipment (EVSE) in the Emirate of Dubai*, Version 1.0; DEWA: Dubai, United Arab Emirates, 2025. Available online: <https://www.dewa.gov.ae/en/builder/useful-tools/regulatory-framework-for-ev-charging-infrastructure> (accessed on 21 June 2026).
33. Dubai Electricity and Water Authority (DEWA). *Annual Statistics Booklet 2025*; DEWA: Dubai, United Arab Emirates, 2025.
34. Dubai Digital Authority. *DDM-003: Data Roles and Responsibilities*, Version 5.0; Dubai Data Manual: Dubai, United Arab Emirates, 2026.
35. Roads and Transport Authority (RTA). Public Transport, Station, Bus-Stop, and Parking Datasets; Data.Dubai/Dubai Pulse Dataset Exports, 2026. Dataset Exports Retained by Authors; Source Portal. Available online: <https://www.dubaipulse.gov.ae/> (accessed on 21 June 2026).
36. Dubai 2040 Urban Master Plan. Urban Master Plan and Sustainable Development. Available online: <https://www.dm.gov.ae/municipality-business/planning-and-construction/dubai-2040-urban-master-plan/> (accessed on 21 June 2026).
37. Dubai Municipality. Open Data. Available online: <https://www.dm.gov.ae/open-data2/> (accessed on 21 June 2026).
38. Dubai Statistics Center. Population by Community [Data Set]. Data.Dubai/Dubai Pulse. Dataset Metadata/Export Retained by Authors. Available online: https://www.gslb.dubaipulse.gov.ae/data/dsc-statistics/dsc_population_by_community-open (accessed on 21 June 2026).
39. Bernard, M.R.; Hall, D. *Efficient Planning and Implementation of Public Chargers: Lessons Learned from European Cities*; International Council on Clean Transportation: Washington, DC, USA, 2021. Available online: <https://theicct.org/publication/efficient-planning-and-implementation-of-public-chargers-lessons-learned-from-european-cities/> (accessed on 21 June 2026).
40. Transport for London. *London's Electric Vehicle Infrastructure Strategy–2025 Update*; Transport for London: London, UK, 2025. Available online: <https://tfl.gov.uk/ruc-cdn/static/cms/documents/electric-vehicle-infrastructure-strategy-2025.pdf> (accessed on 21 June 2026).
41. Land Transport Authority (LTA), Singapore. Regulating the Safety of EV Chargers. Available online: https://www.lta.gov.sg/content/ltagov/en/industry_innovations/technologies/electric_vehicles/regulating_safety_of_ev_chargers.html (accessed on 21 June 2026).
42. ISO 37122:2019; Sustainable Cities and Communities—Indicators for Smart Cities. ISO: Geneva, Switzerland, 2019. Available online: <https://www.iso.org/standard/69050.html> (accessed on 21 June 2026).
43. European Parliament and Council. Regulation (EU) 2023/1804 of 13 September 2023 on the Deployment of Alternative Fuels Infrastructure and Repealing Directive 2014/94/EU. *Off. J. Eur. Union* **2023**, 1–47. Available online: <https://eur-lex.europa.eu/eli/reg/2023/1804/oj/eng> (accessed on 21 June 2026).
44. IEC 61851-1:2017; Electric Vehicle Conductive Charging System—Part 1: General Requirements. IEC: Geneva, Switzerland, 2017. Available online: <https://webstore.iec.ch/en/publication/33644> (accessed on 21 June 2026).
45. ISO 15118-20:2022; Road Vehicles—Vehicle to Grid Communication Interface—Part 20: 2nd Generation Network Layer and Application Layer Requirements. ISO: Geneva, Switzerland, 2022. Available online: <https://www.iso.org/standard/77845.html> (accessed on 21 June 2026).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.