A GIS-Based Multi-Criteria Decision Analysis (MCDA) for Equitable Electric Vehicle Supply Equipment (EVSE) Deployment in Philadelphia

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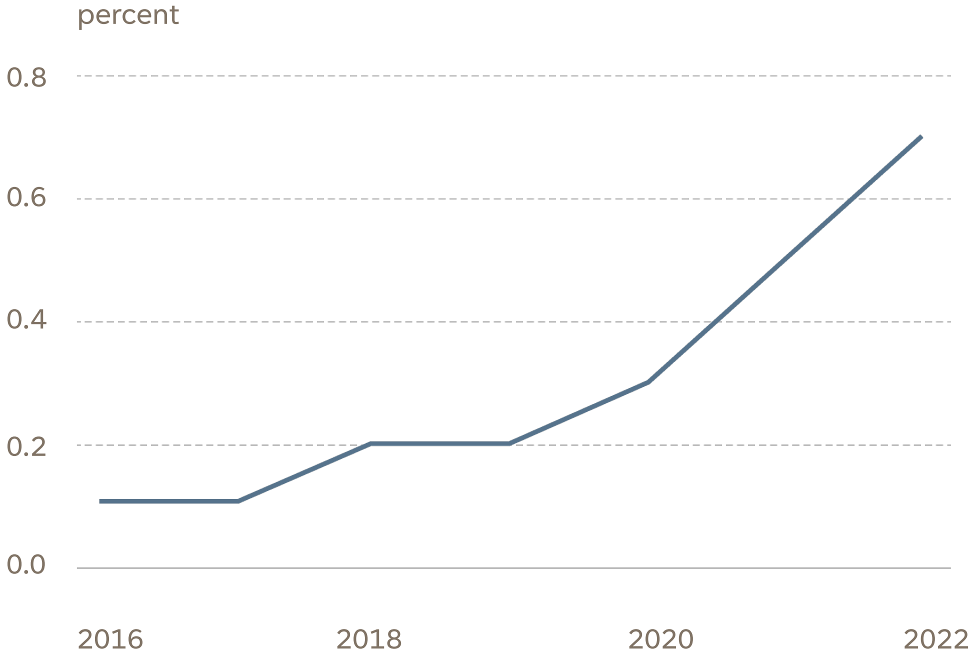
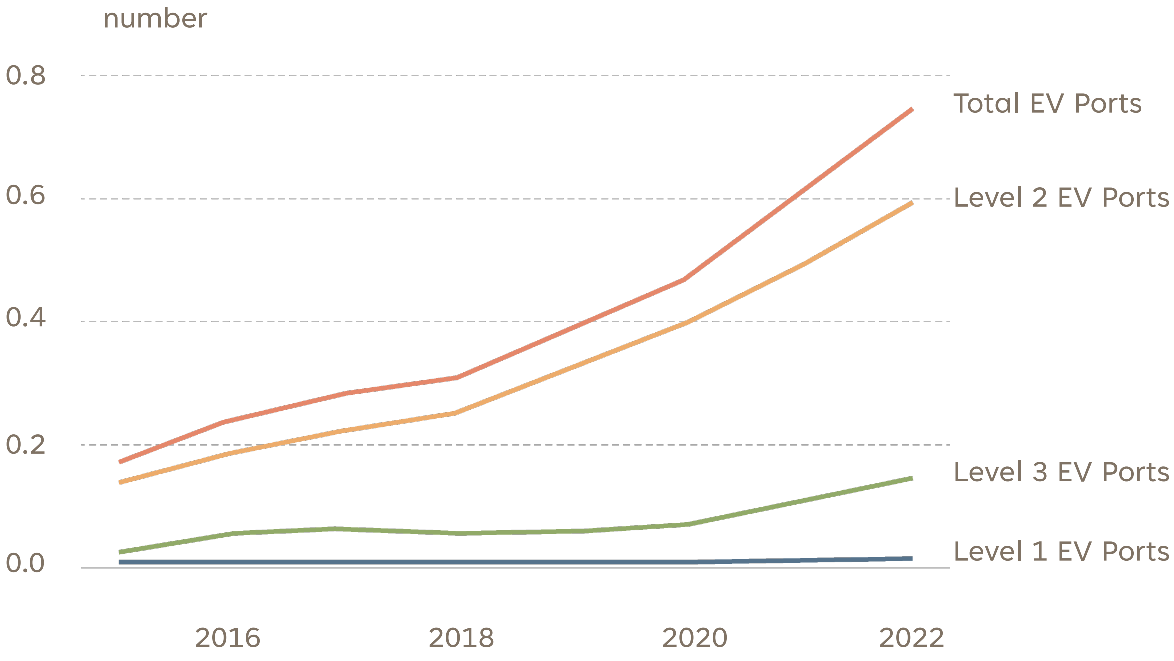
Motivations

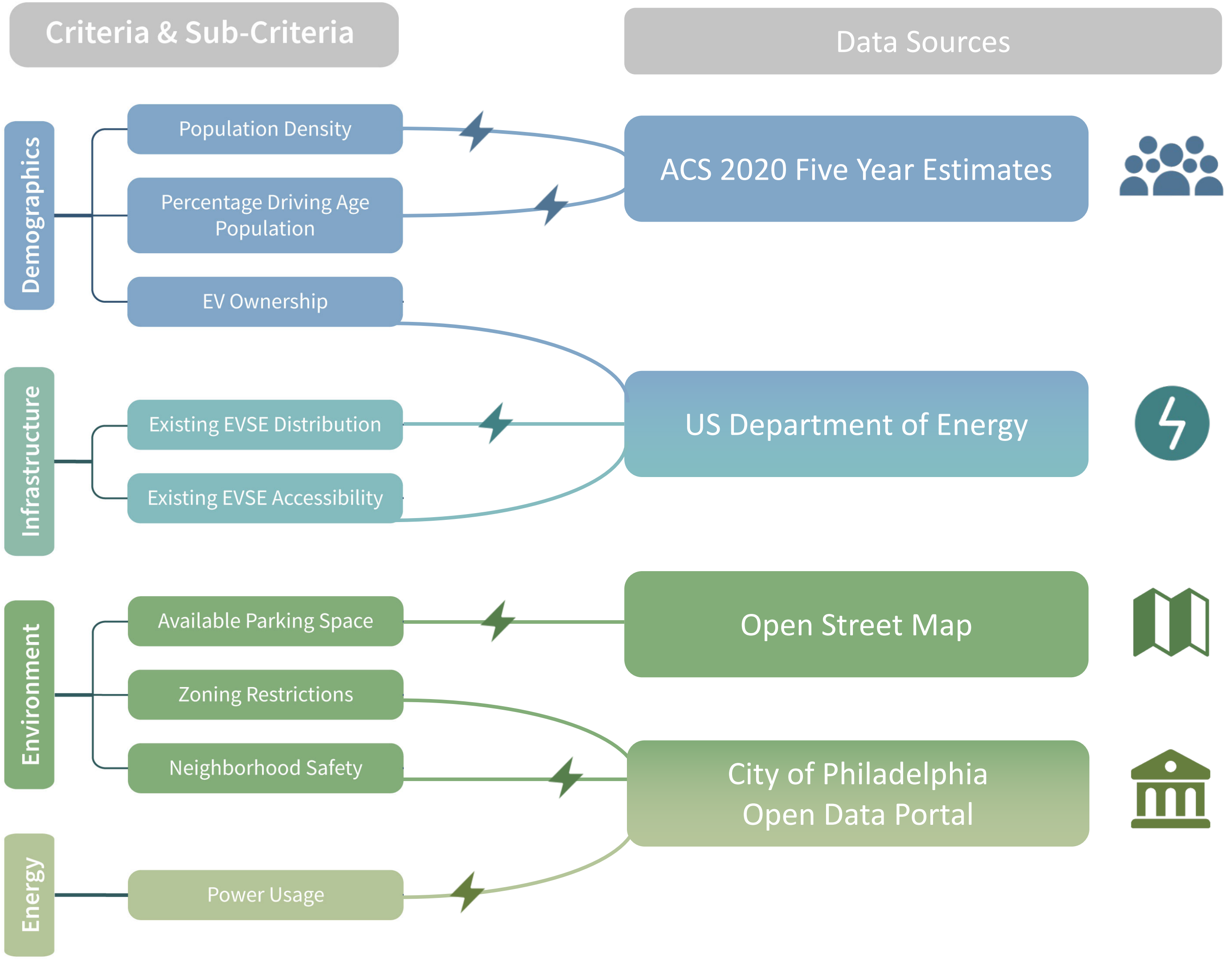
Electric vehicle (EV) share of total light-duty vehicles, annual



Electric vehicle (EV) ports, annual



Data and Criteria



United States Census Bureau

U.S. DEPARTMENT OF ENERGY

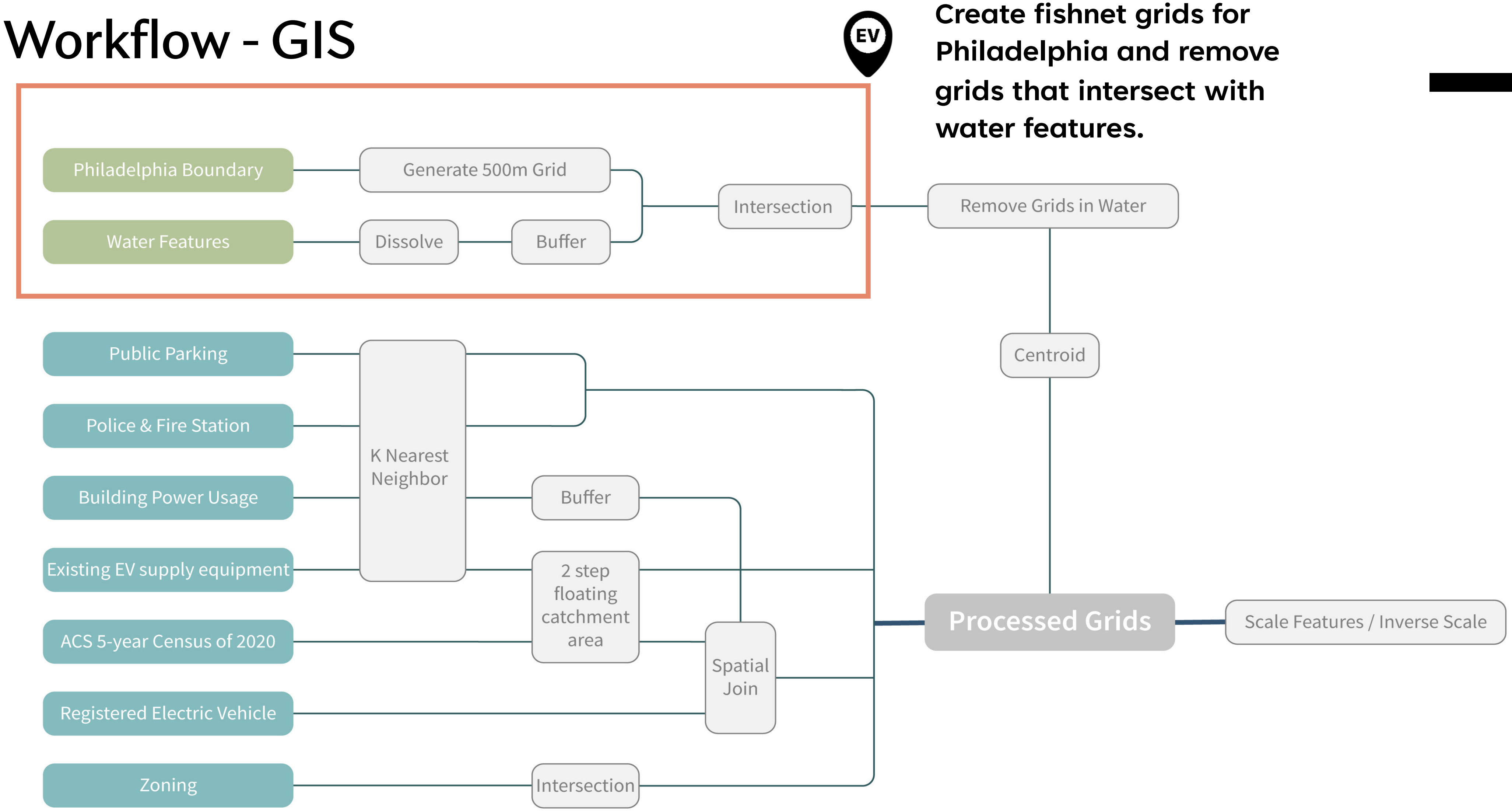
OpenStreetMap

City of Philadelphia

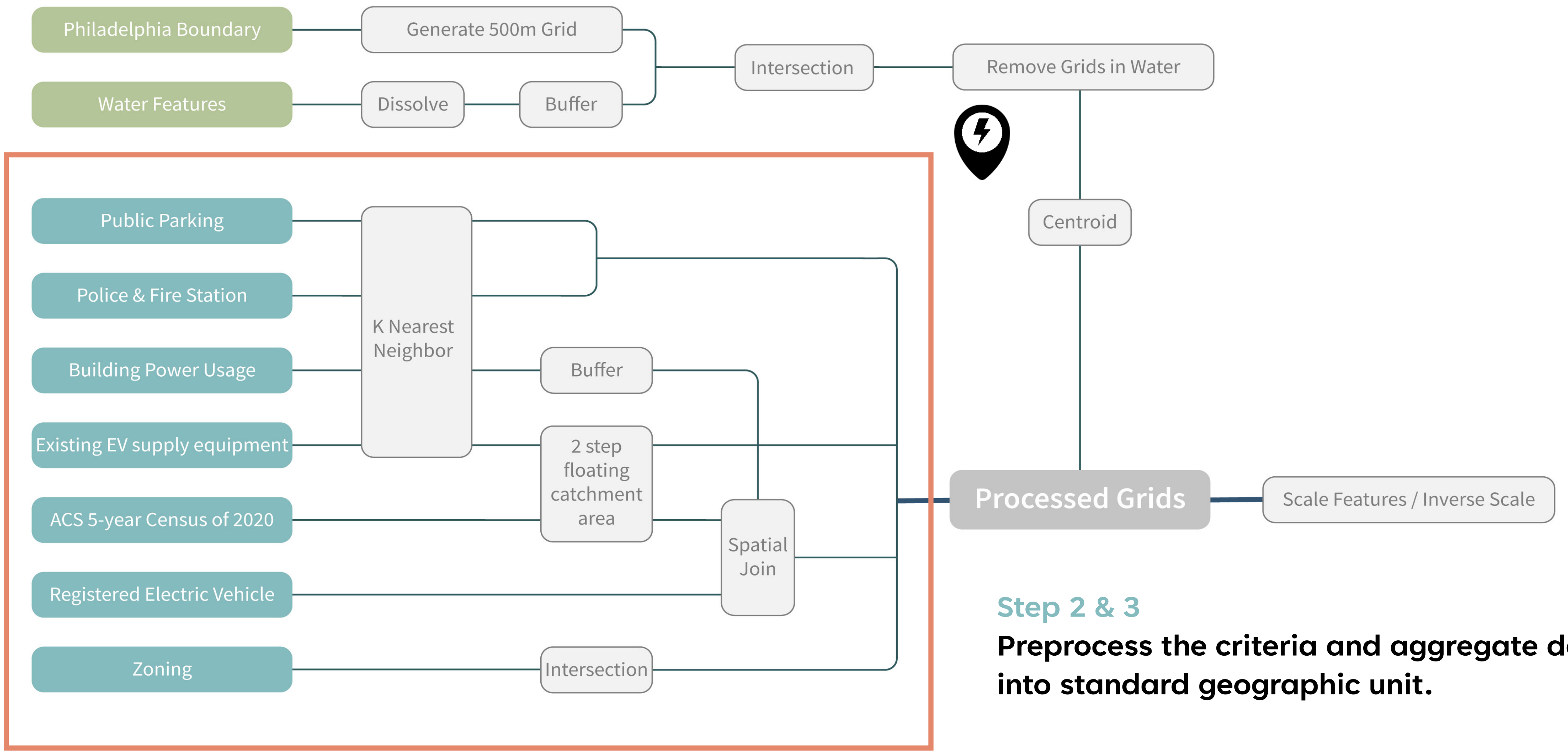
Workflow - GIS

Step 1:

Create fishnet grids for Philadelphia and remove grids that intersect with water features.



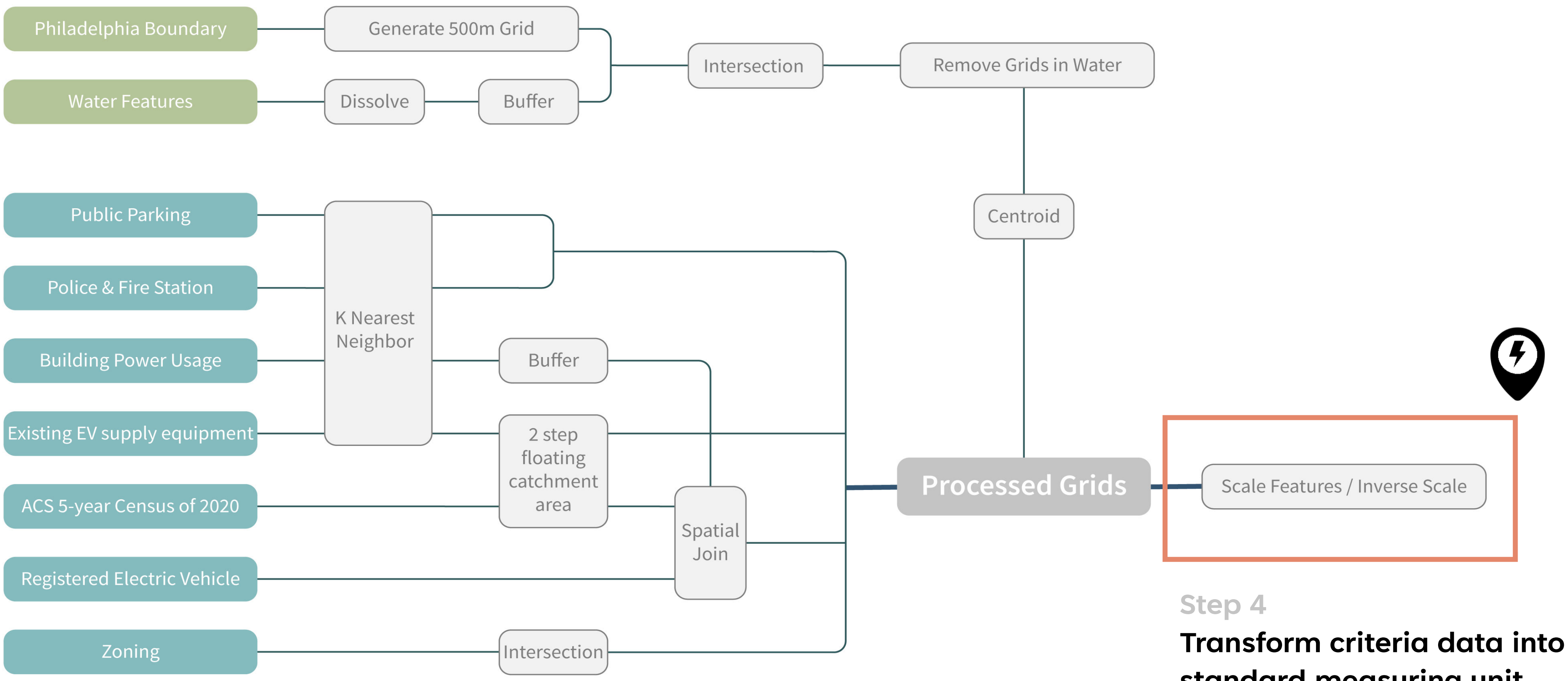
Workflow - GIS



Step 2 & 3

Preprocess the criteria and aggregate data into standard geographic unit.

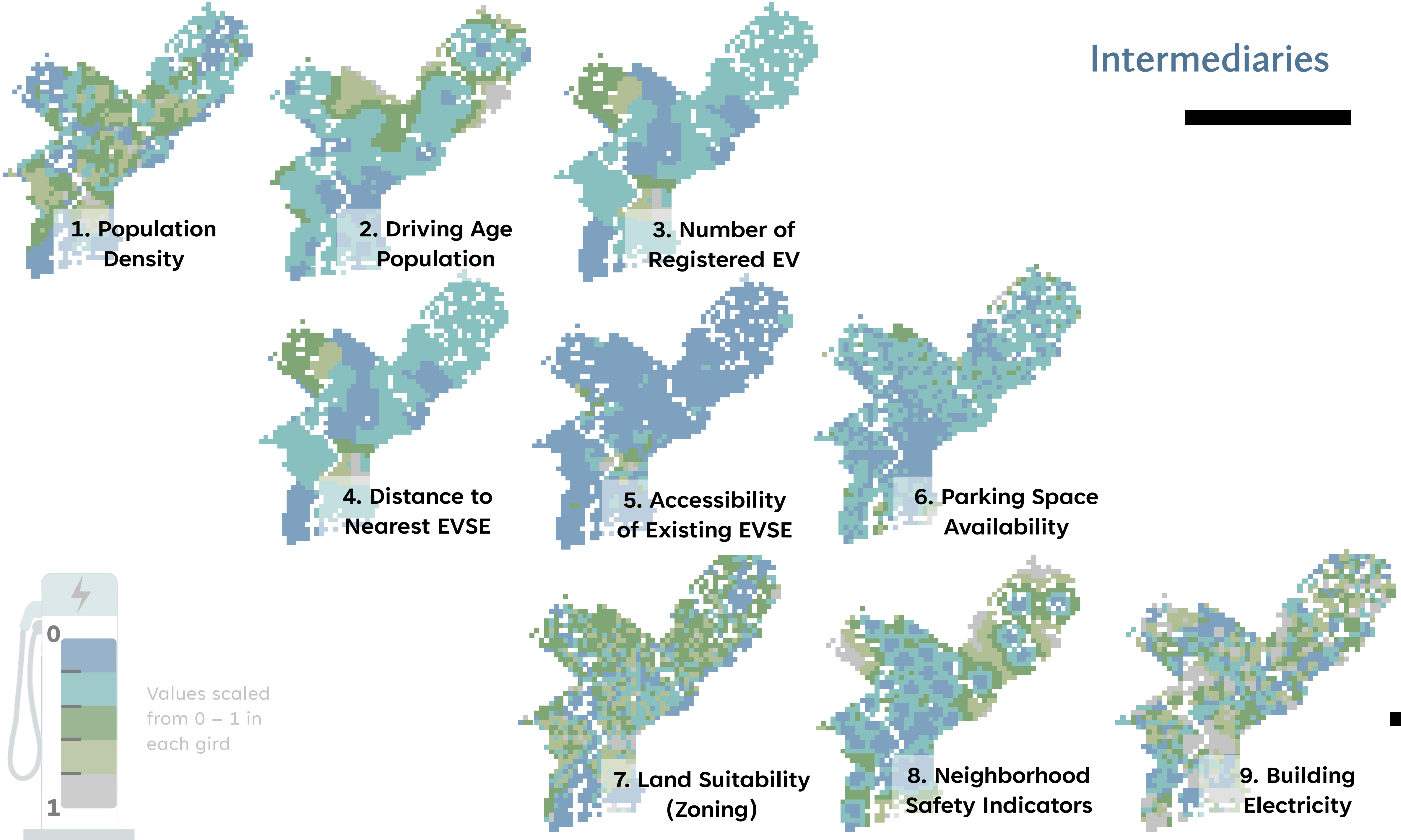
Workflow - GIS



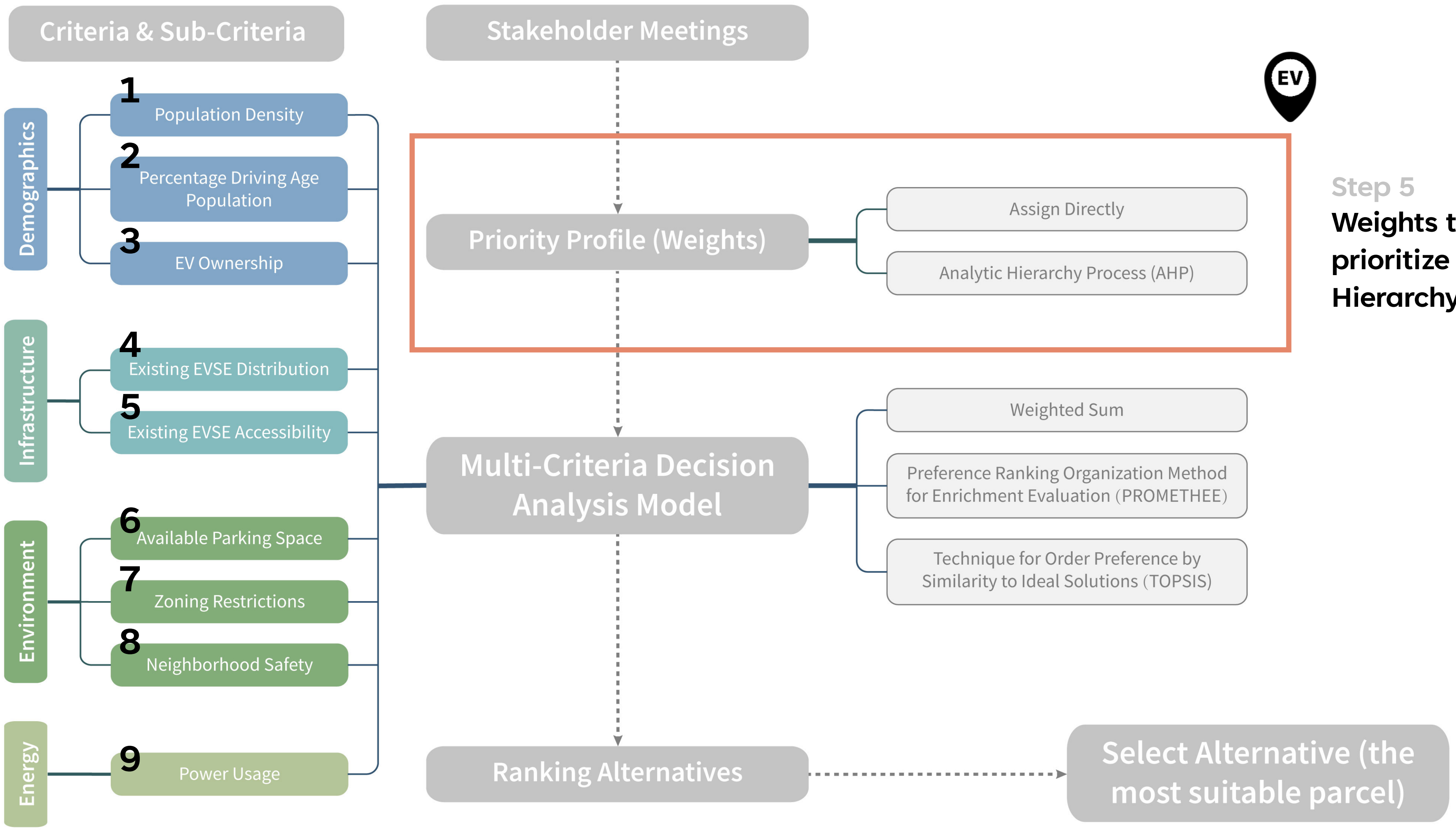
Step 4

Transform criteria data into standard measuring unit.

Intermediaries



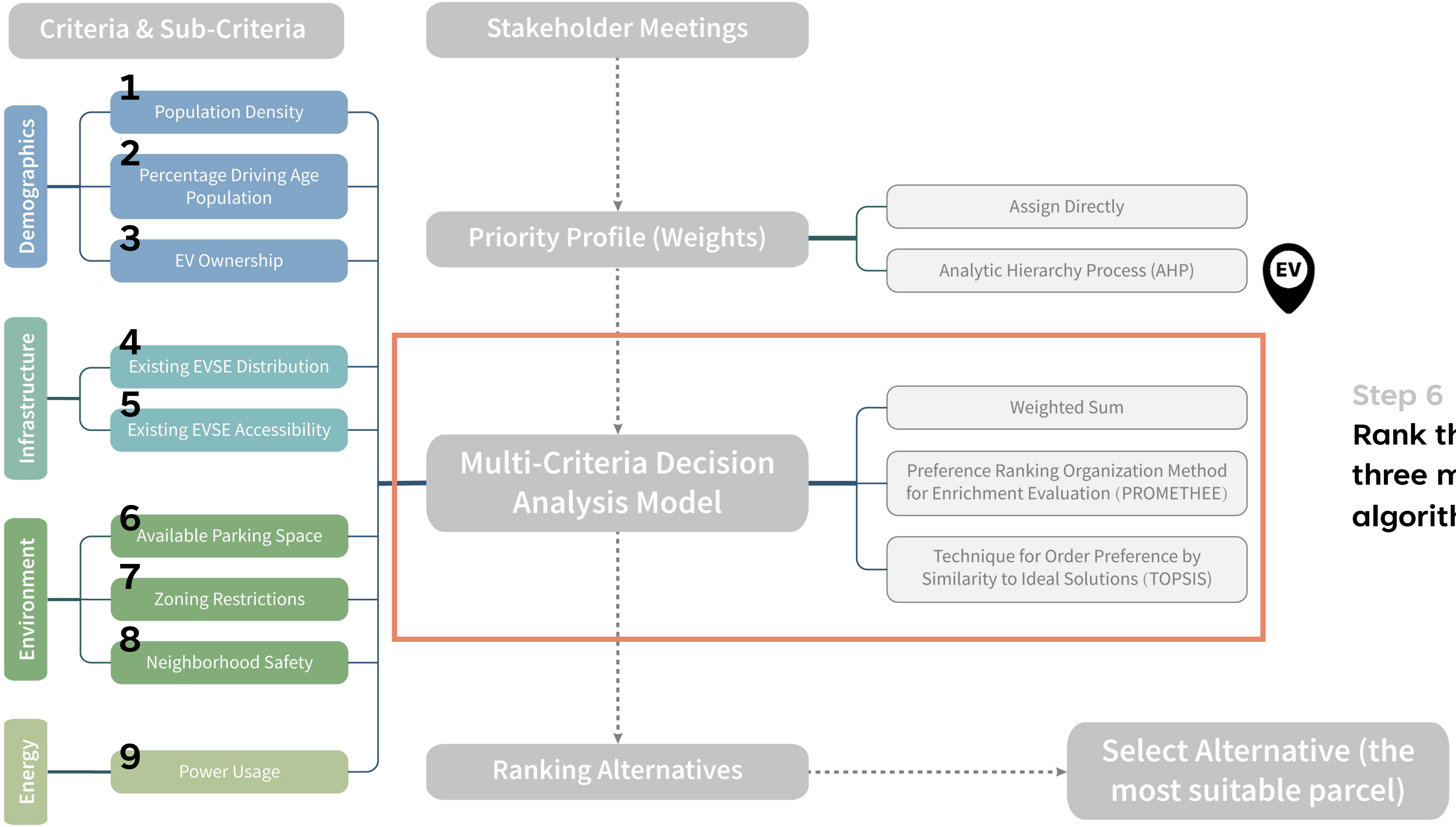
Workflow - MCDA



Step 5

Weights the criteria and prioritize them using Analytic Hierarchy Process (AHP)

Workflow - MCDA



Step 6

Rank the fishnet grids using three most popular MCDA algorithms.

MCDA Methods – WSM

Assign weights to each criteria and score the alternative by summing the products of their weight and value.

Inputs	Algorithms	Output
Criteria Weights Alternatives	**1. Assign weights** $\sum_{j=1}^{j} weight_j = 1$ **2. Compute weighted sum** $S_i = \sum_{j=1}^{j} weight_j \times value$	Rank alternatives based on S_i in descending order. Higher the S_i the better.

i = alternative *j = criteria*

MCDA Methods - TOPSIS

Identifies solutions from a set of alternatives based on their **euclidean distance from an ideal solution.**

Inputs	Algorithms	Output
Criteria Weights Alternatives **Positive Ideal Solution** **Negative Ideal Solution**	**1. Compute Separation Measures** Pos ideal solution: $S_i^+ = \sqrt{\sum_{j=1}^{n}(value_{ij} - best_j)^2}$ Neg Ideal solution: $S_i^- = \sqrt{\sum_{j=1}^{n}(value_{ij} - worst_j)^2}$ **2. Measure Relative Closeness** $C_i^* = \frac{S_i^-}{S_i^+ + S_i^-}$	Rank alternatives based on C_i^* in descending order. Higher the C_i^* the better.

i = alternative　*j = criteria*

MCDA Method - PROMETHEE

Compares *alternatives* **pairwise** for each criteria and use **preference function** to evaluate one alternative over another.

Inputs

Criteria

Weights

Alternatives

Preference Function

Preference Threshold

Indifference Threshold

Algorithms

1. Compute difference in values for each criterion between all pairs of alternatives.

2. Apply preference function to translate difference in values into preference value between 0 and 1, using preference and indifference thresholds are parameters,

3. Aggregate preference values

4. Compute outranking flows:

Net flow = how much an alternative outrank all other alternatives + how much an alternative is outranked by all other alternatives

Output

Alternatives with the highest **net flow** value is consider the best.

MCDA Method - AHP

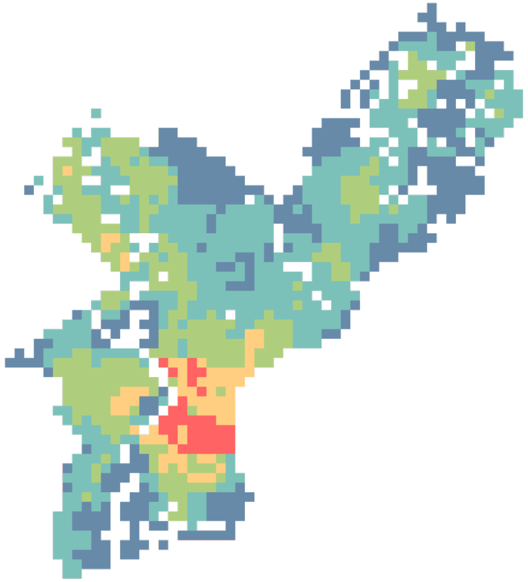
Compares *criteria* **pairwise** and re-assign weights based on their **relative importance.**

Inputs	Algorithms	Output
Criteria Weights	**1. Construct pairwise comparison matrix** by determining the relative importance of criterion 1 over 2.	New weights

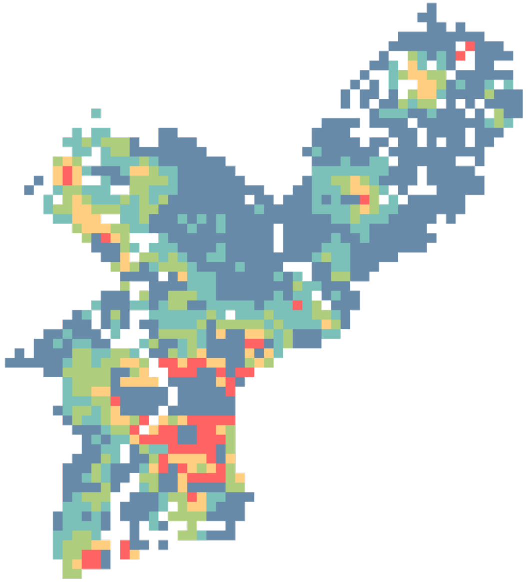
$$A = \begin{bmatrix} 1 & w1 & \cdots & wj \\ \frac{1}{w1} & 1 & \cdots & w2 \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{wj} & \frac{1}{w2} & \cdots & 1 \end{bmatrix}$$

2. Calculate the weights by normalizing the matrix and calculate the average of each row

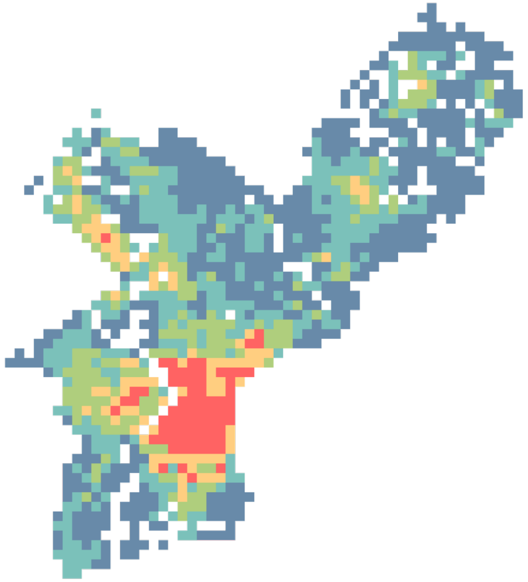
Ranking Results



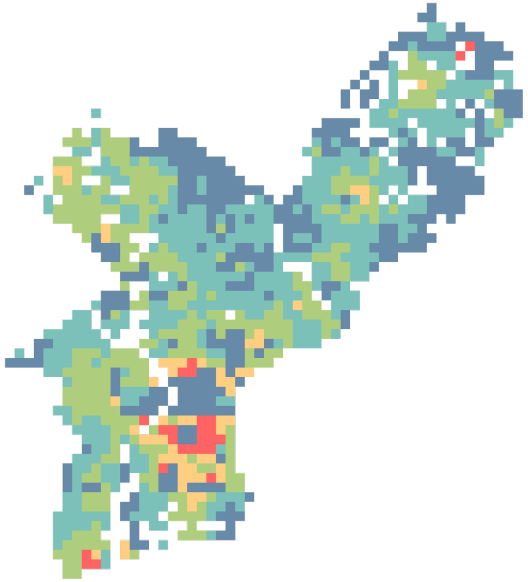
Self-assign weights
+
Weighted Sum (WSM)



Self-assign weights
+
Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS)



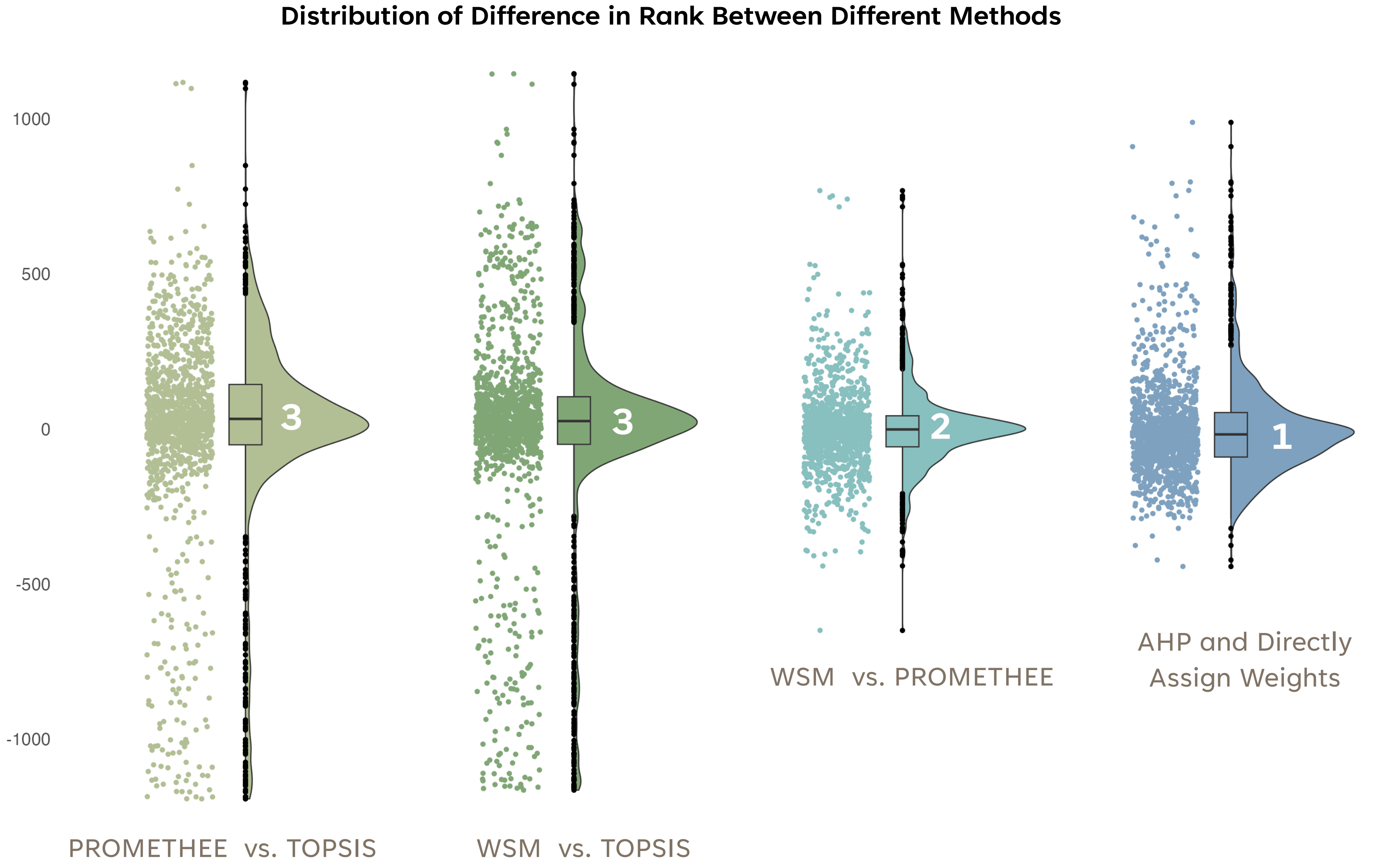
Self-assign weights
+
Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)



Analytic Hierarchy Process (AHP)
+
TOPSIS

Top 20%
20% - 40%
40% - 60%
60% - 80%
80% - 100%

Compare – Ranking Results



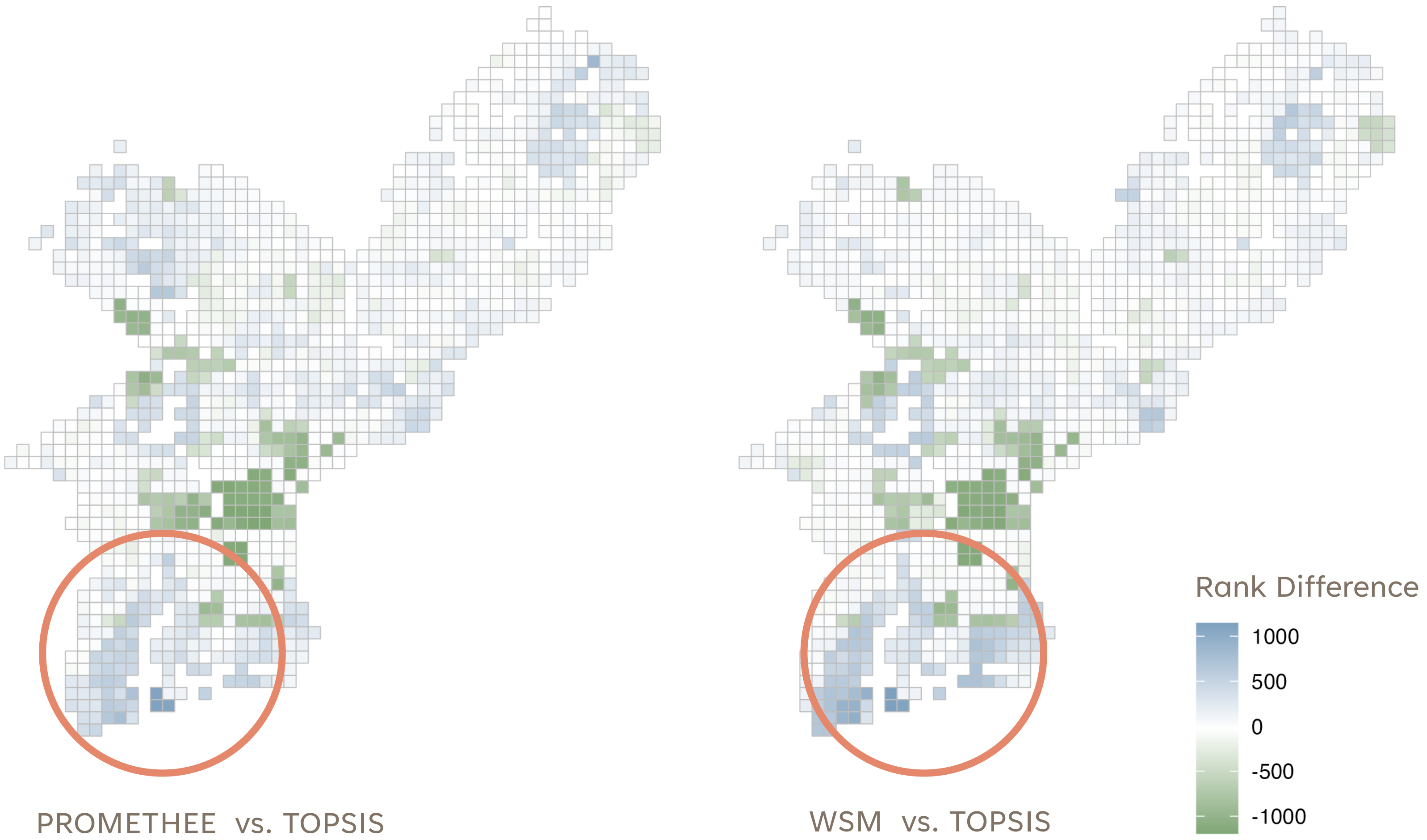
1 Using AHP to prioritize weights increase the rank for several grids.

2 The difference in rank between WSM and PROMETHEE method is the smallest.

3 TOPSIS method is leading to rank reversal issue for some parts of Philadelphia.

Compare – Ranking Results

Rank Differences between TOPSIS and Other Approaches



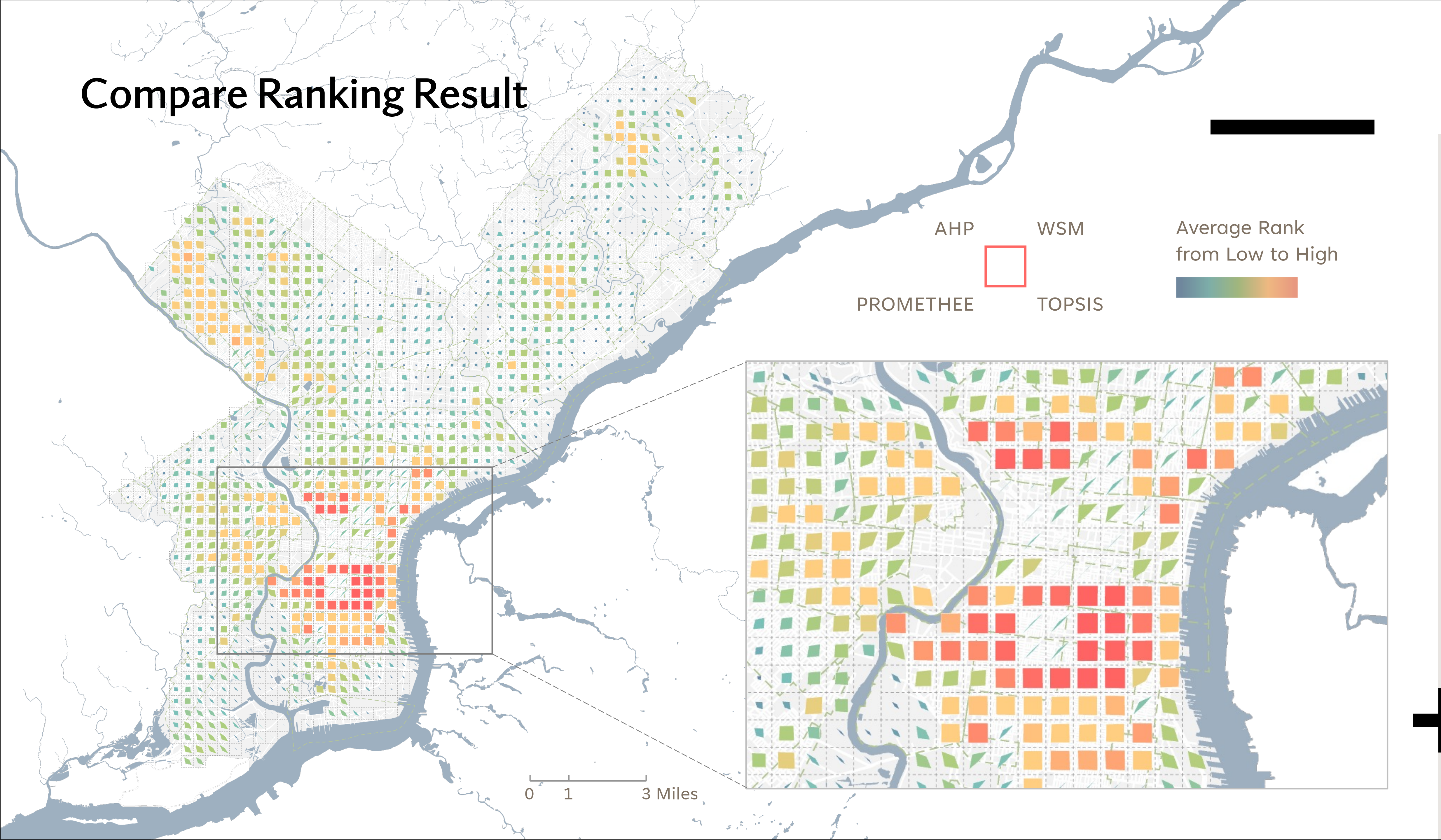
Closer examination of these grids reveals that they are located in industrial areas that use a lot of electricity.

The presence of extreme values can significantly influence the ideal and negative-ideal solutions.

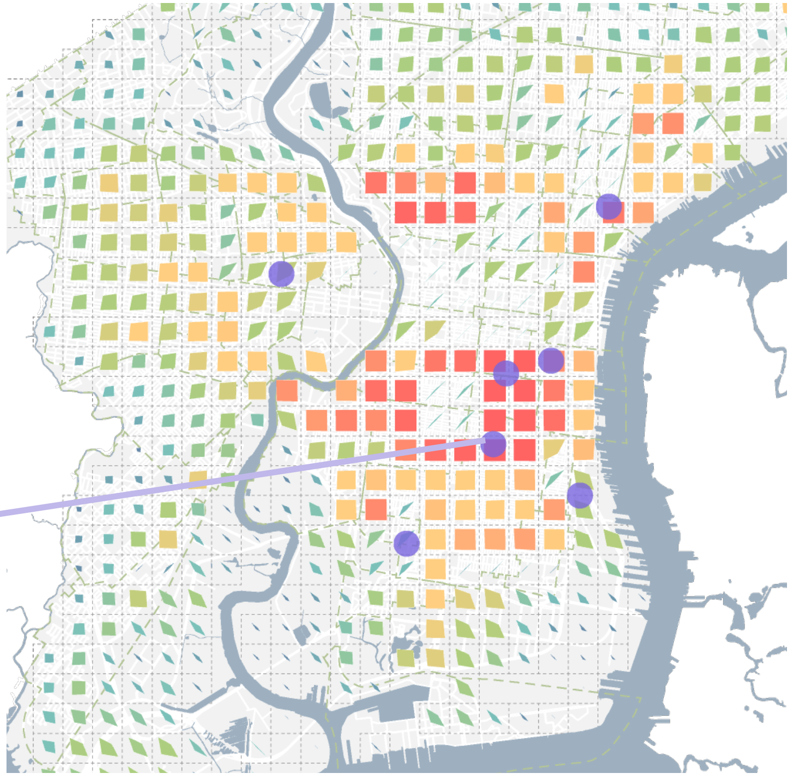
Comparison - MCDA Methods

	Potentials	Limitations
WSM	Easy to understand and implement	Assume independence between criteria Ranking highly dependent on weights
TOPSIS	Easy to understand, implement, and more comprehensive	Assume independence between criteria Sensitive to extreme values (rank reversal) Need to decide positive and negative ideal scenarios
PROMETHEE	Most robust statistical model	Require careful selection of preference function, preference threshold, and indifference threshold
AHP	Break complex decisions into smaller segments	Pairwise comparison is time consuming Hard to maintain consistency

Compare Ranking Result



Applications



Public private partnership between local grocery store (ACME) and the City of Philadelphia.

Financial analyses for cost and revenue breakdown.

Phased implementation timeline and maintenance plan

1

2

3

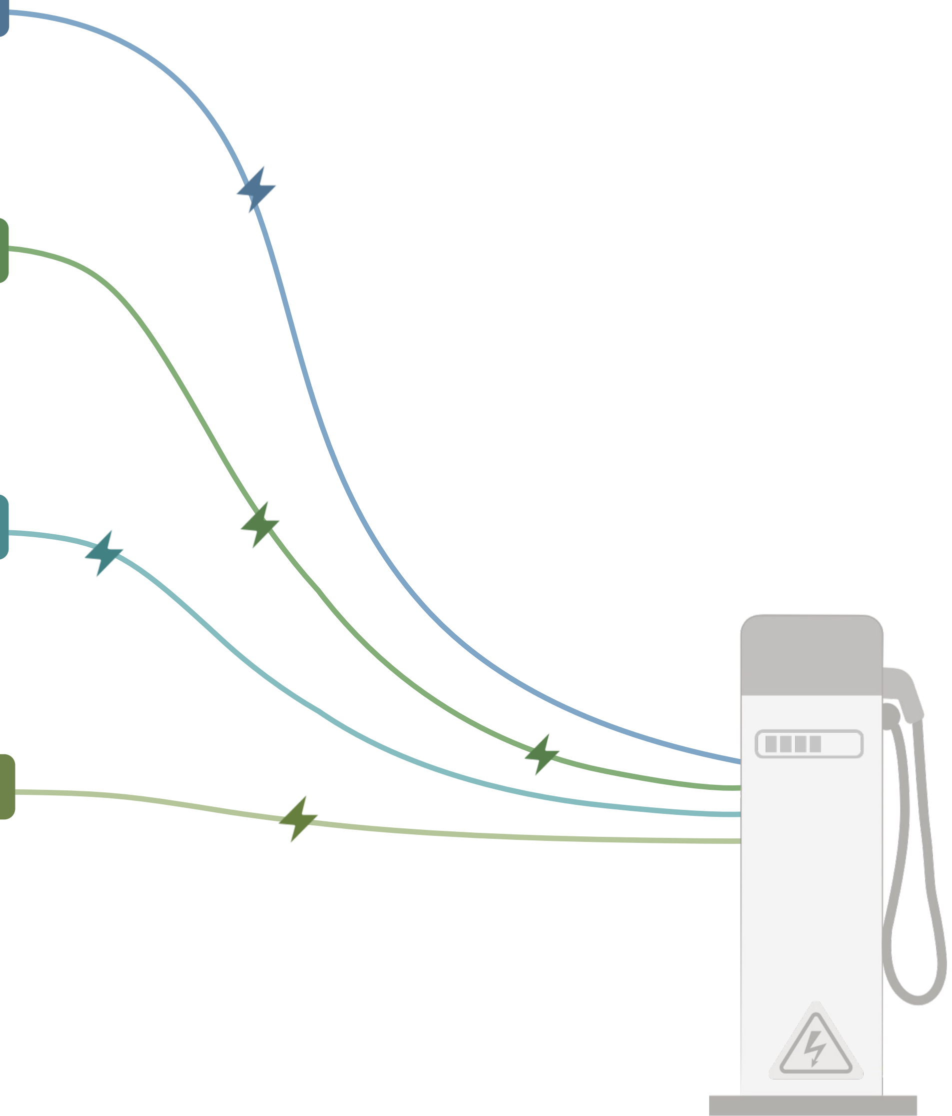
Summary

1. GIS-MCDA is a robust criteria-based methodology that support multiple criteria and statistical models at once.

2. Challenges of agreeing on the input criteria, weighting schemes, various other inputs required for MCDA models, and parameterizing any qualitative criteria

3. Methods that are more comprehensive and robust mathematically 1) requires more decision inputs and introduces more subjectivity, 2) could be more computationally intensive, 3) are less intuitive to non-experts.

4. Recurrent challenges in geospatial model for decision-making: MAUP, spatial interpolations, and ecological fallacy.



Thank You ！

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www.github.com/emilyzhou112/CAGIS-UCGIS-2024

docs.google.com/presentation/d/1InCorQ6SBzq1HmtYEnOWX7MqIRcmrIxQJglYLg8KYdk/edit?usp=sharing

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