Grid Integration and Intelligent Control:
Energy Management Strategies for Smart EV Charging Infrastructures

GIS-Based Site Selection and Multi-Criteria Decision Analysis

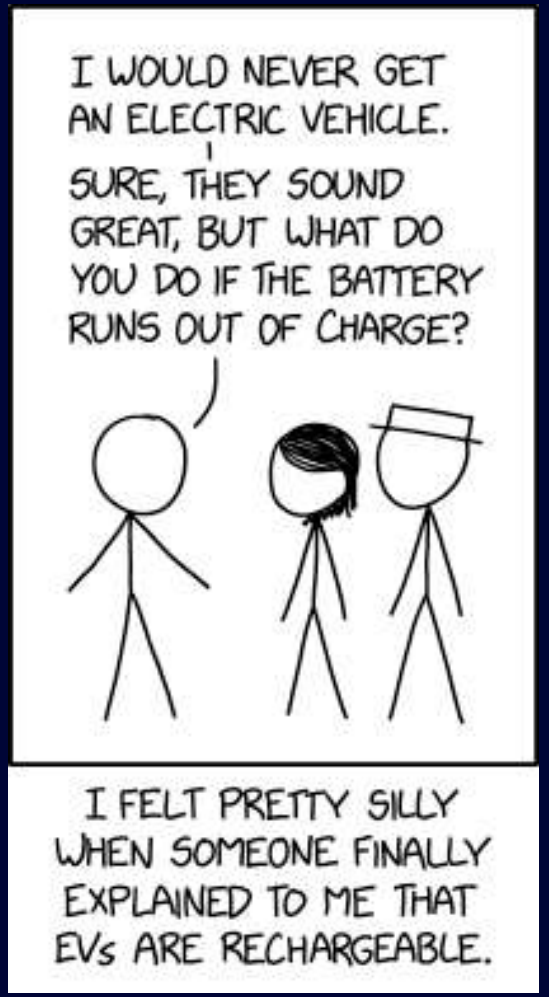
Geospatial Intelligence for EV Charging Infrastructure



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"The future of electric mobility depends not only on better vehicles, but on smarter locations."

Outline of this session



- Introduction
- Need for a calculated approach
- Multi-Criteria Decision Analysis (MCDA)
- Foundation of Geospatial Analysis
- Case study with OpenStreetMap data
- Conclusion

Image source: https://xkcd.com/3214/

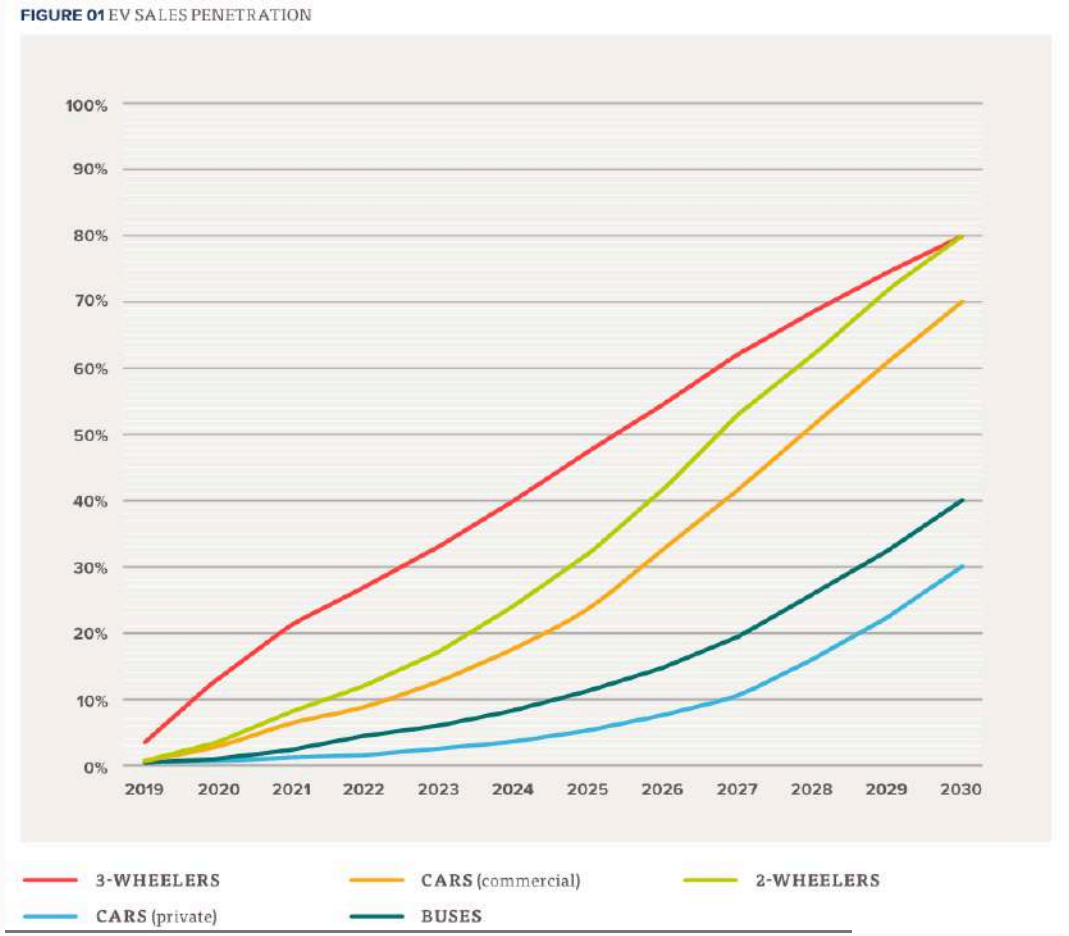
India's Electric Vehicle Growth Trajectory (FY2020-FY2026)

- India's EV penetration has risen from 0.71% in FY2020 to 8.26% in FY2026 – a more than **eleven-fold increase** within six years.
- As of July 2026, the national EV fleet exceeded **10 million** registered vehicles.

- In FY2025-26 alone, EV sales reached 25.45 lakh units, a year-on-year growth of 25%; alternative estimates place the figure at 2.6 million units, representing 9.5% of total vehicle sales.

- The Government of India has articulated a national target of **30% EV penetration by 2030**.

- This implies a fleet of several tens of millions of EVs within the next four years.
- Every such vehicle will require access to reliable charging infrastructure, making the strategic placement of charging stations a matter of urgent national importance.



1. *https://www.psa.gov.in/CMS/web/sites/default/files/publication/rmi-niti-ev-report.pdf*
2. *https://www.pib.gov.in/PressReleasePage.aspx?PRID=2287125&lang=2&reg=48*

The Charging Infrastructure Gap: A Reality Check

- As of 31 March 2026, India operated 52,718 public EV charging stations.
- Against a fleet of 10 million EVs, this yields a ratio of approximately **one public charger for every 190 EVs**.
- By comparison, mature EV markets such as China and Norway maintain ratios close to **1:20**.
- While India's ratio has improved from 1:250 a year earlier, the gap remains substantial.
- BMW Group India has acknowledged this improvement as "**very, very significant**", yet the target ratio of 1:20 implies a need for roughly **500,000 public chargers** at current fleet levels – and more as the fleet expands.

> *The critical challenge is not only the number of chargers but their spatial distribution, which determines actual accessibility and utilization.*

Source:

- *https://www.pib.gov.in/PressReleasePage.aspx?PRID=2287125&lang=2&reg=48*
- *https://www.iea.org/reports/global-ev-outlook-2026/electric-vehicle-charging-chap-6-and-10*

So What's the Problem? Why Can't We Just Build Everywhere?

- The capital cost of a single 60kW charging station is approximately **₹15 lakh**, comprising ₹7 lakh for the charger and ₹7 lakh for upstream infrastructure.
- For chargers above 150 kW, upstream infrastructure alone can cost ₹24 lakh.
- Scaling this to thousands of stations entails investments running into several thousand crore rupees.
- Industry reports indicate that average utilization rates often fall below 5%.
- Tata Power reportedly paused its expansion due to persistently low utilization.
- Poorly sited chargers result in **stranded assets**, wasted public funds, and frustrated EV owners ultimately slowing adoption.
- The "**build and they will come**" approach is financially imprudent; data-driven spatial intelligence is essential to ensure that every charger serves a demonstrable demand.

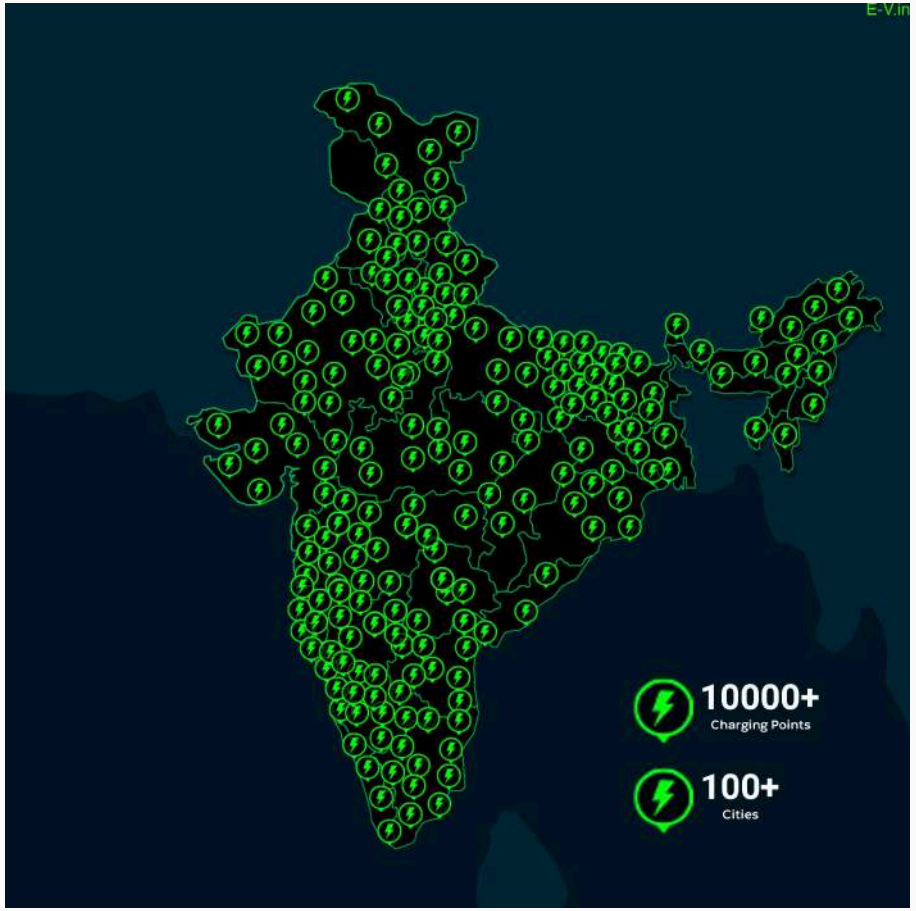


Image Source: https://E-V.in

Let's discuss GIS - The "Where" Question Answered

> Geographic Information Systems (GIS) enable the capture, storage, analysis, and visualization of spatial data. In the context of EV charging, GIS facilitates the layering of multiple datasets to reveal spatial relationships and patterns.

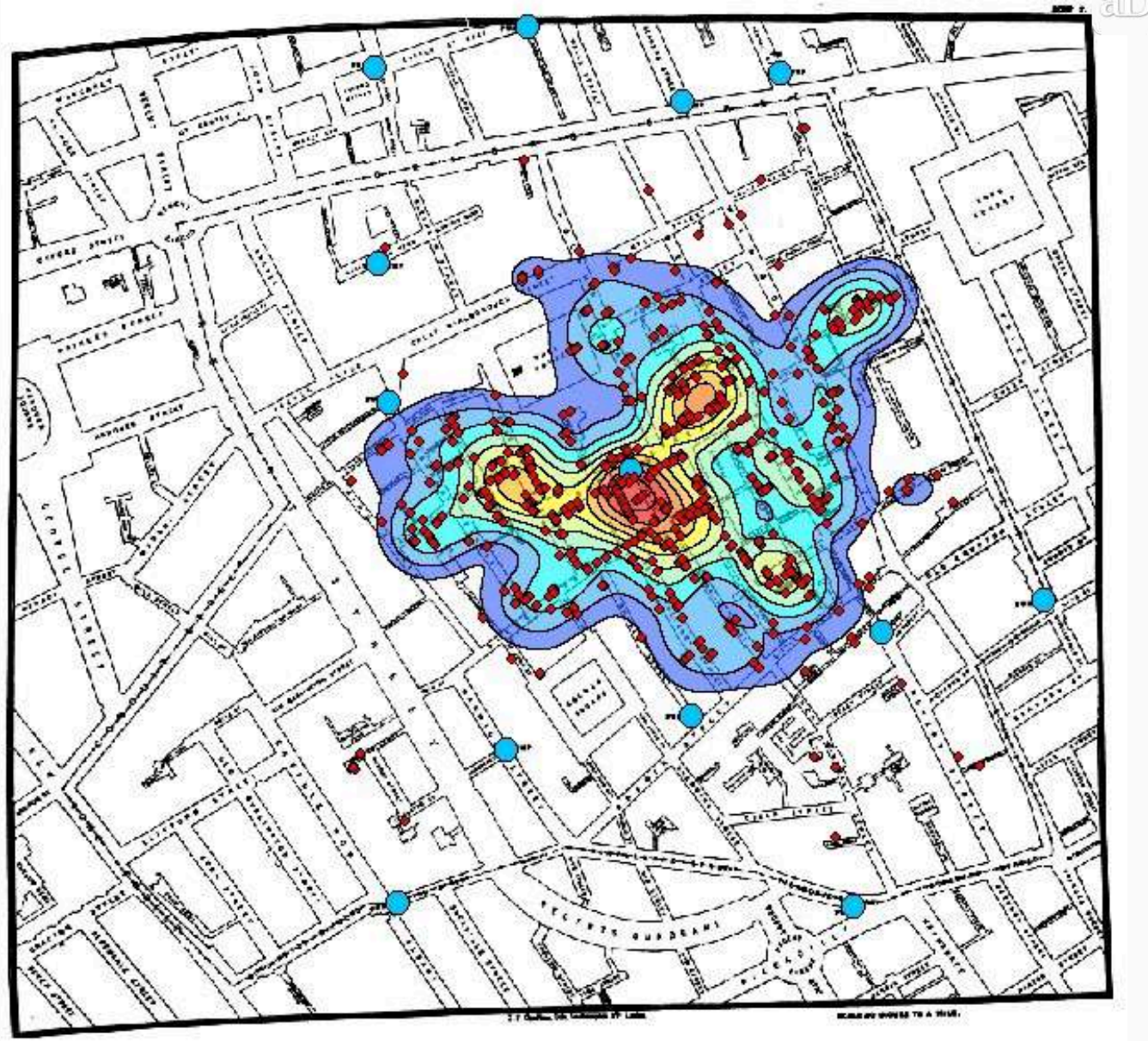
Key layers include:

> - **Population density** and demographic distribution
> - **Traffic flow** volumes and temporal patterns
> - Existing charging infrastructure and service gaps
> - **Land use** (residential, commercial, industrial)
> - **Road network** hierarchy (highways, arterial roads, local streets)
> - **Power grid** capacity and proximity to substations.

GIS as a Foundational Spatial Decision-Support Tool

But, what is GIS

- Geographic Information System (GIS) is a computer-based system for capturing, storing, managing, analyzing, and visualizing data that has a geographic (spatial) location.
- Key components of GIS include software, hardware, spatial data, people, and methods, each contributing to the effective use of geographic information.
- Example: QGIS, ArcGIS



Resource: *John Snow and the 1854 Broad Street cholera outbreak*

MCDA - To Answer "Why Here"

- While GIS answers *where*, Multi-Criteria Decision Analysis (MCDA) answers *why* a particular site is preferable over others.
- Site selection for EV charging stations involves multiple, often conflicting criteria – traffic volume vs. grid capacity, land cost vs. proximity to amenities, etc.
- MCDA provides a structured framework for evaluating and weighting these criteria, enabling objective ranking of candidate locations.

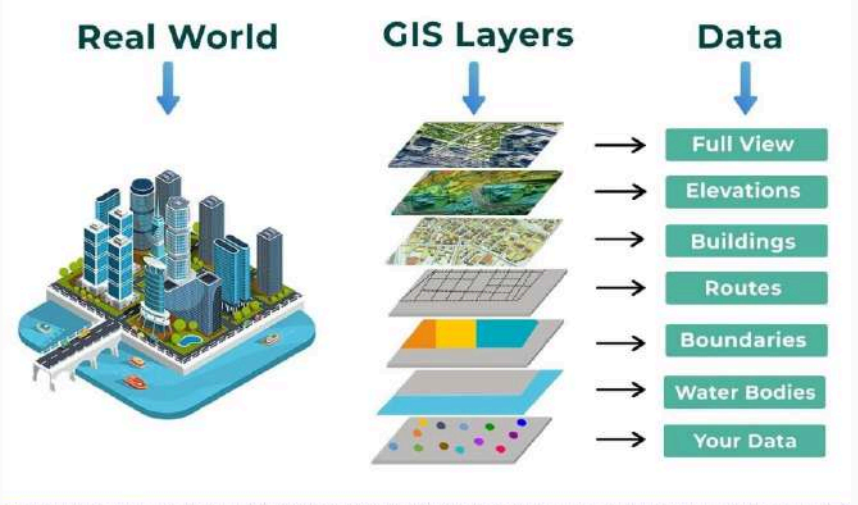
> *The common objective of MCDA is to move beyond subjective judgment towards a reproducible, transparent decision-making process that maximizes overall system performance.*

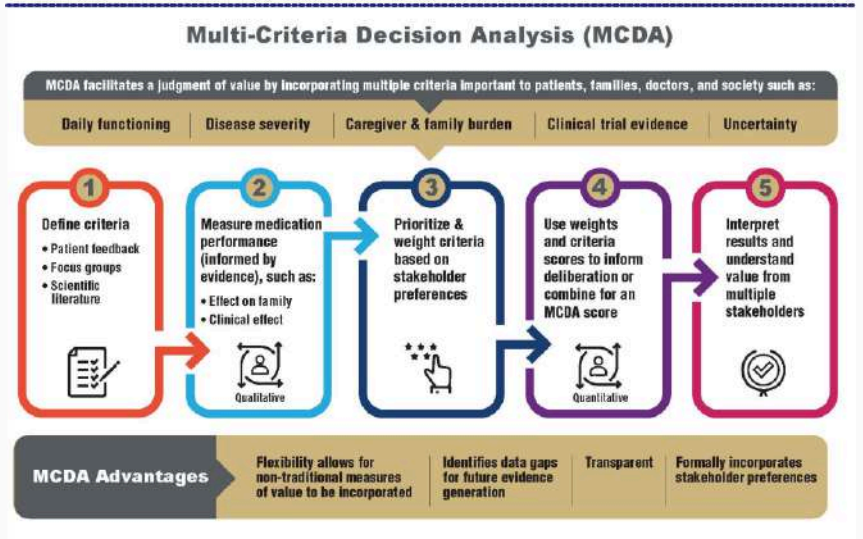
Smart EV Charging Site Selection with GIS

- The rapid electrification of India's transport sector demands a corresponding expansion of public charging networks.
- Only the addition of charging stations is insufficient; their spatial and functional optimisation is critical.

Location is the key!

- GIS and MCDA provides the analytical rigor needed to ensure that public and private investments yield maximum utility, accessibility, and financial viability.





How GIS and MCDA Work Together

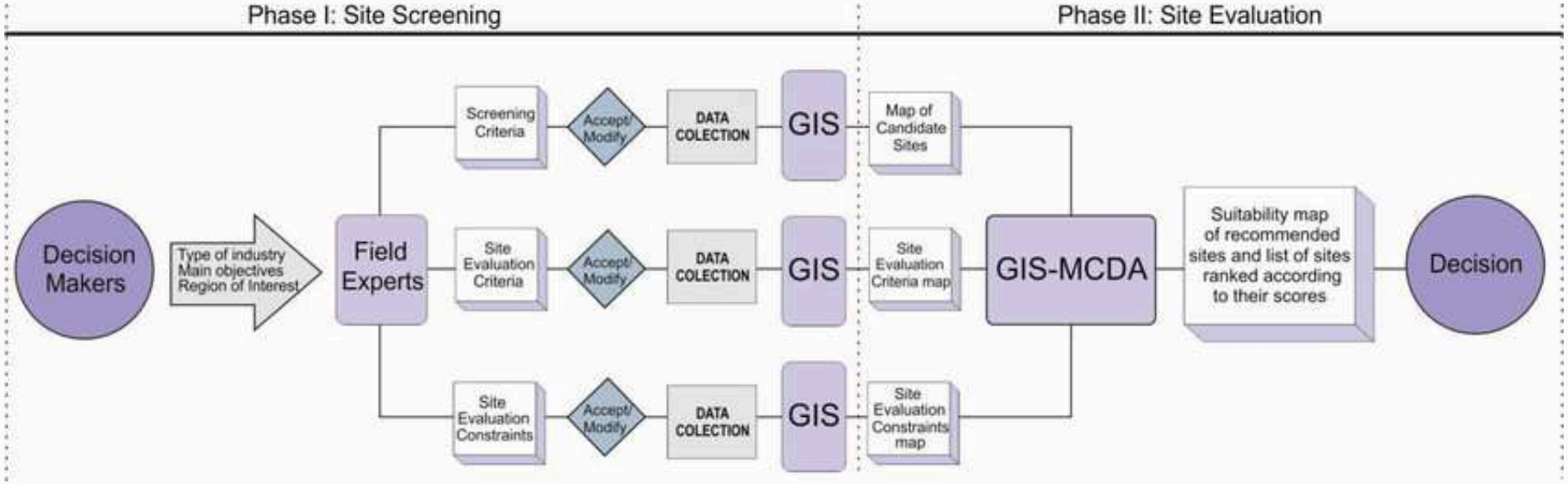
Criteria Definition – Identify all relevant technical, economic, social, and environmental factors.

Spatial Mapping (GIS) – Create thematic layers for each criterion across the study area.

Criteria Weighting (MCDA) – Assign relative importance weights using methods like AHP, CRITIC, or Entropy.

Suitability Overlay – Combine weighted layers in GIS to generate a composite suitability map.

Ranking and Validation – Rank candidate sites using MCDA techniques (AHP, TOPSIS, etc.) and validate against real-world utilization data.



GIS-MCDA

The suitability analysis is addressed and formulated as the intersection of two scientific fields:

- i. spatial analysis, and
- ii. spatial decision-making.

> GIS-MCDA is a process that converts and combines geographical maps and decision makers' preferences to get a decision map

The components of MCDA are the following:

- Goal or a set of goals to be attained;
- Decision makers, who can be individuals or groups;
- **Criteria** (attributes or objectives), which should be comprehensible and measurable;
- Decision alternatives, which consist in action (what to do) and location (where to do it), specified by decision variables that may be binary, discrete or continuous;
- Decision matrix formed by the decision alternatives (rows) and the criteria (columns).

GIS-MCDA procedures involve three main concepts

1. **Criterion Weights**: The AHP method is employed to define a weight to each evaluation criterion by a paired comparison analysis;
2. **Value Function** (standardization methods): The score range procedure is the most commonly used approach for standardizing criteria.
3. **Combination Rules**: Also known as decision rules, this is a technique to evaluate and sort a set of alternatives.

Real Criteria that Matter

The following criteria can be useful for optimum charging station location

- **Demand-related:** population density, registered EV counts, traffic volume, proximity to commercial/office zones.
- **Accessibility:** distance from major roads and highways, spacing from existing chargers (to avoid clustering), parking availability.
- **Infrastructure:** grid capacity, distance to substations, land availability and cost, proximity to distribution networks.
- **Sustainability:** solar energy potential, environmental impact, NDVI (vegetation) and NDWI (water) indices.

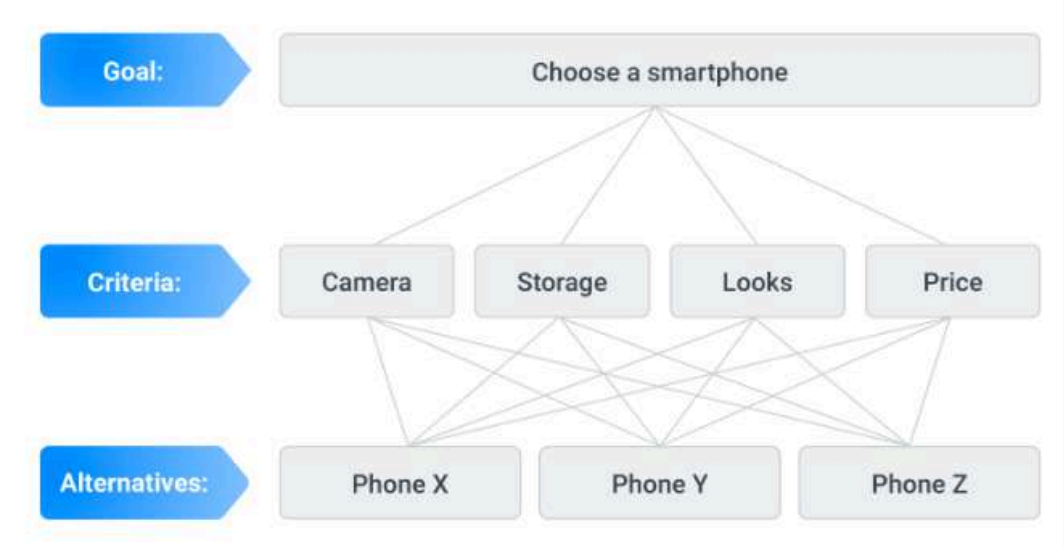
Criterion	Rationale
Population density	Higher concentration of potential EV users
Traffic volume	Represents charging demand from passing vehicles
Distance to major roads	Ensures easy access and visibility
Distance to power substations	Minimizes grid connection cost and power losses
Existing charging stations	Improves network coverage and avoids redundancy
Land use/Land cover	Favors commercial, transport, and public land
Land cost	Reduces installation and acquisition costs
Flood-prone areas	Avoids disruption and infrastructure damage
Protected areas / Water bodies	Excludes environmentally sensitive and unsuitable locations

What is the Analytic Hierarchy Process (AHP)

- A decision-making method used by individuals and organizations to rank alternatives they are considering based on **pairwise comparisons** (Saaty 1977, 1980).
- The Analytic Hierarchy Process (AHP) is a multi-criteria decision analysis (MCDA) method that begins by breaking down decisions into a hierarchical structure of a decision-making goal, criteria and alternatives.

Input	Process	Output
Criteria layers + Expert pairwise comparisons	Analytical Hierarchy Process (AHP)	Ranked Weights for Criteria

The simple three-level hierarchical structure outlined above can be represented by a tree diagram like this:



AHP process provides the weightage of each spatial layer.

Learning Resource: https://www.1000minds.com/decision-making/analytic-hierarchy-process-ahp

A Sample Criterion weights obtained by the AHP

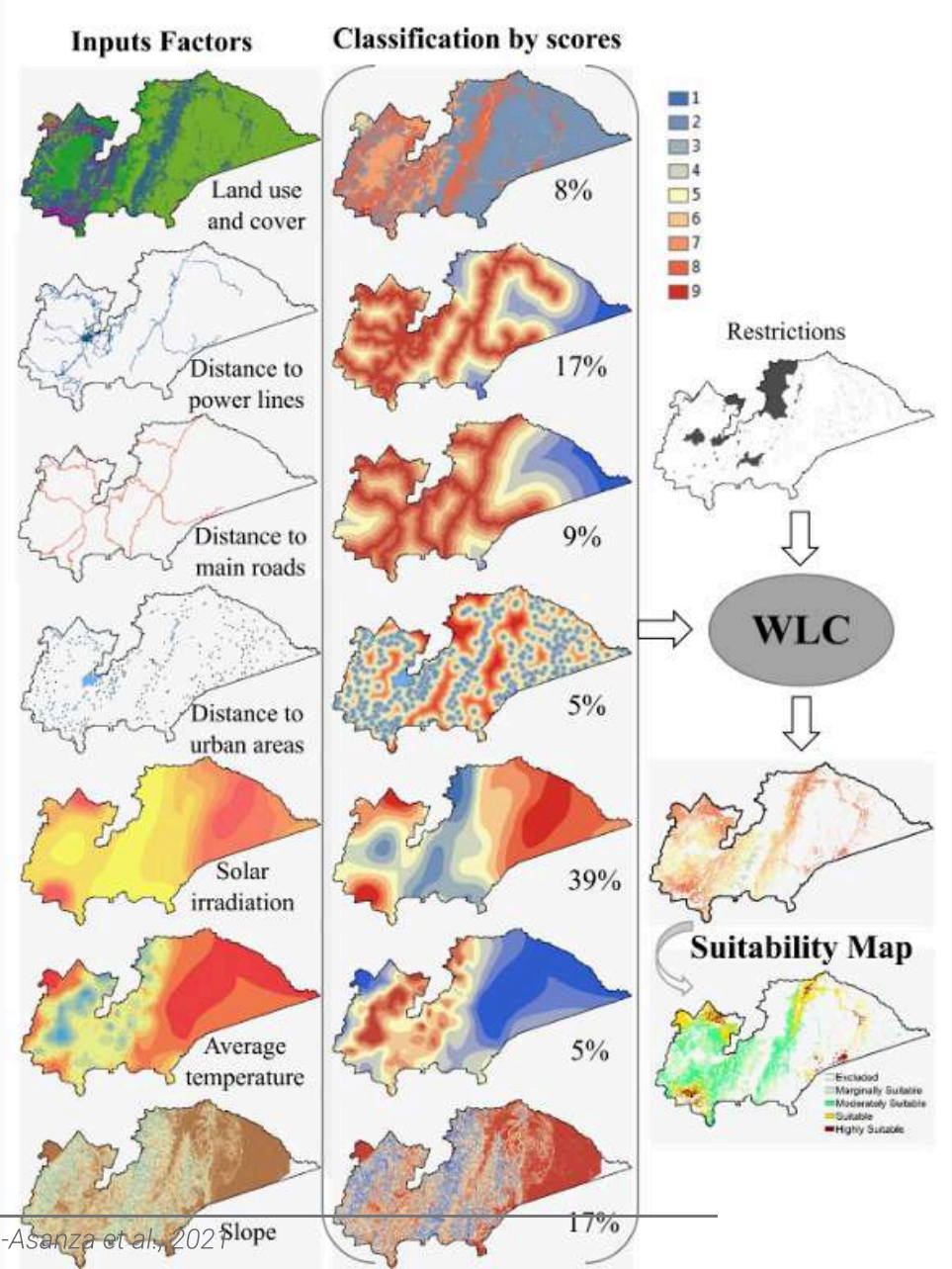
Criteria	Criteria Weight	#	Sub-criteria (Factors)	Unit	Weight (w)
Environmental Location	38.6%	k1	Land use and cover	Type	7.6%
Environmental Location	38.6%	k2	Distance to power lines	km	17.1%
Environmental Location	38.6%	k3	Distance to main roads	km	8.8%
Environmental Location	38.6%	k4	Distance to urban areas	km	5.1%
Climatic	43.9%	k5	Solar irradiation	$kWh/m^2/year$	39.3%
Climatic	43.9%	k6	Average temperature	$\circ C$	4.6%
Orography	17.5%	k7	Slope	$\circ$	17.5%

- AHP assigns relative importance to each criterion through pairwise comparisons, producing normalized weights that reflect expert judgment.
- In the above example, climatic factors (43.9%), particularly solar irradiation (39.3%), have the greatest influence, followed by environmental location (38.6%) and orographic conditions (17.5%).

Suitability Assessment Process using GIS

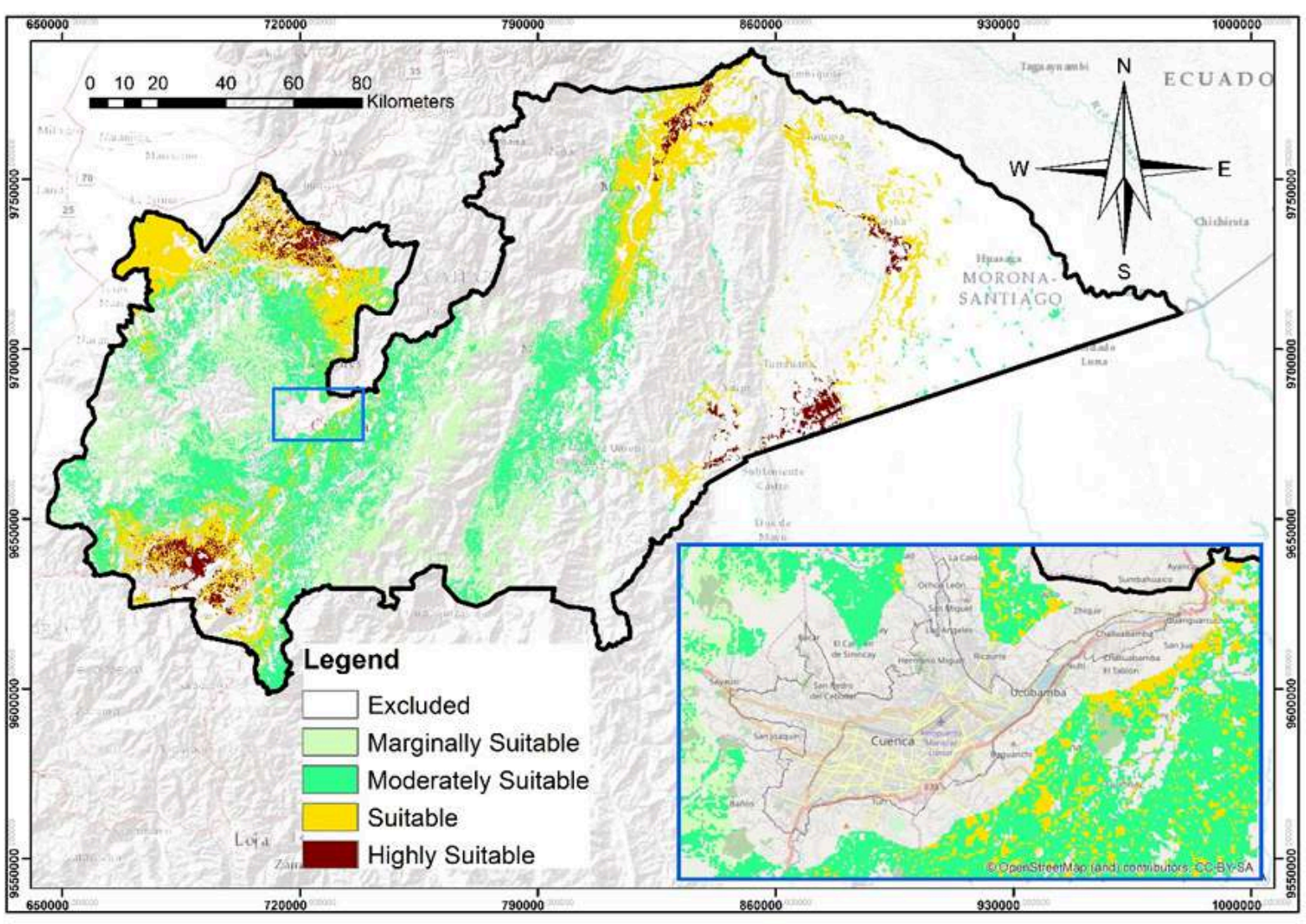
Potential locations for a specific use or activity are often found systematically with a suitability analysis

- Suitability Assessment process with the help of a GIS MCDM.
- The maps on the first column show the entry criteria before the geoprocessing.
- The second column presents heat maps with the result of the standardization process (scoring on a 1-9 color scale),



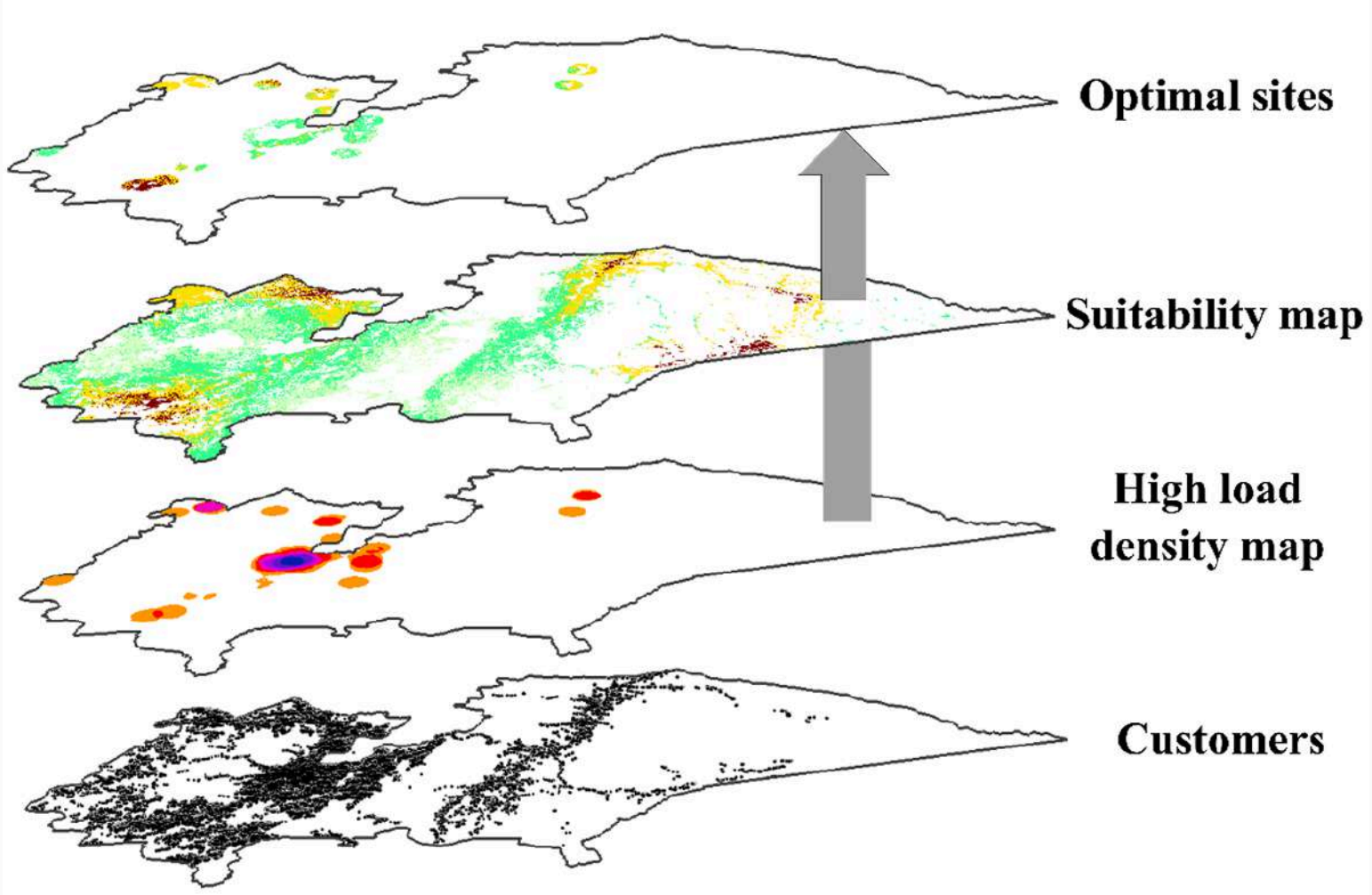
Zambrano-Asanza et al., 2021

Suitability map for solar power plants locations



Optimal Site Location Map

- The last step of the analysis is to obtain the best suitability sites using a spatial overlay,
- Spatial overlay between the suitability map and the electric load density map



Zambrano-Asanza et al., 2021

To QGIS to Understand Process of GIS Layer Management!

Thank You!

Resources and References

1. https://www.qgistutorials.com/en/docs/3/multi_criteria_overlay.html
2. Zambrano-Asanza, S., Quiros-Tortos, J., & Franco, J. F. (2021). Optimal site selection for photovoltaic power plants using a GIS-based multi-criteria decision making and spatial overlay with electric load. Renewable and Sustainable Energy Reviews, 143, 110853.