OAK RIDGE National Laboratory

Estimating Petroleum Product Consumption at Terminals using Satellite Images and Weighted Voronoi Diagram

prepared by

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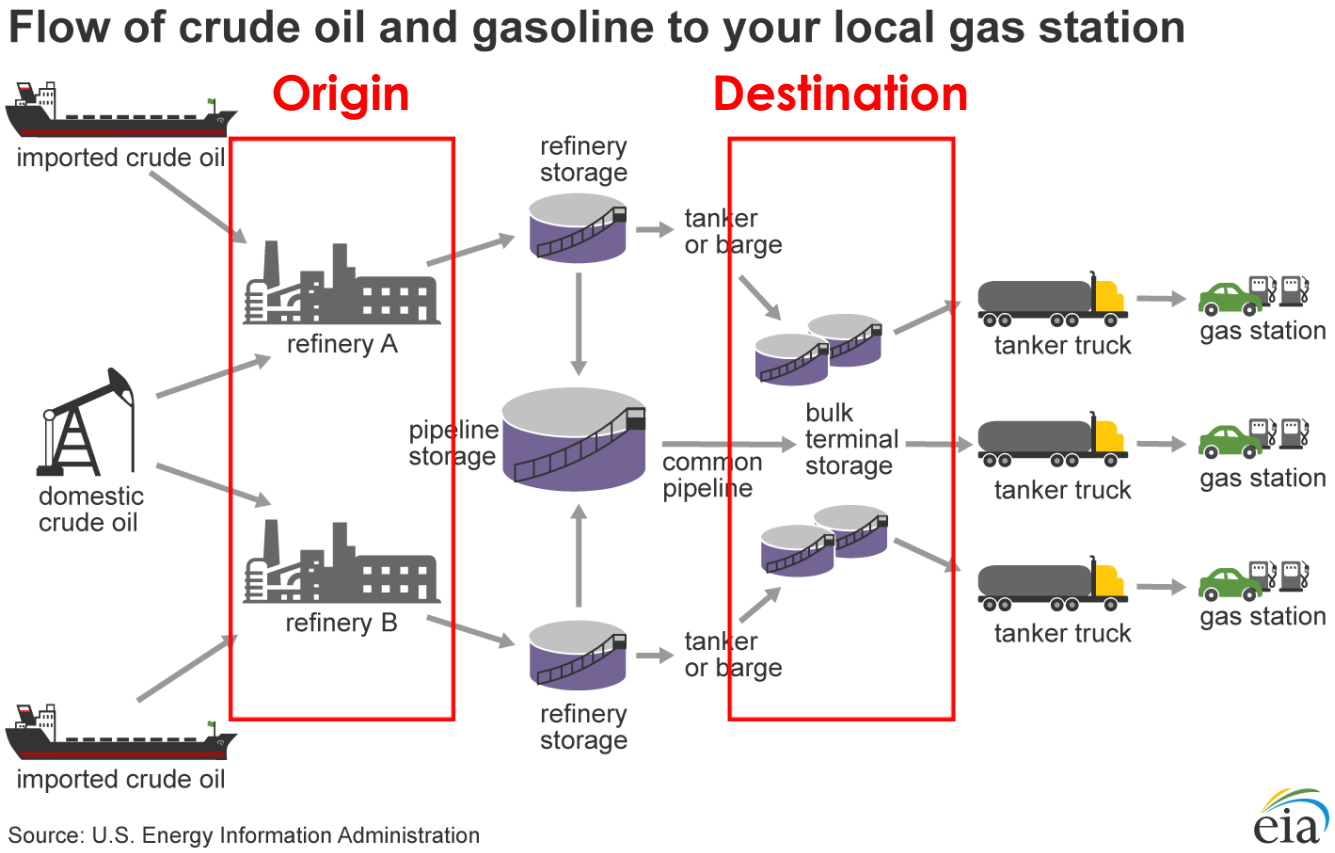
U.S. DEPARTMENT OF ENERGY

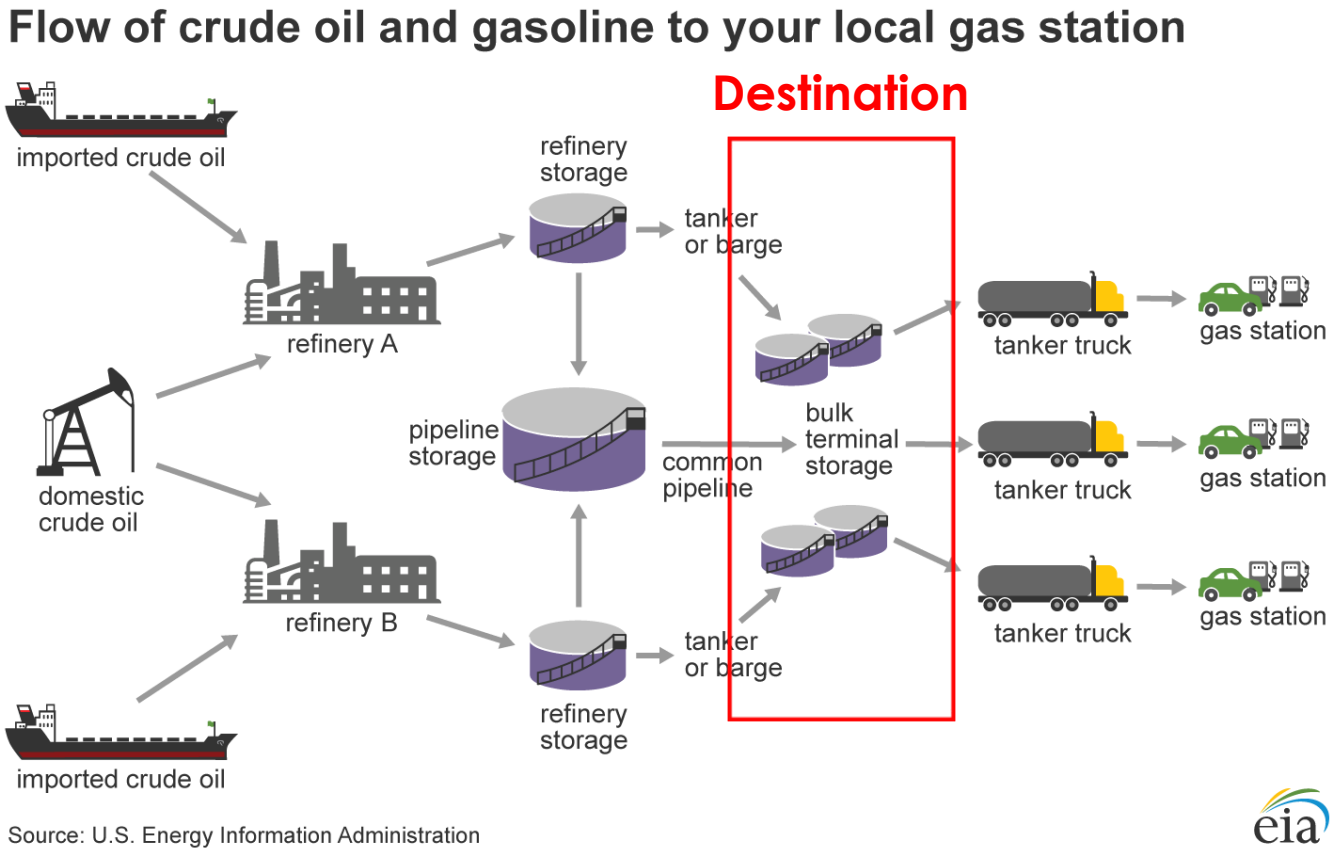
Problem to Solve

- How can we estimate movements of petroleum products at detailed geographical level (e.g., county)?



Problem to Solve

- As the part of process in estimating the petroleum product movements, how can we better estimate the petroleum product consumptions?



Challenges

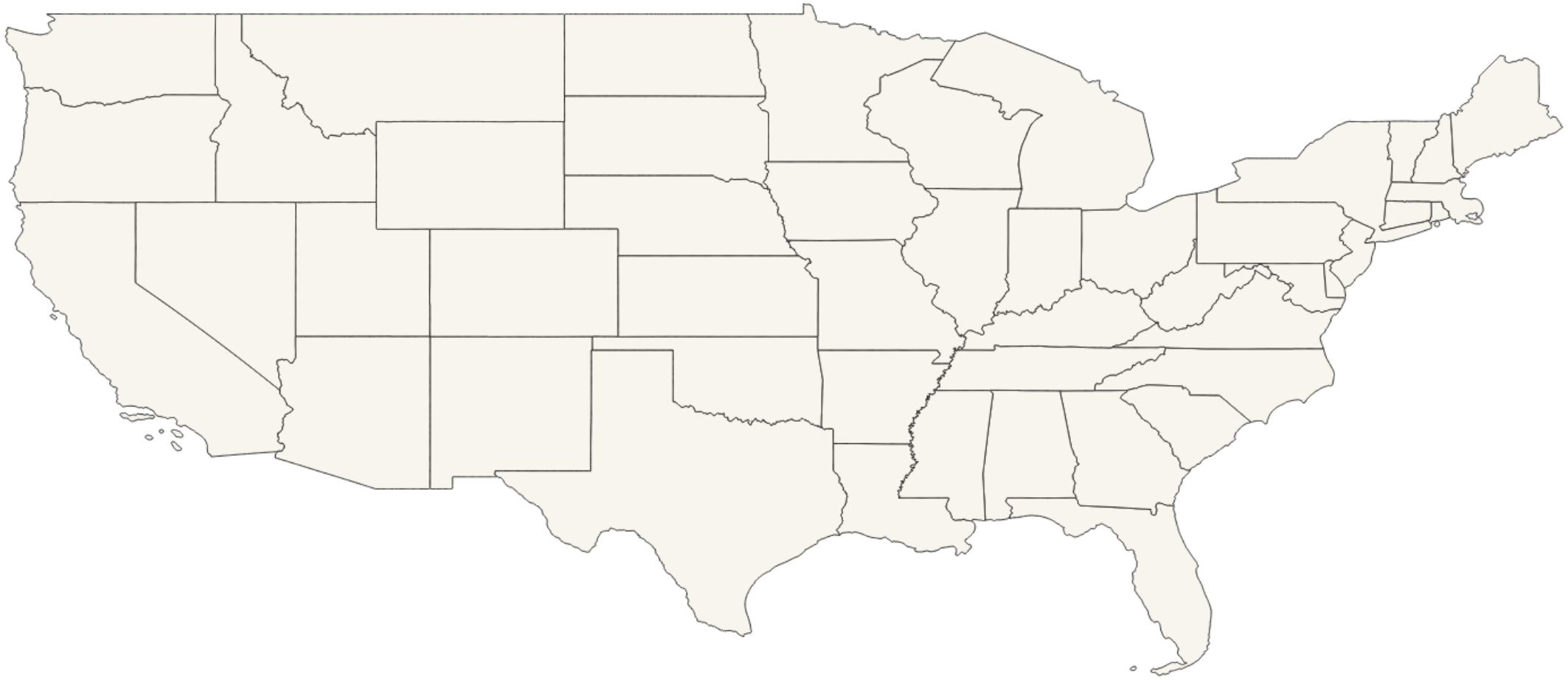
- US Energy Information Administration (EIA) provides productions and consumptions at highly aggregated level (e.g., PADD and state).
- Input variables at different levels

$$\hat{y} = f([x_1, x_2|state], [x_3|county], [x_4, x_5|link], [x_6|point], \dots)$$

- No y? No readily available data to validate the estimation results at the county level.
- There are location information of petroleum product terminals, but no consumption/termination information.
- Potentially, we can integrate other data sources, such as HPMS or FAF. But, how?

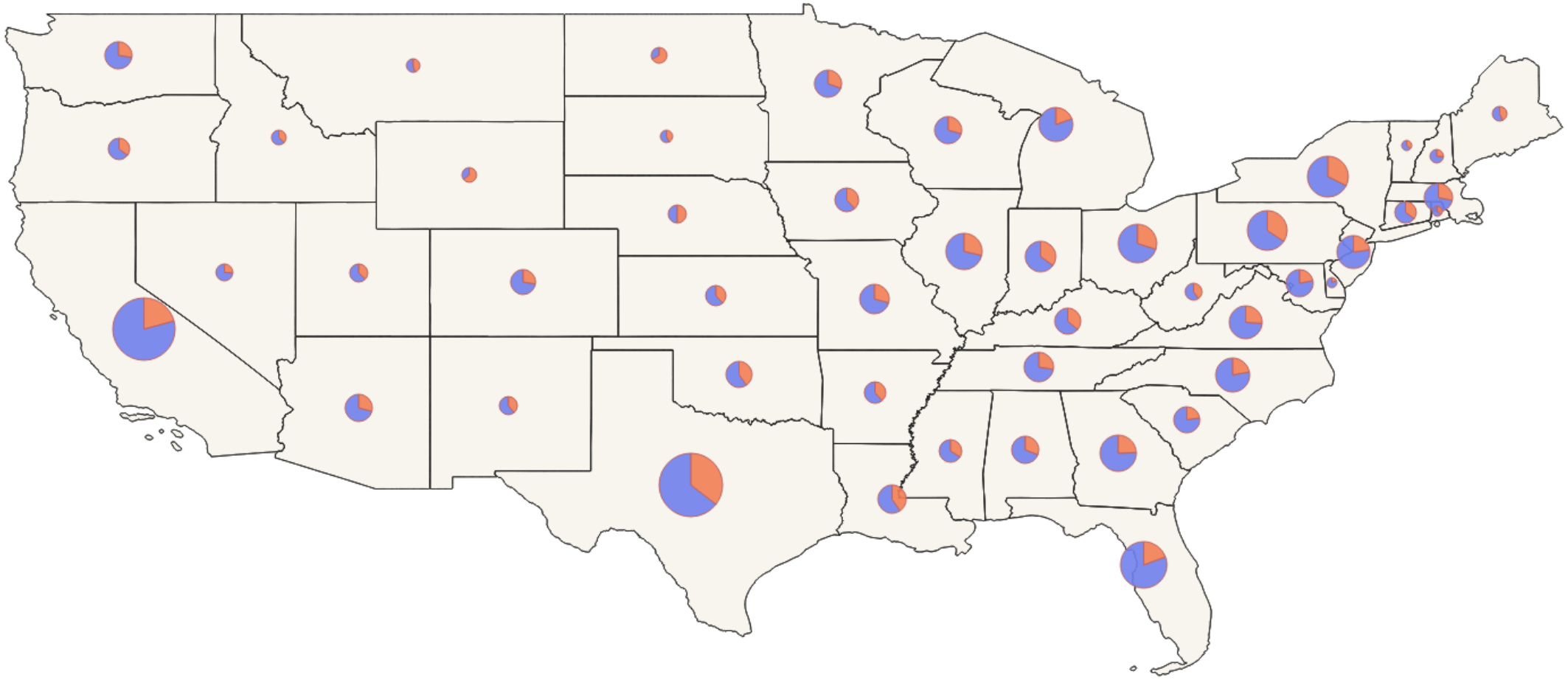
Data Sources

- What are the available data sources?



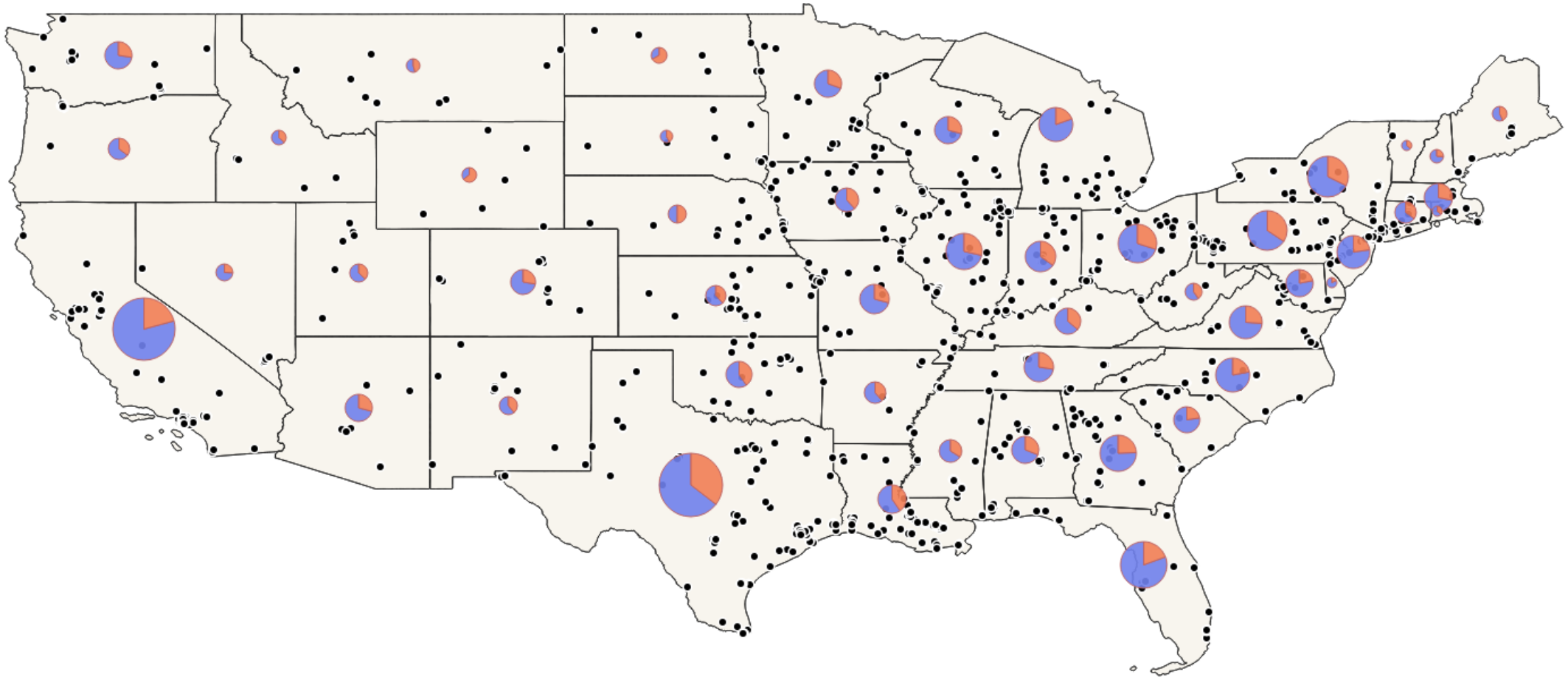
Data Sources

- State level petroleum product consumptions (EIA)



Data Sources

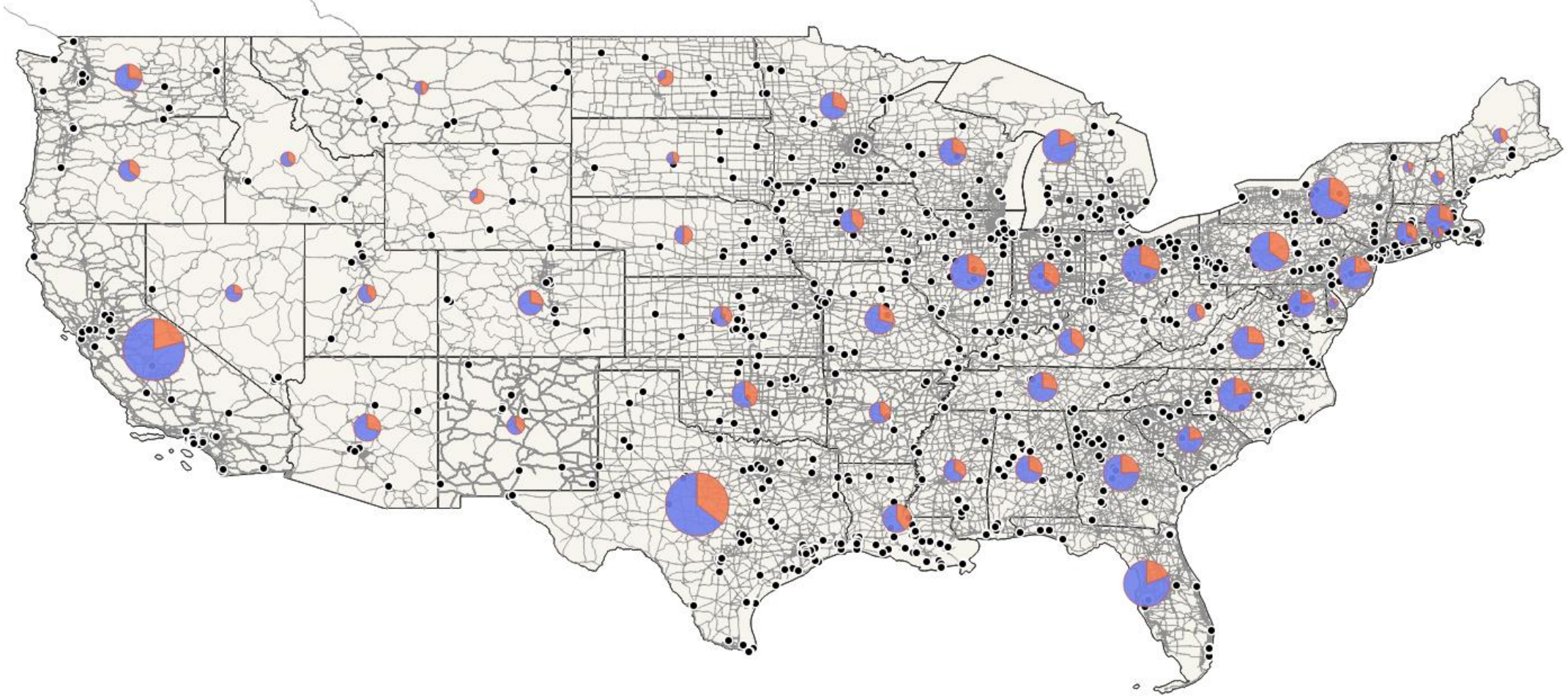
- Locations of petroleum product terminals, but no consumption/capacity information.



Data Sources

- Vehicle Miles Traveled of Light Duty Vehicles and Medium/Heavy Duty Trucks (FAF/HPMS)

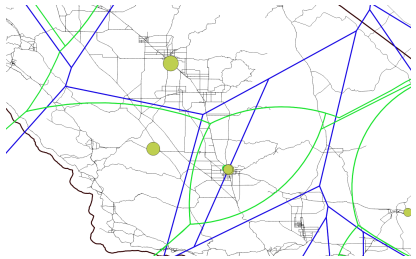
$$\hat{y} = f([x_1, x_2|state], [x_3|county], [x_4, x_5|link], [x_6|point], \dots)$$



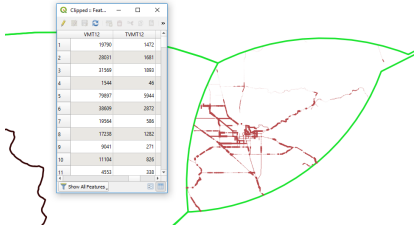
Estimation Process

Process 1
Terminal Capacity

Process 2
Terminal Coverage



Process 3
VMT



Process 4
Consumption Estimate1

$$[LFC12]_i = [LVMT12]_i \times [LAFC]$$

$$[TFC12]_i = [TVMT12]_i \times [TAFC]$$

Process 5
Validation/Calibration

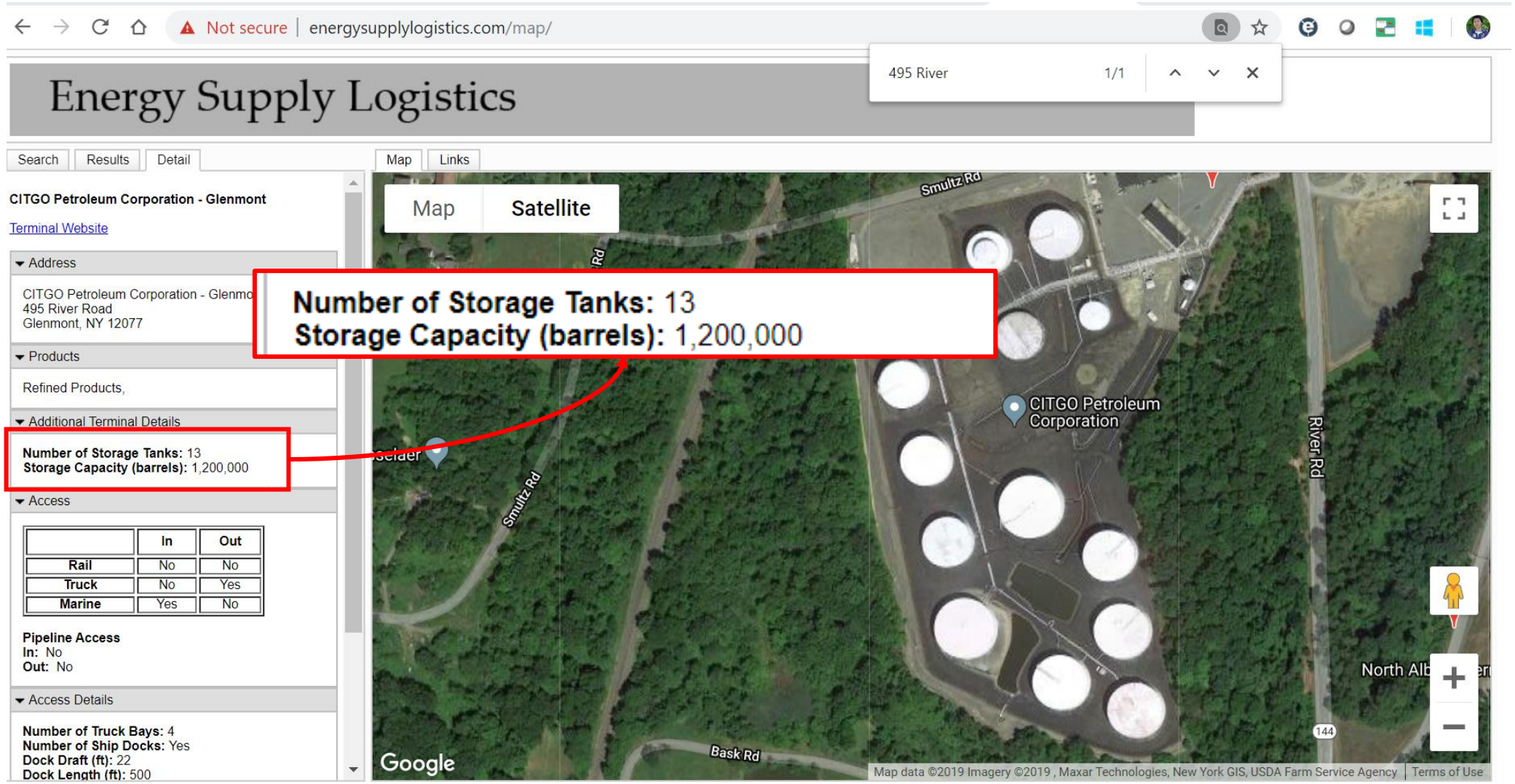
$\widehat{\boldsymbol{Y}}$ vs $\boldsymbol{Y}$

State-level Estimates vs EIA

Calibrate weight parameters for Voronoi diagram

Process 6 (Final) – Adjustment by EIA's state level petroleum product consumptions

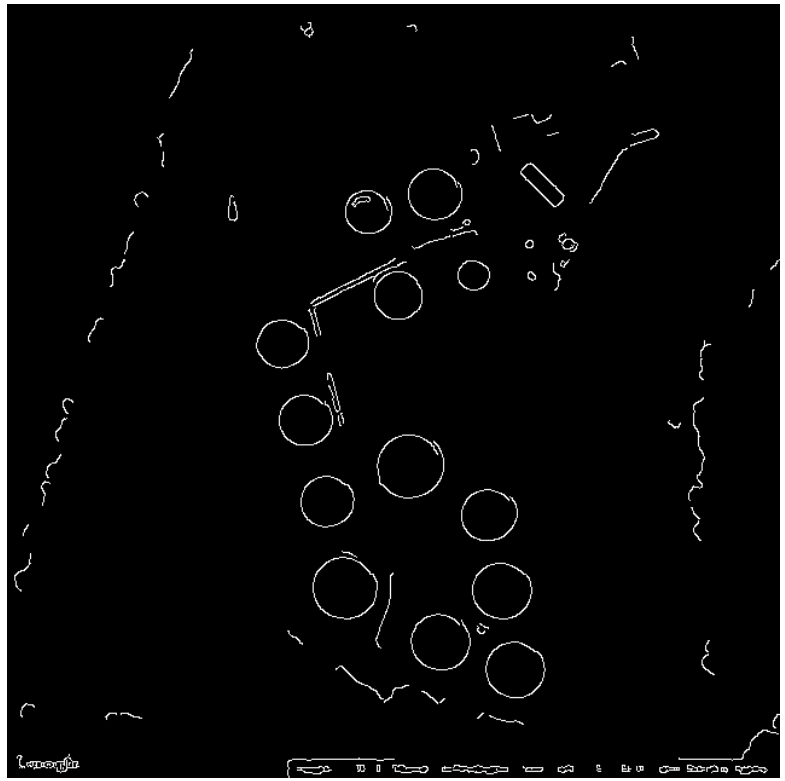
Process 1 – Petroleum Product Terminal Capacity



Process 1 – Petroleum Product Terminal Capacity

Circle Hough Transform (CHT)

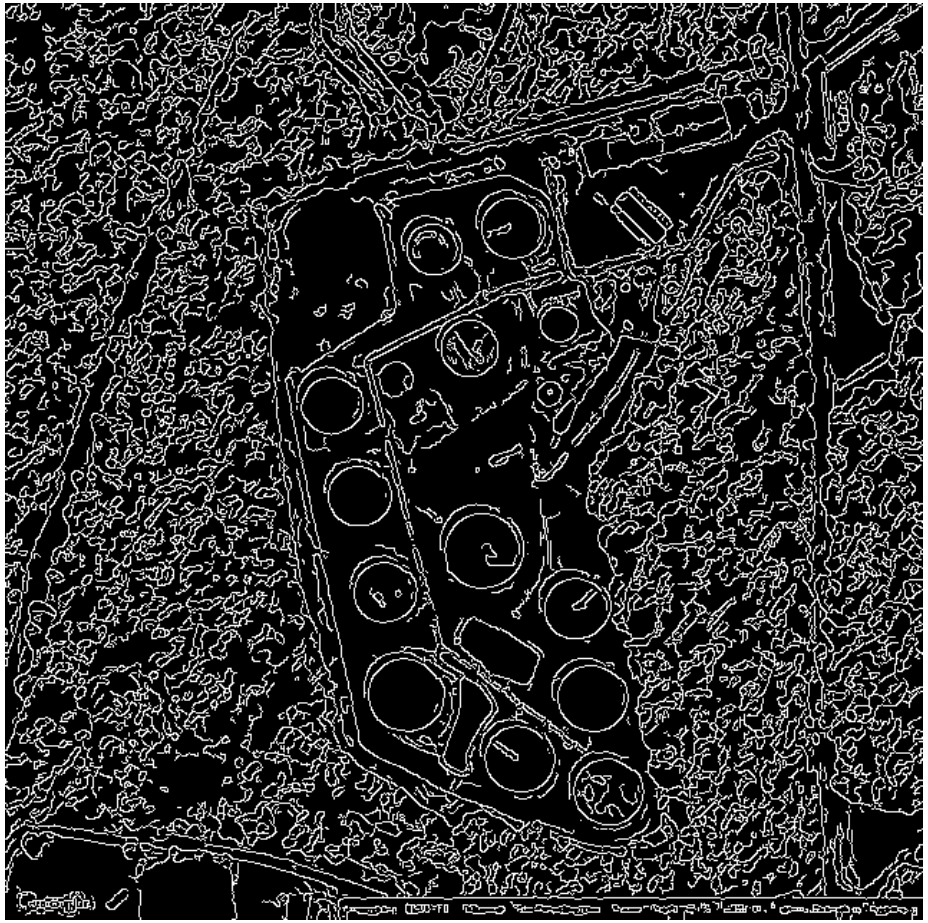
- The circle candidates are produced by "voting" in the Hough parameter space and then select the local maxima in a so-called accumulator matrix.



Process 1 – Petroleum Product Terminal Capacity

Two Main Parameters in Hough Transform

- Parameter 1: the higher threshold of the two passed to the Canny edge detector



Process 1 – Petroleum Product Terminal Capacity

Two Main Parameters in Hough Transform

- Parameter 2: the accumulator threshold for the circle centers at the detection stage. The smaller it is, the more false circles may be detected.

Process 1 – Petroleum Product Terminal Capacity

Estimating Capacity from Radius

- $V = \pi r^2 h$

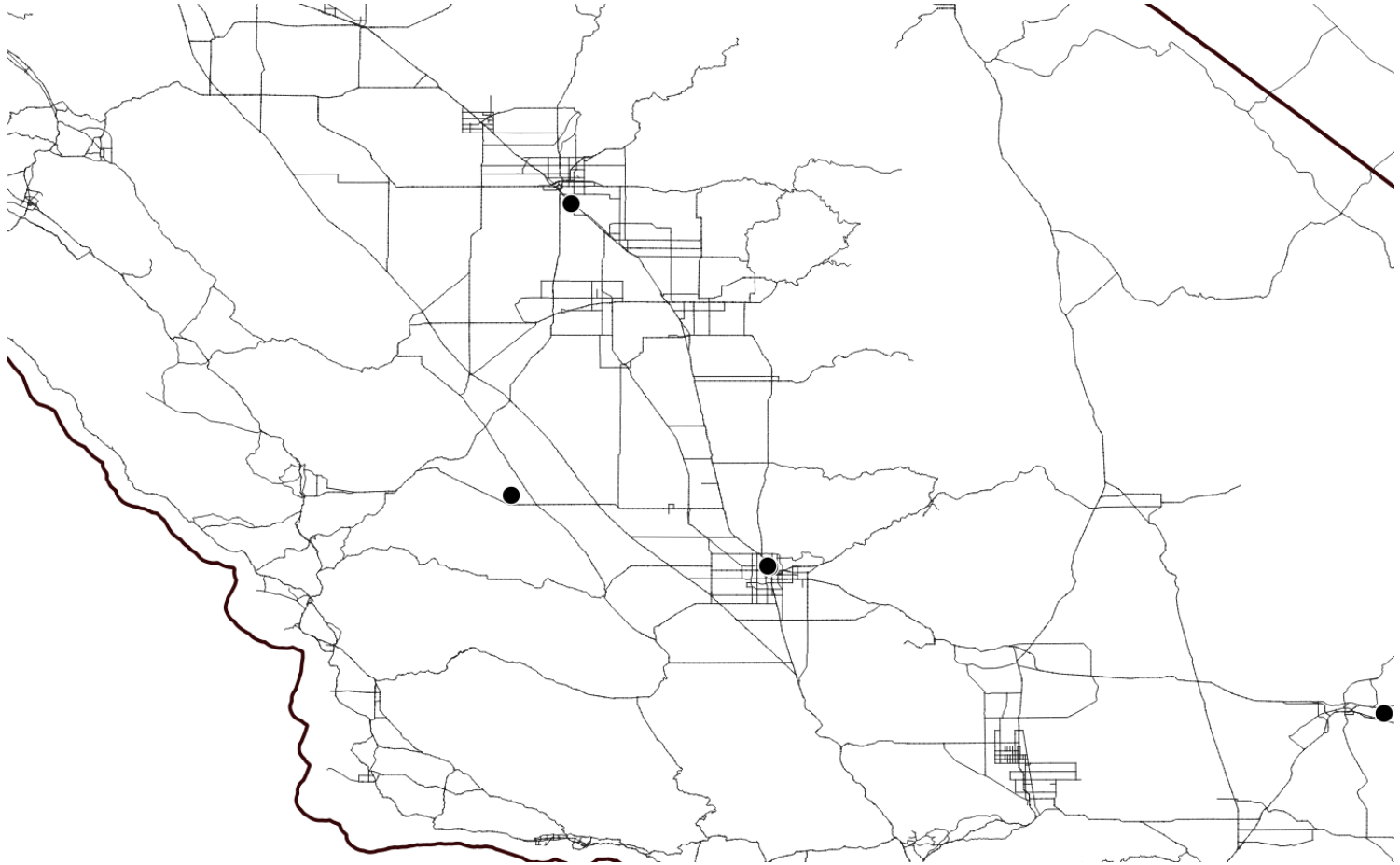
[r_1=xx,
r_2=xx,
r_3=xx,
…]

$$Estimated\ Capacity \propto \sum r^{\alpha}$$

- Determine α based on r-squared of estimated capacity in the validation set
- α is expected to be between 2 and 3

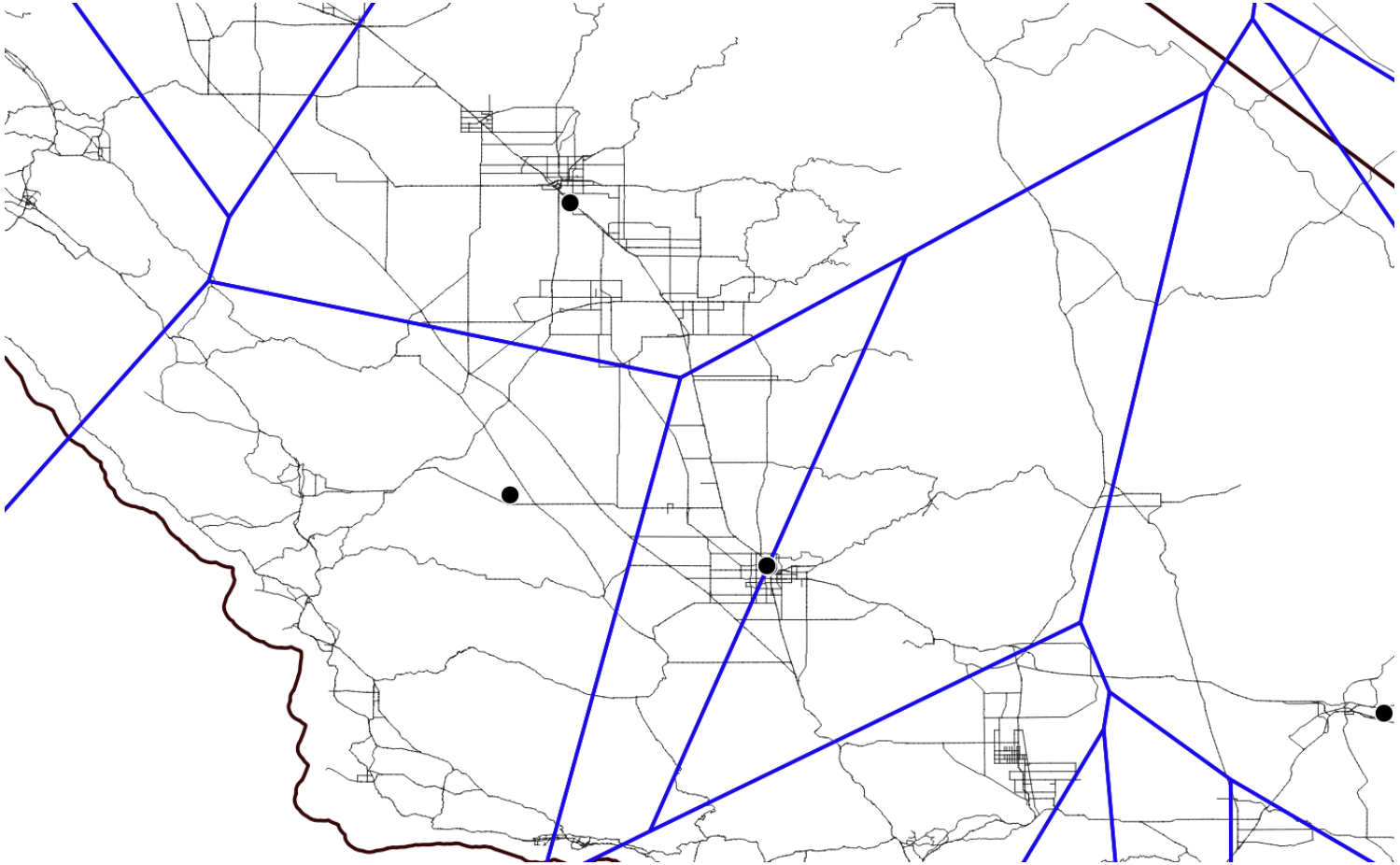
Process 2 – Coverage by Weighted Voronoi Diagram

- If the petroleum product terminal capacity was not considered…



Process 2 – Coverage by Weighted Voronoi Diagram

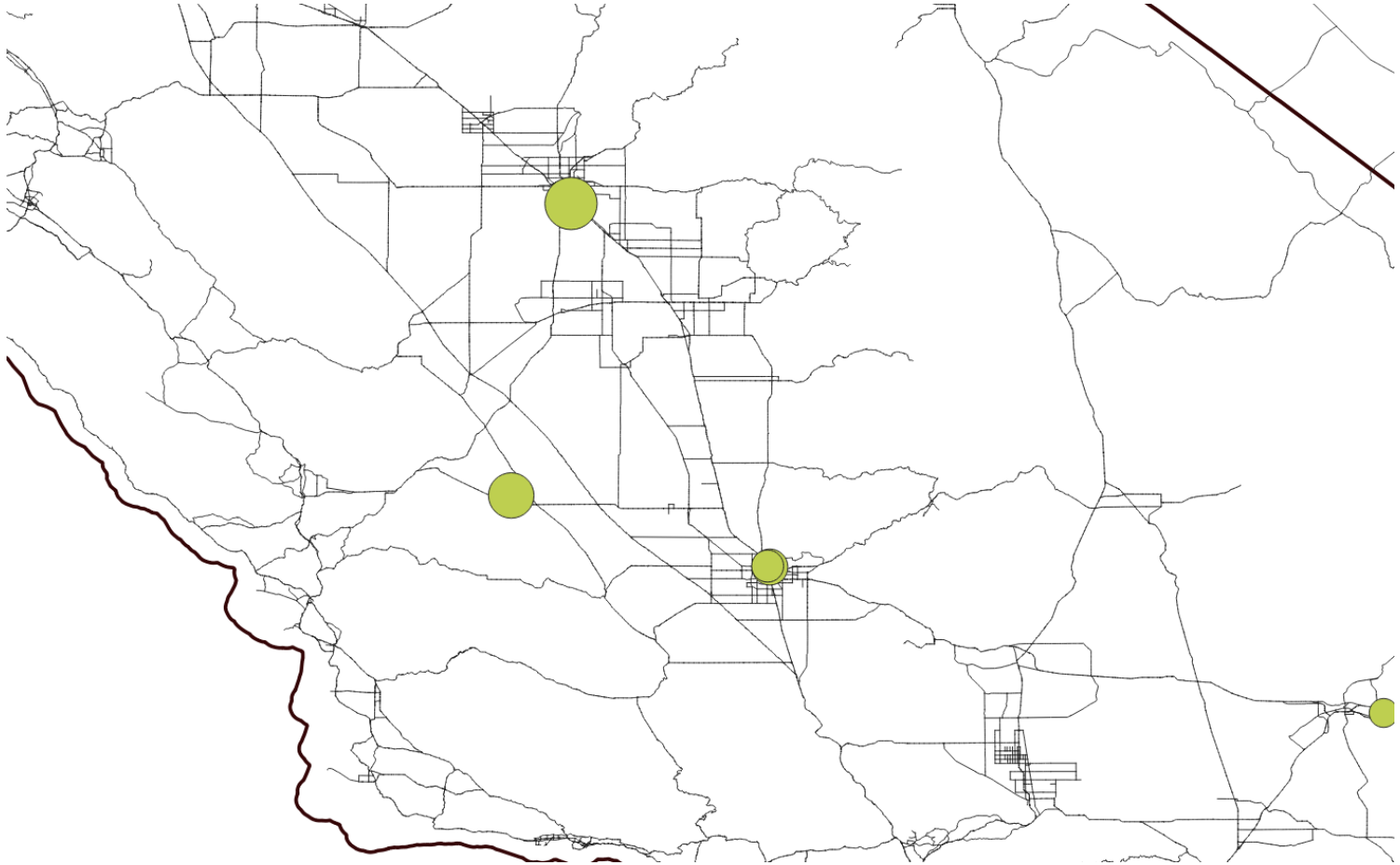
- Unweighted Voronoi Diagram (based on Euclidean Distance)



Process 2 – Coverage by Weighted Voronoi Diagram

- Weighted Voronoi Diagram (based on Euclidean Distance + Estimated Capacity)

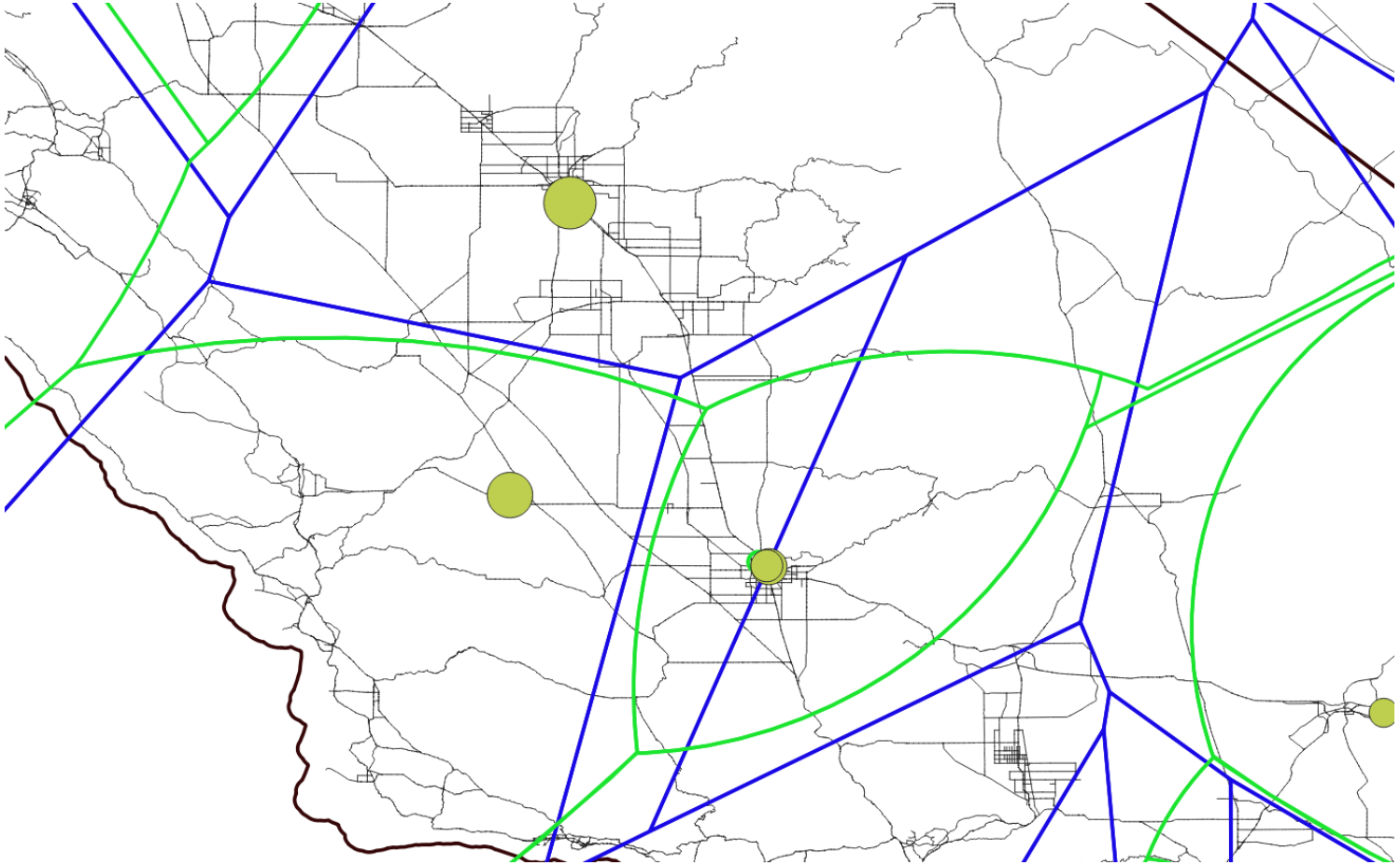
$$Weight\ for\ Voronoi\ Diagram = [Estimated\ Capacity]^{\beta}$$



Process 2 – Coverage by Weighted Voronoi Diagram

- Weighted Voronoi Diagram (based on Euclidean Distance + Estimated Capacity)

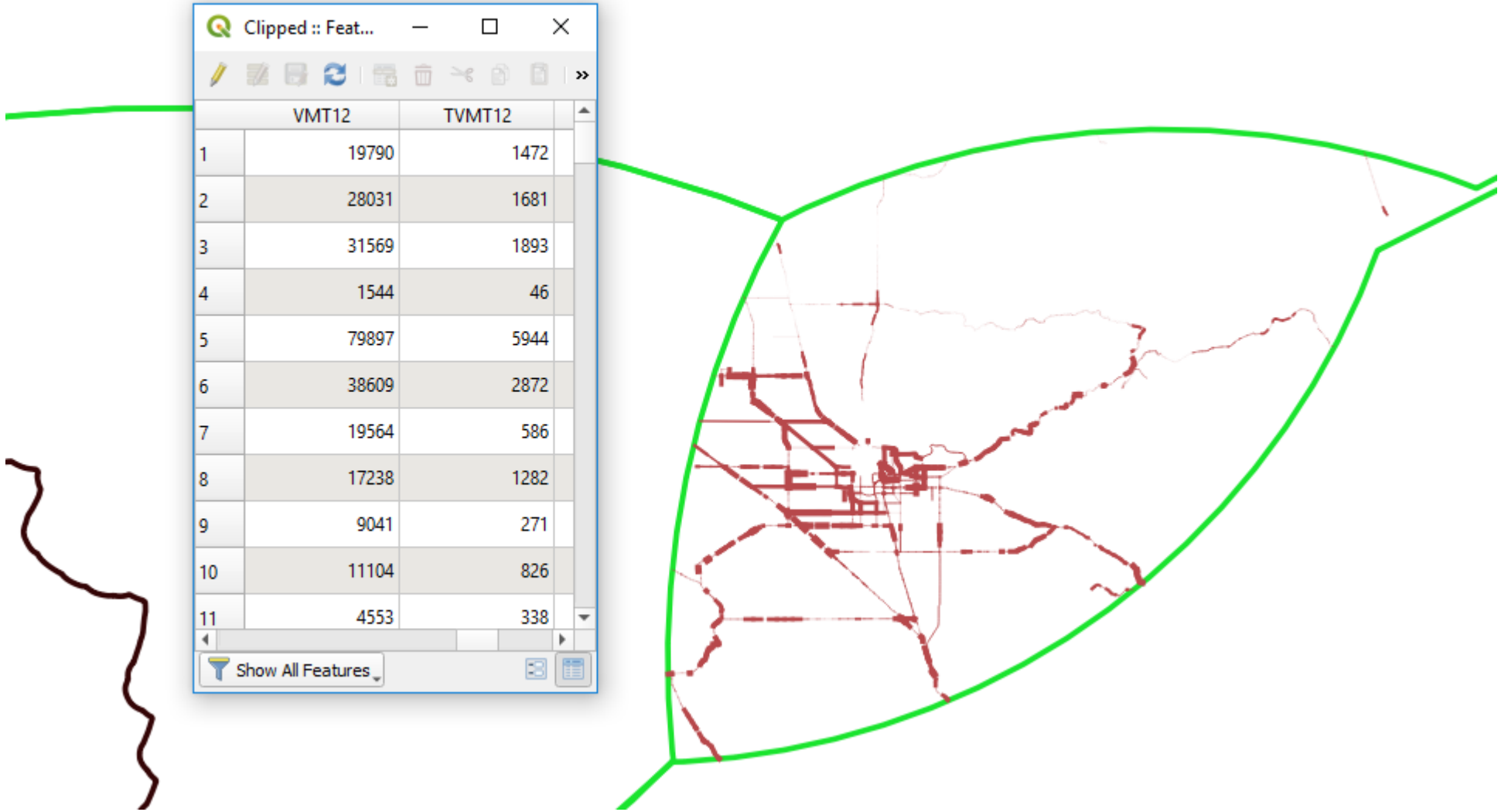
$$Weight\ for\ Voronoi\ Diagram = [Estimated\ Capacity]^{\beta}$$



Process 3 – Total VMT within the Coverage

VMT within the Coverage

- LVMT12 = VMT12 (HPMS) – TVMT12 (FAF4)



Process 4 – Estimating Petroleum Product Consumptions

Fuel Consumption Estimates from the VMT at Process 3

- $[LFC12]_i = [LVMT12]_i \times [LAFC]$, $[TFC12]_i = [TVMT12]_i \times [TAFC]$
- LAFC/TAFC is the average fuel consumption per VMT

FID	Company	State	PADD	Sum_LFC12	Sum_TFC12
0	BUCKEYE CARRIBEAN TERMINALS LLC	PR	6	0	0
1	PETRO 49 INC	AK	5	32773194.462	8485580.098
2	CPD ALASKA LLC	AK	5	998789.558	167389.544
3	CHEVRON USA INC	CA	5	546308615.214	256061637.798
4	HOLLY ENERGY PARTNERS OPER LP	NE	2	90431862.75	59542537.438
5	CENTER POINT TERMINAL LLC	WV	1	276696926.584	107566817.861
6	TRISTAR TERMINALS GUAM INC	GU	7	0	0
7	PAR HAWAII INC	HI	5	81041024.386	8494075.432
8	TRANSMONTAIGNE PRODT SVCS INC	FL	1	677645397.178001	237807367.526
9	ARGUINDEGUI OIL CO II LTD	TX	3	2935484.55	793527.124
10	PAR HAWAII REFINING LLC	HI	5	20142217.118	2331811.862
11	PLAINS LPG SERVICES LP	CA	5	107797071.736	32242624.308
12	HOLLY ENERGY PARTNERS OPER LP	AZ	5	30594646.406	64316443.183
13	WESTERN REFINING SOUTHWEST INC	NM	3	815970619.755999	160629303.309
14	JP ENERGY CADDO LLC	TX	3	176977663.014	97016084.996
15	TRANSMONTAIGNE PRODT SVCS INC	MS	3	237004265.458	62715702.008
16	PHILLIPS 66	GA	1	79122332.764	30250625.806

Process 5 – State Level Validation and Calibration

Compare State-level Estimates vs EIA

- To calibrate model parameters (weighting factor for Voronoi diagram)
  $Weight\ for\ Voronoi\ Diagram = [Estimated\ Capacity]^{\beta}$

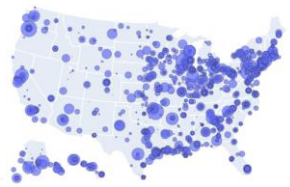
Terminal ID	$terminal\ estimate\ \hat{y}$
0001 … 0047	359 … 122
0048 … 0082	704 … 1,331
0083 …	4,014 …

State	$state\ estimate\ \hat{Y}$	$EIA\ state\ consumption\ Y$
AK	6,091	6,661
AL	49,326	60,653
AR	53,806	33,732
…	…	…

Final Results

$$\textbf{\textit{Final Petroleum Consumption at Terminal}}$$

$$\hat{y}^* = Y \times \frac{\hat{y}}{\sum \hat{y}} \quad , \quad \sum \hat{y}^* = Y$$



Terminal ID	$\hat{y}^*$ Adjusted	State	$\hat{Y}^*$ Adjusted	Y EIA state consumption
0001	359 -> **392**			
⋮	⋮			
0047	122 -> **134**	AK	6,091 -> **6,661**	6,661
0048	704 -> **866**			
⋮	⋮			
0082	1,331 -> **1,637**	AL	49,326 -> **60,653**	60,653
0083	4,014 -> **2,516**			
⋮	⋮	AR	53,806 -> **33,732**	33,732
		⋮	⋮	⋮

Conclusions

Common research questions to be answered…

- Is there a better method to estimate fuel consumptions?
- How can we validate the results?
- Other data sources?

Other things that we can do with AI/ML…

- Verifying inactive/invalid petroleum product terminal locations
- Access of transportation mode at a certain location