

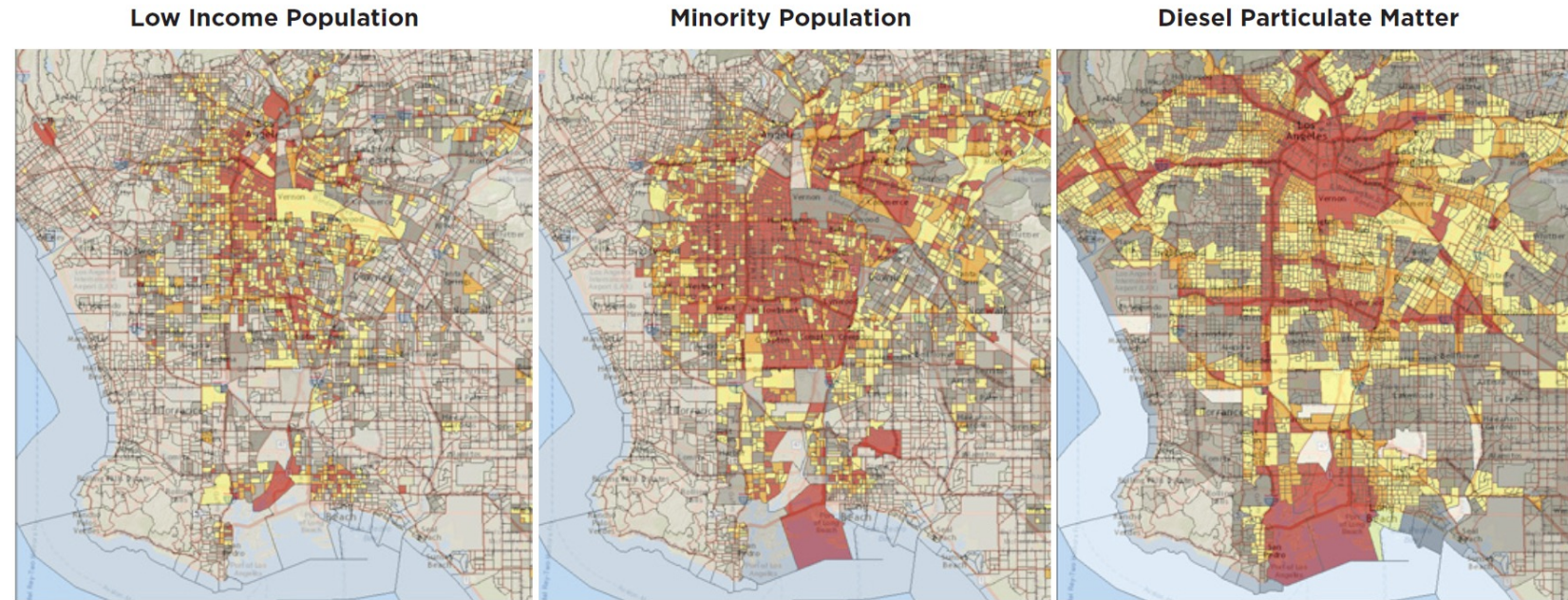
Freight eco-routing – carrier’s trade-offs and system-wide impacts

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Motivation

- Freight is fundamental to economy, but heavy-duty trucks are heavy emitters of greenhouse gases and criteria pollutants.



Maps of the Los Angeles area suggest the correlation of air pollution (diesel particulate matter in this example) to income and race.

Notes: "Minority population" refers to the fraction of California's population that is all but non-Hispanic white. "Diesel particulate matter" represents the amount of this pollution in a given area relative to other areas in California. "Low income population" refers to the percent of Californians whose household income was less than two times the poverty level in the past 12 months. Percentiles are as follows: yellow: 80-90 percent; orange: 90-95 percent; red: 95-100 percent. Percentiles are relative to California's population.

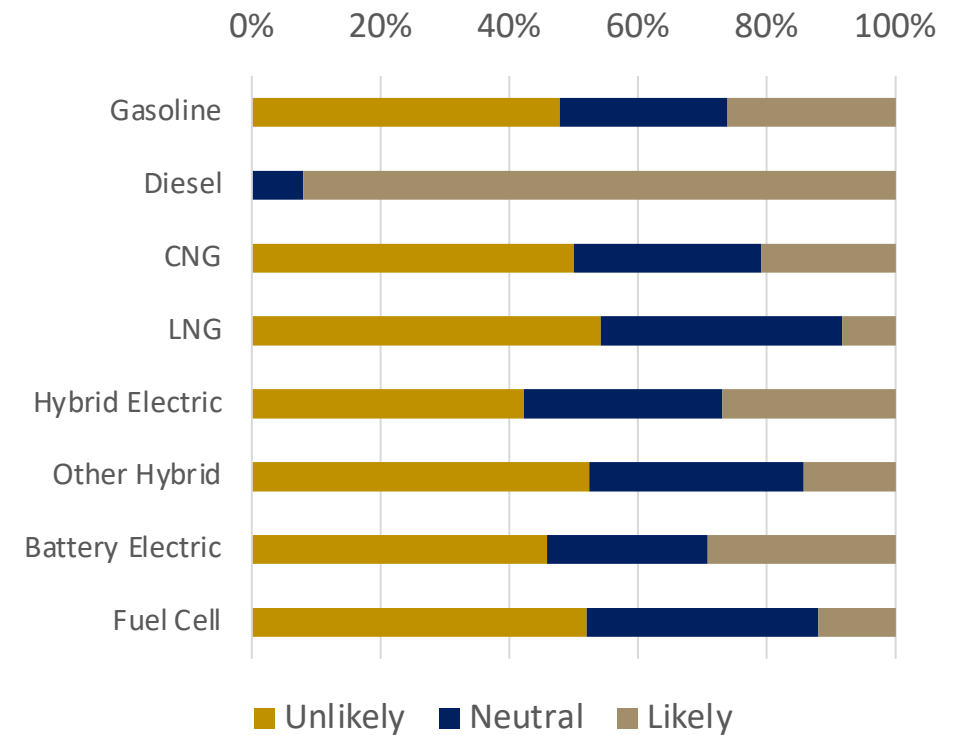
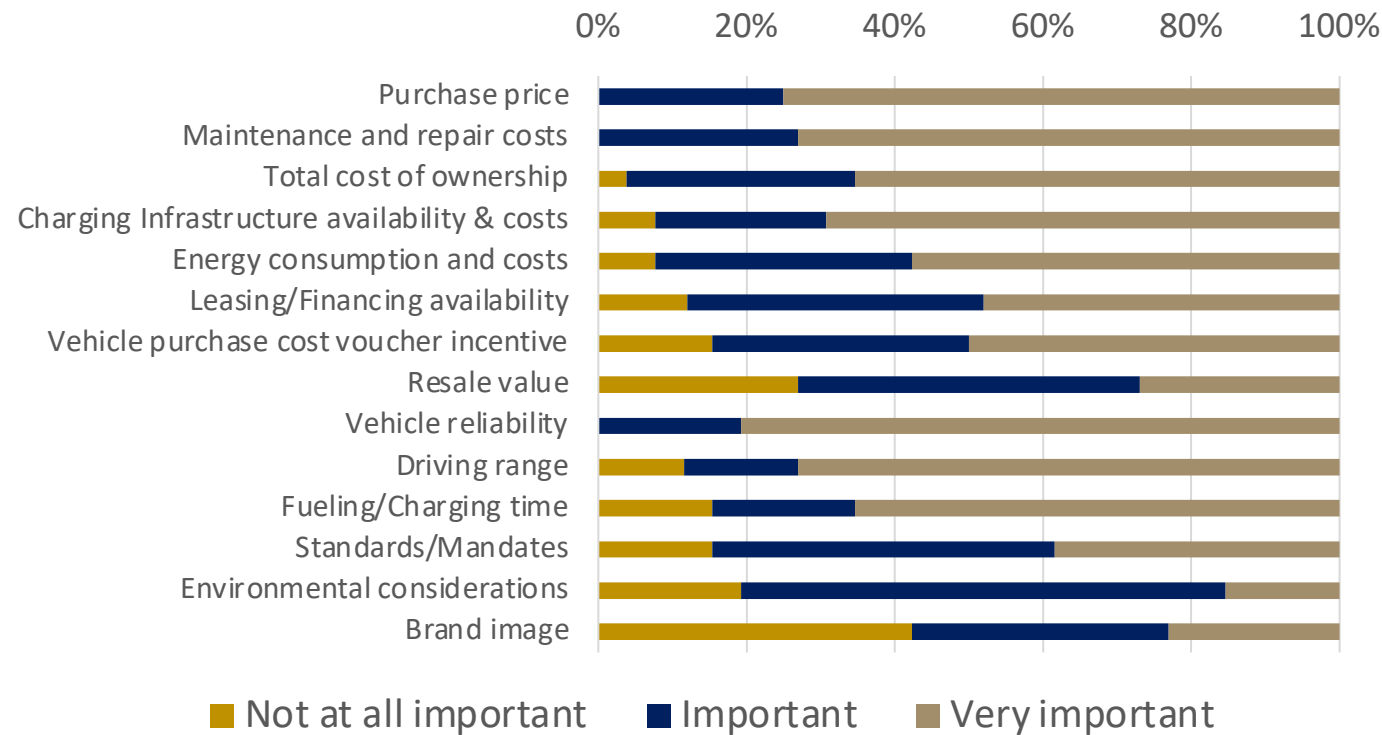
SOURCE: EPA 2016B.

<http://www.ucsusa.org/clean-vehicles/electric-vehicles/freight-electrification>

Diesel vehicles dominate the market

Determinant factors for vehicle purchase

Next purchase



Survey to carriers in 2019

Today

- Transition to alternate fuel delivery vehicles has been slow.
- Immediate alternatives to address global climate change and local pollution impacts of urban freight.

So...

During the transition, we can...

- Design them better (e.g., drivetrain, powertrain)
- Choose them better (e.g., right sizing)
- Drive them better (e.g., eco-driving, eco-routing)
- Manage how they perform (e.g., geo-fencing)

we can also...

- Use them differently by changing our distribution networks
- Change the logistics systems

Before we can...

- Replace them for zero emission vehicles
- Automate the system

Defining eco-routing

- **Explicit eco-routing**
 - carrier explicitly accounts for externalities in its routing decisions
- **Implicit eco-routing**
 - policy initiatives that encourage carriers to implicitly consider the impact of their emissions in their routing decisions.
 - Geofencing and access control

Eco-routing vs. Conventional routing

- **Eco-routing**
 - Explicit eco-routes
 - Least Fuel-use Path (LFP)
 - Least pollutant X Emissions Path (LEP-X)
 - Implicit eco-routes
 - Geofence Restricted Path (GRP)
- **Conventional routing**
 - Shortest Path (SP)
 - Fastest Path (FP)
 - Least Cost Path (LCP)*

*Cost pertains to operational costs that includes maintenance cost, driver wages, and fuel costs.

Objectives

- **Private impacts**
 - Cost-benefits and tradeoffs of eco-routing for a carrier
 - Point-to-Point routing
- **System-wide impacts**
 - System-wide change in externalities due to network-wide freight eco-routing
 - Multi-class Traffic Assignment

Case Study

Southern California Association of Governments (SCAG) region

- Port of LA (POLA)
- LAX airport
- Freight Terminals at San Bernardino

Freight sector

- 20% of the workforce
- 16% of SCAG's GDP

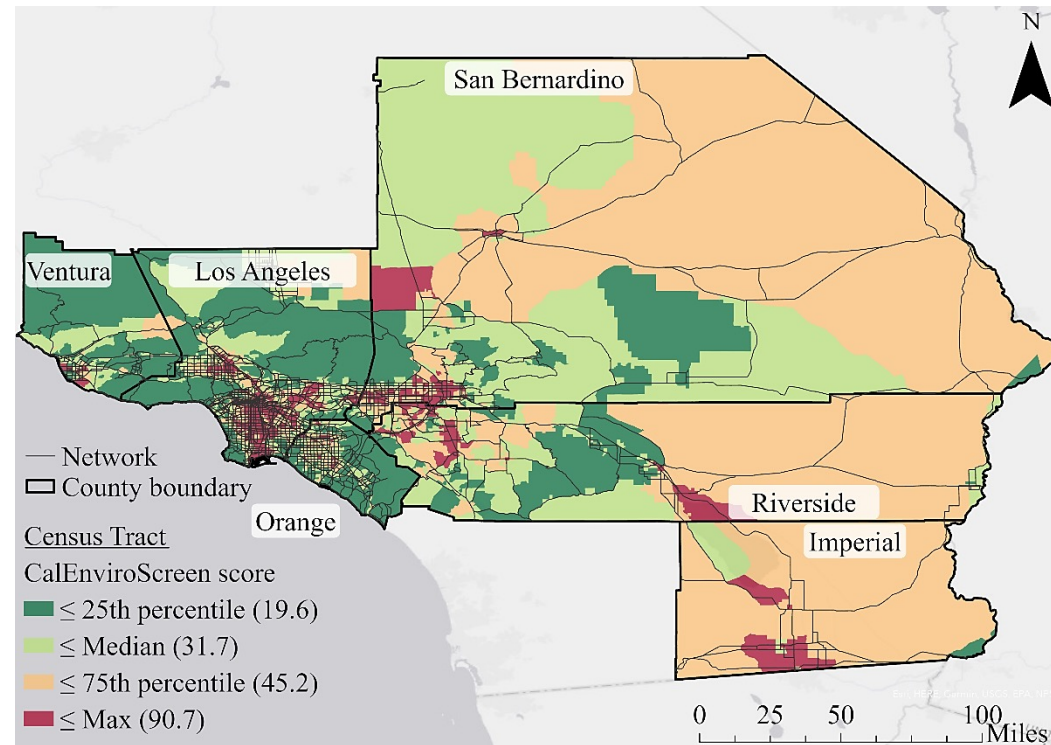


Figure 1. Southern California Association of Governments (SCAG) region

Case Study

Disadvantaged communities

- California Communities Environmental Health Screening Tool
- California Office of Environmental Health Hazard Assessment, 2017

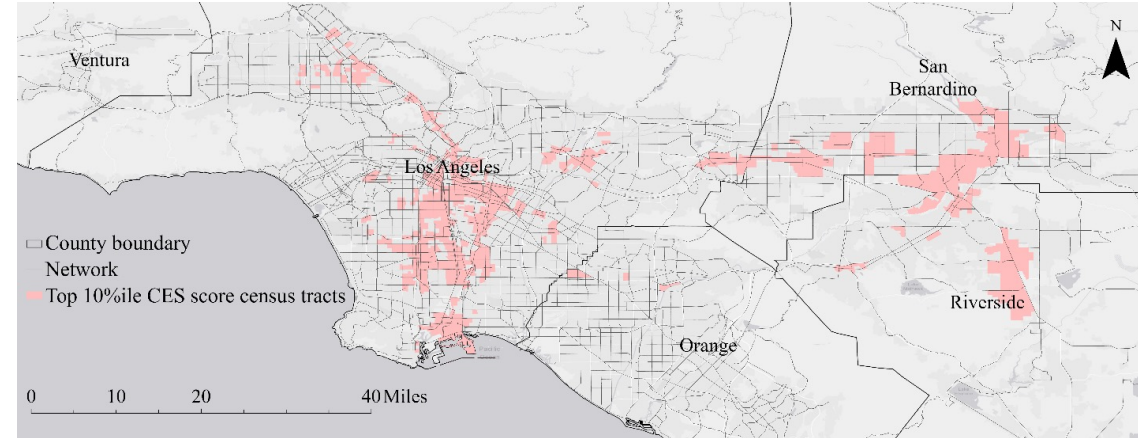


Figure 2. Top 10%ile CalEnviroScreen Score Census Tracts

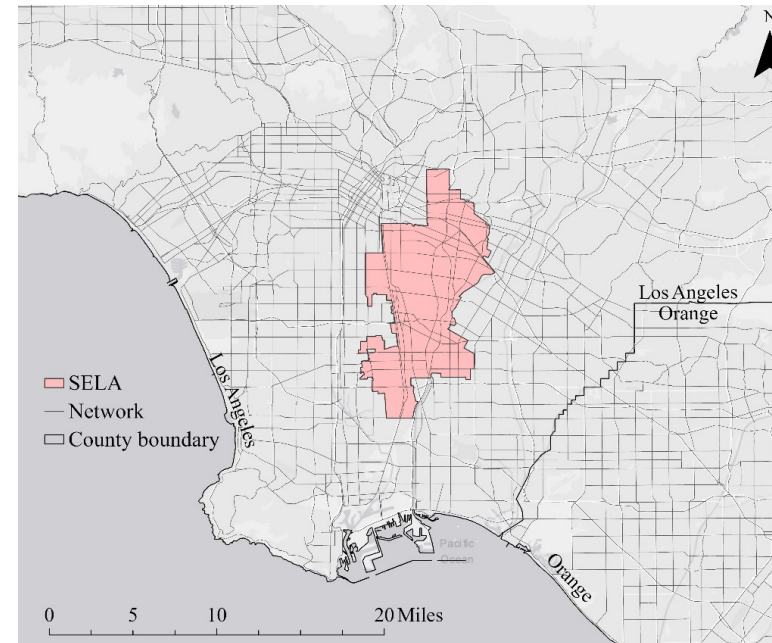


Figure 3. South-East LA (SELA)

Case Study

- Fuel consumption
- Greenhouse Gases
CH₄, CO₂, ROG
- Criteria pollutants
CO, NO_x, PM
- Vehicle Class
Heavy-Duty Trucks (HDT)
Light-Duty Automobile (LDA)

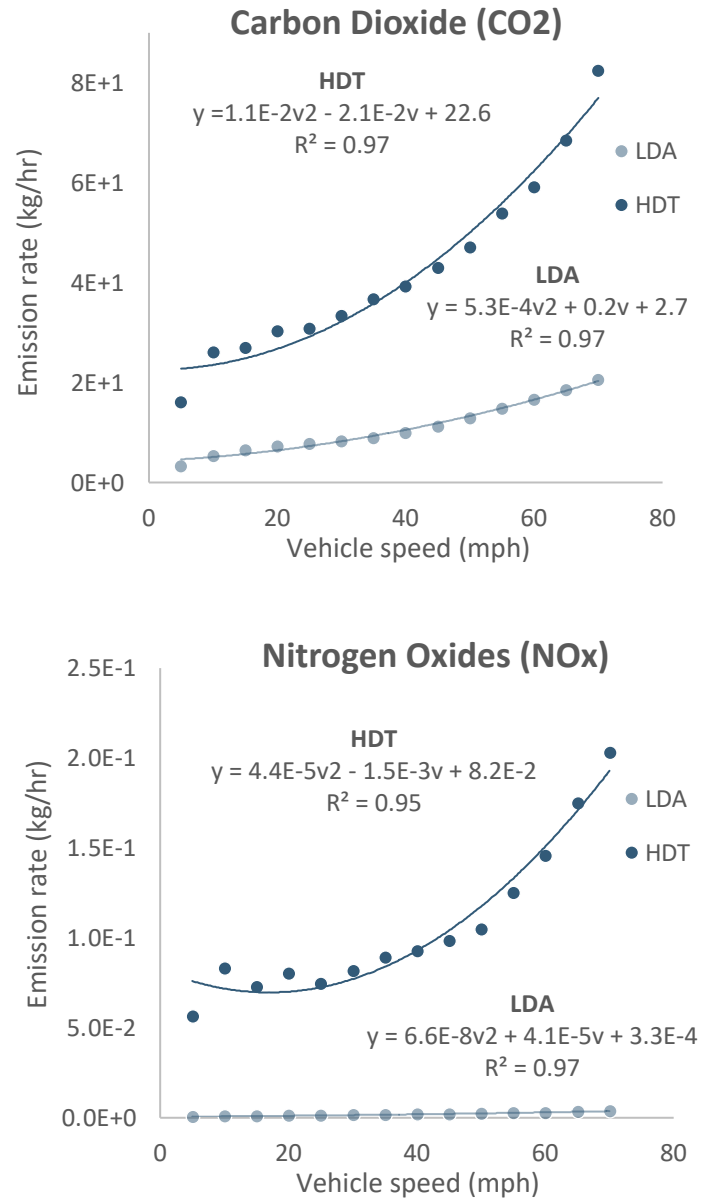


Table 1. Fuel and emission cost

Parameter	Cost
<i>Fuel consumption (FC) (litre/hr)</i>	
FC	\$1.051/litre ^a
<i>Green-House Gases (GHG) (kg/hr)</i>	
CH ₄	\$1.781/kg ^b
CO ₂	\$0.068/kg ^b
ROG	\$4.925/kg ^c
<i>Criteria Pollutants (CP) (kg/hr)</i>	
CO	\$0.199/kg ^c
NO _x	\$79.28/kg ^c
PM	\$649.2/kg ^c

^a AAA Gas Prices (n.d.)

^b Environmental Protection Agency (2019a)

^c Caltrans (2017)

Figure 4. CO₂ and NO_x emission rates for Light-Duty Automobiles and Heavy-Duty Trucks

Explicit eco-routing

Private impacts

- Eco-routes render significant reduction in emissions (up to 5%) but at increased cost to the carrier (also by 5% at worst).
- Benefits of reduced exposure are compensated by increase in cost to the carrier.
- Appropriate valuation of emissions for stakeholders and regulators
 - NO_x emissions must be valued at \$792.8/kg instead of their current value of \$79.28/kg
 - Each kilogram of CO₂ emissions must be valued at a dollar instead of its current value of 7¢

Explicit eco-routing System-wide impacts

Net reduction but possibility of net increase in externalities.

- CO2 emissions: LEP-CO2 vs. LCP assignment
- CH4 emissions: LEP-NOx vs. FP assignment

Does not disproportionately affect the disadvantaged communities.

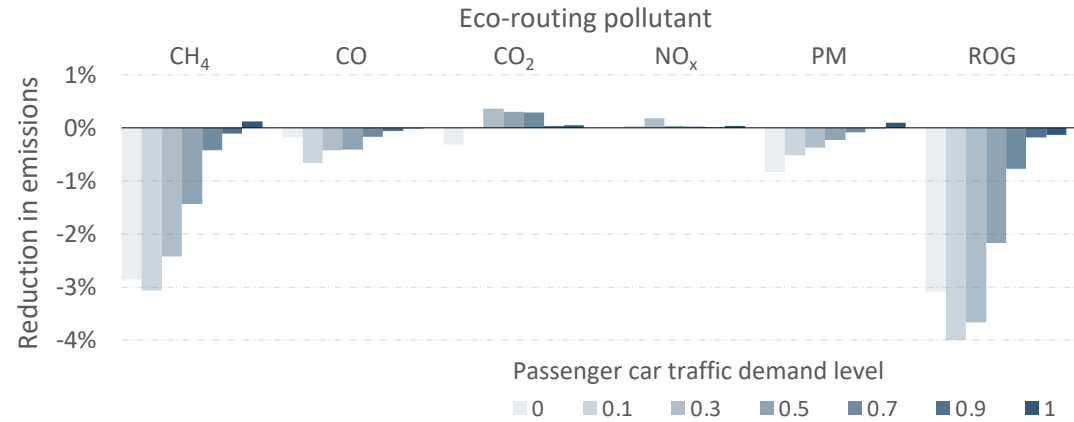


Figure 5. System-wide impact of eco-routing LEP-X assignment vs. FP assignment

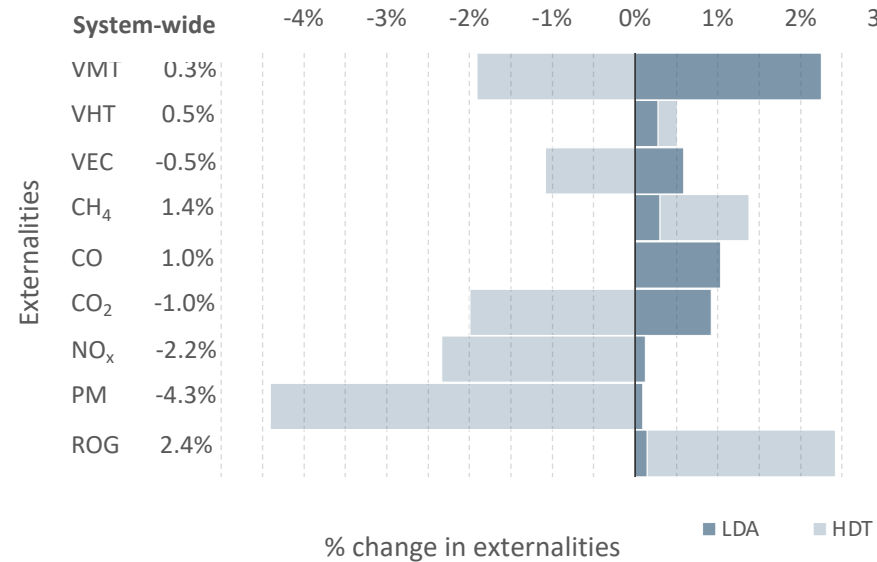


Figure 6. Traffic dynamics: LEP-NOx assignment vs. FP assignment

Policy implications

- Carriers routing their fleet on SP observe a reduction in travel time and fuel-use from eco-routing.
- Carriers routing their fleet on FP can be nudged to eco-route and minimize CP emissions
- Carriers routing their fleet on LCP can be nudged to eco-route and minimize GHG emissions
- The benefits from eco-routing are best realized in off-peak hours when there are fewer passenger cars.
- LFP does not render a reduction in emissions as is widely thought.

Implicit eco-routing

Private impacts

- Nearly half of all freight trips from POLA route through SELA (44% of shortest paths, 53% of fastest paths, and 39% of least cost paths)
- An individual in SELA would observe a reduction in exposure by 0.02g of NO_x emissions, 0.0004g of PM emissions, and 0.006g of CO emissions, resulting in 0.2¢ fewer emissions cost.
- For the carrier having to re-route, geofence renders 10.9% longer, 14.3% slower, and 15.6% more expensive shortest, fastest, and least cost paths, respectively.

Implicit eco-routing

System-wide impacts

Criteria pollutant emissions drop by 40% - 75%, saving \$5 per person in SELA.

SCAG observes slight increase in externalities.

Disadvantaged communities observe \$3 reduction in emission costs per person.

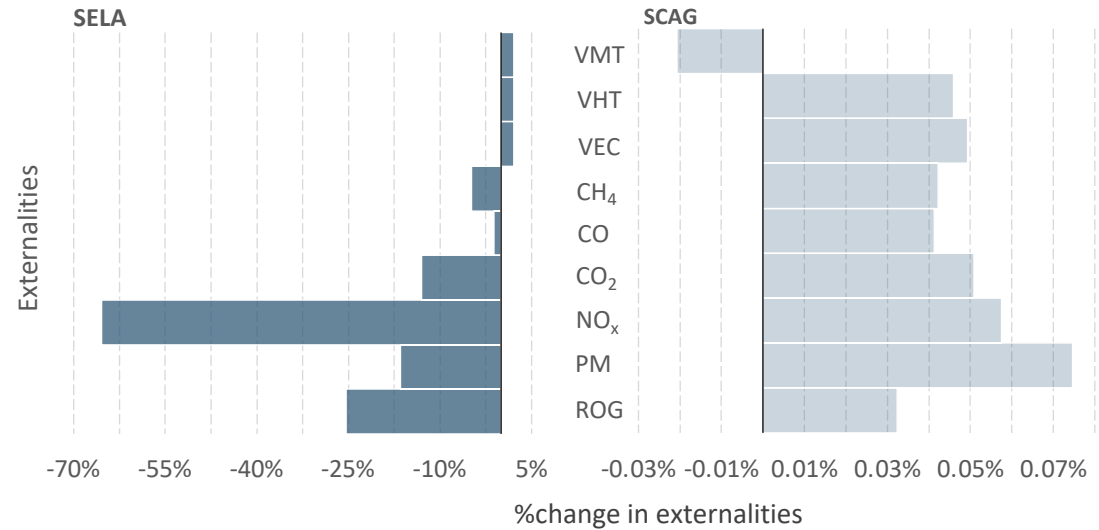


Figure 7. System-wide impact of eco-routing GRP assignment vs. FP assignment

Policy implications

- The monetary benefits of reductions in emissions inside the geofence could far outweigh the cost of increased emissions elsewhere.
- Important to consider costs and benefits heterogeneously across the population.
- Appropriate valuation of emissions for stakeholders and regulators to take appropriate measures to cope with freight-related externalities.

References

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Questions?

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Appendix A

multi-class traffic assignment by paired alternative segments (mTAPAS)

Input: ϵ – minimal flow level, θ – minimal cost level, tol – tolerance level, n, m – algorithm parameters

Output: x_{ij}^{kr} – origin-based arc flows

Step 1. Initialize origin-based arc flows - x_{ij}^{kr} , origin-based reduced arc cost - π_{ij}^{kr} , least cost path predecessor labels for every origin, every vehicle class - L_r^k , and an empty set for paired alternative segments - ρ .

Step 2. Perform All-or-Nothing (AON) assignment: For each origin - r , find the least cost path to every destination - s , for every vehicle class - k . Assign demand q_{rs}^k for this path. Update x_{ij}^{kr} and π_{ij}^{kr} for arcs on this path.

Step 3. Iterate to adjust flows on arcs until the algorithm converges.

Step 3.1. Identify potential arcs with substantial origin-based flow and reduced cost ($x_{ij}^{kr} > \epsilon$; $\pi_{ij}^{kr} > \theta$).

Step 3.2. Develop and store PAS for this potential arc using the Maximum Cost Search procedure.

Step 3.3. Perform an initial flow shift on this PAS using the Newton Method.

Step 3.4. Perform flow shifts on n randomly selected PAS to fasten the algorithm convergence.

Step 4. Remove PAS which no longer results in significant improvement in the solution.

Step 5. If relative gap - rg , is smaller than the tolerance level - tol , then go to Step 6, else repeat Step 3.

Step 6. Return set of origin-based arc flows.

Appendix B

Maximum Cost Search (MCS) procedure

Input: a – arc, k – vehicle class, r – origin node

Output: (e_1, e_2) – PAS

Step 1. Initialize status label l_n for each node $n \in N$ and maximum cost predecessor label set L .

Step 2. Set the tail and head node on arc a and iterate.

Step 2.1. Maximum Cost Search

Step 2.1.1. Set the head node to the tail node.

Step 2.1.2. Fetch the maximum cost arc towards this head node and set the tail node on the tail of this maximum cost arc

Step 2.1.3. Set the predecessor label of the head node to this tail node.

Step 2.2. If this predecessor is on the least cost path from origin to node j , then establish the first segment of the PAS using maximum cost labels and the second segment using least cost labels.

Step 2.3. If this predecessor is previously identified, then a loop is established, but a PAS cannot be established.

Step 2.4. Else update the status of this predecessor and continue to step 2.1

Step 3. Return PAS segments.
