Environmental Impacts of Freight Transportation in the U.S.

Using a Spatial Database to Identify Commodity-Specific Air Emissions

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GEOG 676
Ethan Frost

Introduction and Background

On-road vehicles contribute significantly to emissions that lead to poor air quality and negative health impacts. According to data from the 2011 National Emissions Inventory (NEI)[1], on-road vehicles contribute 34% of total US carbon monoxide (CO) emissions and 38% of total US nitrogen oxide (NO_x) emissions. Furthermore, on-road vehicles are the largest source of mobile sector volatile organic compound (VOC) and particulate matter (PM) emissions.

Heavy duty diesel vehicles (HDDV)[2] in particular emit large quantities of NO_x and PM. Based on 2011 NEI data, HDDV represent 44% of all on-road NO_x emissions and 61% of all on-road PM emissions in the US. Moreover, according to the Federal Highway Administration (FHWA), combination unit trucks, which are the primary form of HDDV, account for 1% of total vehicle registrations and 6% of total vehicle travel[3]. Thus, HDDV emit large quantities of NO_x and PM in both absolute and relative terms.

Leveraging economics effectively is an area of opportunity in managing HDDV emissions. A large amount of freight in the U.S. travels via HDDV. Determining how specific freight flows contribute to on-road emissions would provide policy makers with greater and more impactful options to balance economics with public health.

In this study we combine multiple data sets to explore the ways in which commodity flows impact on-road emissions. We use traffic volume data from the Federal Highway Administrtation (FHWA) along with freight flow data from the FHWA Freight Analysis Framework (FAF) and emissions data from the Environmental Protection Agency (EPA) 2011 National Emissions Inventory (NEI) to explore the connections between traffic flows, freight flows, and on-road emissions.

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[1] We base our calculations on the interactive data contained in the pages belong to the following website: http://www.epa.gov/air/emissions/index.htm

[2] We use the terms "HDDV" and "truck" interchangeably. When using the term "truck", we are not referring to light-duty vehicles such as pick-up trucks, sport utility vehicles, or minivans.

[3] Vehicle registration and VMT data taken from Highway Statistics 2010: Table VM-1, which can be found at: http://www.fhwa.dot.gov/policyinformation/statistics/2010/vm1.cfm

Our work seeks to answer multiple questions:

- How impactful is freight both economically and from environmental and public health perspectives?
- How are commodities and emissions linked?
- What commodities should be targeted for modal shifts to reduce emissions and improve air quality?
- Where would these policies have the greatest impact?

To address the first question, we isolate the contribution of freight truck activity to economics and emissions, respectively. To address the second question, we look for connections between flows freight truck commodity flows and freight truck emissions. To address the third question, we identify commodities that have either high economic or environmental leverage. To address the fourth question, we consider the geographic and socioeconomic context of where freight impacts occur to determine how much benefit could be expected from reducing freight impacts.

Conceptual Design

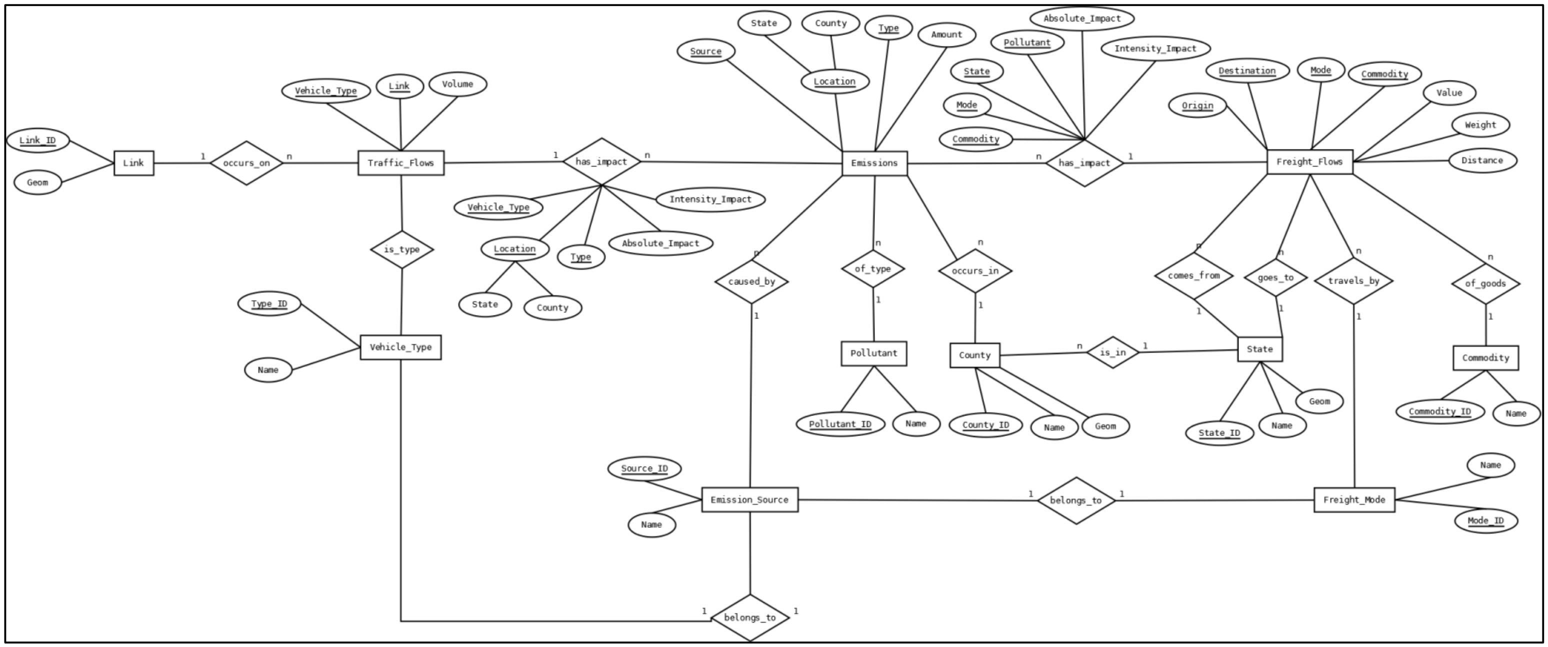

Figure 1: Spatial database conceptual design

Conceptually, this study revolves around three entities: freight flows, traffic flows, and emissions. We are specifically interested in the relationships between freight flows and emissions and between traffic flows and emissions. To make comparisons between these entities, we use multiple relationships to reconcile differences in terminology between the attributes of each entity. Additionally, these entities are instantiated at different scales and thus have different geographic attributes which must also be reconciled to provide an accurate comparison.

Logical Design

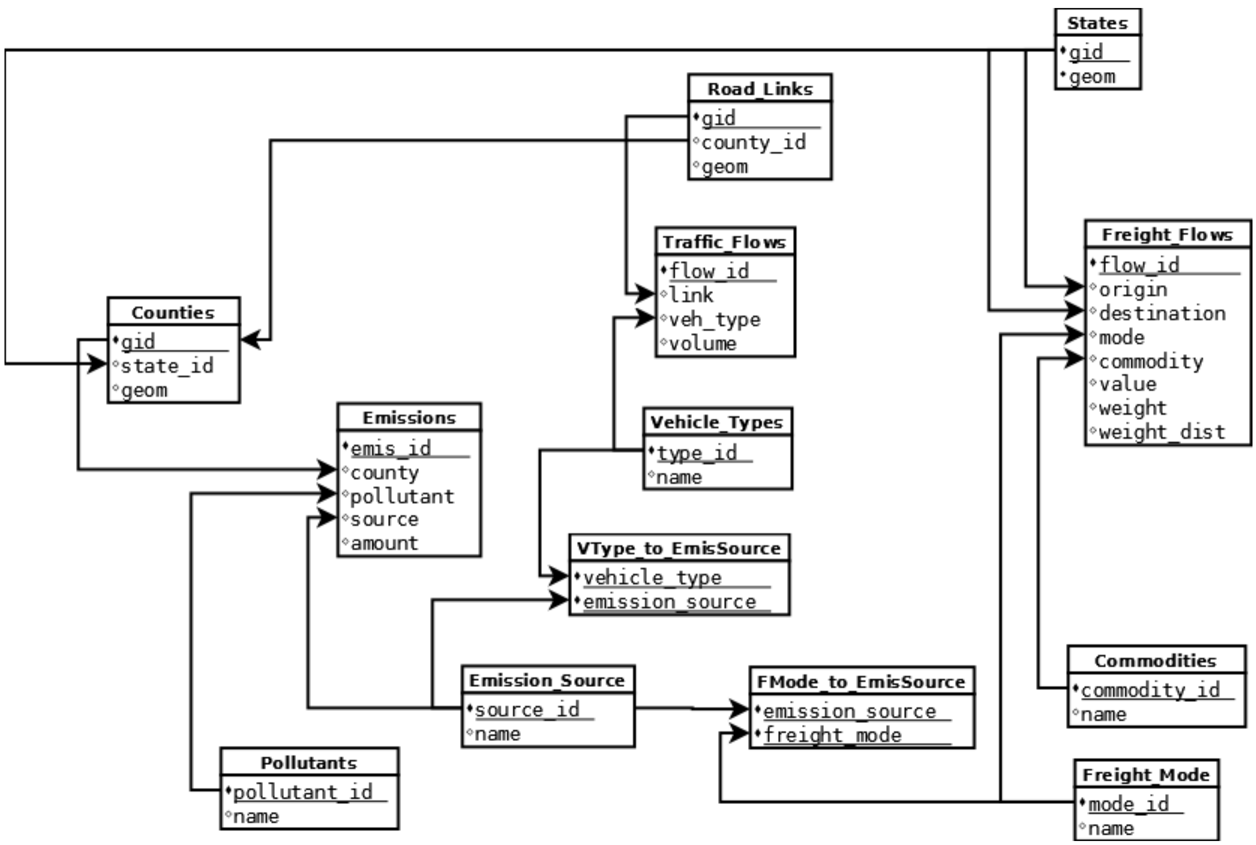

Figure 2: Spatial database logical design (arrows originate at primary key and end at foreign key references)

To implement our conceptual design, we form a collection of normalized relations. Our main entity types each have a surrogate primary key to identify each record. The natural key fields correspond to a series of dimensions, each of which is a reference to another supporting entity type. Finally, each of our main entity types has one or more fields that represent a measurement that describes the instance of that entity type given the natural key or dimension fields.

Methods

To compare emissions, freight flows, and traffic flows, we find the total of each of these entity types at the state level. We begin with freight flows and then calculate state level emissions and traffic flows. Finally, we combine all of the state level data into a single relation to facilitate further analysis and visualization.

To find the total flows of each commodity going into or out of each state:

```
create view total_flows as
select state, commodity, sum(sum_val) as tot_val, sum(sum_wt) as tot_wt, sum(sum_wtdist) as
tot_wtdist
from
	(
	select origin as state, commodity, sum(value) as sum_val, sum(weight) as sum_wt,
	sum(weight_dist) as sum_wtdist
	from freight_flows
	where mode=1
	group by state, commodity
	)
	union
	(
	select destination as state, commodity, sum(value) as sum_val, sum(weight) as sum_wt,
	sum(weight_dist) as sum_wtdist
	from freight_flows
	where mode=1
	group by state, commodity
	)
group by state, commodity;
```

To determine the most "important" commodity and total flows across all commodities in each state by value, weight, and weighted distance, respectively:

```
create view state_flows as
select a.state, b.commodity as val_comm, c.commodity as wt_comm, d.commodity as wtdist_comm,
a.state_value, a.state_wt, a.state_wtdist
from
(
(
	(
	select state, sum(tot_val) as state_value, sum(tot_wt) as state_wt, sum(tot_wtdist) as
	state_wtdist
	from total_flows
	group by state
	)
as a inner join
	(
	select a.state as state, a.commodity as commodity
	from total_flows as a inner join (select state, max(tot_val) as max_val from total_flows group by
	state) as b
	on a.state=b.state
	where a.tot_val=b.max_val
	)
as b on a.state=b.state
)
inner join
	(
	select a.state as state, a.commodity as commodity
	from total_flows as a inner join (select state, max(tot_wt) as max_wt from total_flows group by
	state) as b
	on a.state=b.state
	where a.tot_wt=b.max_wt
	)
as c on a.state=c.state
)
inner join
	(
	select a.state as state, a.commodity as commodity
	from total_flows as a inner join (select state, max(tot_wtdist) as max_wtdist from total_flows
	group by state) as b
	on a.state=b.state
	where a.tot_wtdist=b.max_wtdist
	)
as d on a.state=d.state
```

To find the total freight truck NO_x emissions in each state:

```
create view state_emissions as
select c.gid, sum(amount) as st_emis
from
(
(
(
(
(
emissions as a
inner join
counties as b
on a.county=b.gid
)
inner join
states as c
on b.state_id=c.gid
)
inner join
pollutants as d
on a.pollutant=d.pollutant_id
)
inner join
emission_source as e
on a.source=d.source_id
)
inner join
FMode_to_EmisSource as f
on e.source_id=f.emission_source
)
inner join
freight_mode as g
on f.freight_mode=g.name
where d.name='NOX' and g.name='Truck'
group by c.gid;
```

To find the total state freight truck traffic in each state:

```
create view state_traffic as
select d.gid, sum(a.volume) as st_traffic
from traffic_flows as a
(
inner join
road_links as b on a.link=b.gid
)
inner join
counties as c on b.gid=c.gid
)
inner join
States as d on c.state_id=d.gid
)
inner join
vehicle_types as e on a.veh_type=e.type_id
)
inner join
vtype_to_emisSource as f on e.type_id=f.vehicle_type
)
inner join
emission_source as g on f.emission_source=g.source_id
)
inner join
fmode_to_emissource as h on g.source_id=h.emission_source
)
inner join
freight_mode as j on h.freight_mode=j.mode_id
where j.name='Truck'
group by d.gid;
```

To combine freight flows, traffic flows, and emissions:

```
create view combined_state_stats
select a.state, a.val_comm, a.wt_comm, a.wtdist_comm, a.state_value, a.state_wt, a.state_wtdist,
b.st_emis, c.st_traffic, d.geom
from
(
(
state_flows as a
inner join
state_emissions as b
on a.state=b.gid
)
inner join
state_traffic as c
on a.state=c.gid
)
inner join
states as d
on a.state=d.gid
```

NOTE:

The data I used was given with keys referencing road links to counties and counties to states. Therefore, I used relational joins instead of spatial functions to find all emissions and traffic within each state. However, if there were no keys given, the spatial st_within function could have been used to find the total emissions and traffic within each state.

With the state level freight flows, emissions, and traffic contained in one relation, we use QGIS to further analyze and visualize the data.

Results

By plotting the data in the combined_state_stats view and the ratios of various columns we arrive at the following set of maps:

1	Live Animals and Fish
2	Cereal Grains
4	Animal Feed and Products of Animal Origin
7	Other Prepared Foodstuffs and Fats and Oils
12	Gravel and Crushed Stone
15	Coal
18	Fuel Oils
21	Pharmaceutical Products
25	Logs and Other Wood In the Rough
26	Wood Products
31	Nonmetallic Mineral Products
32	Base Metal in Primary of Semi-Finished Forms and in Finished Basic Shapes
34	Machinery
36	Motorized and Other Vehicles
41	Waste and Scrap
43	Mixed Freight

Table 1: Commodity ID numbers and corresponding descriptions

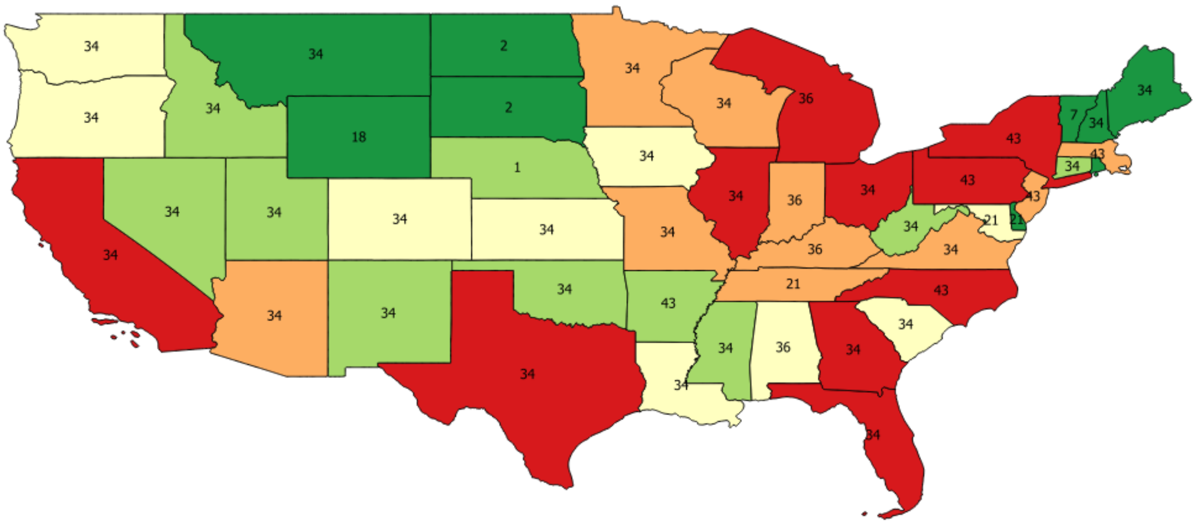

Figure 3: Total freight flow value (green to red) by quintile and most valuable commodity id (label)

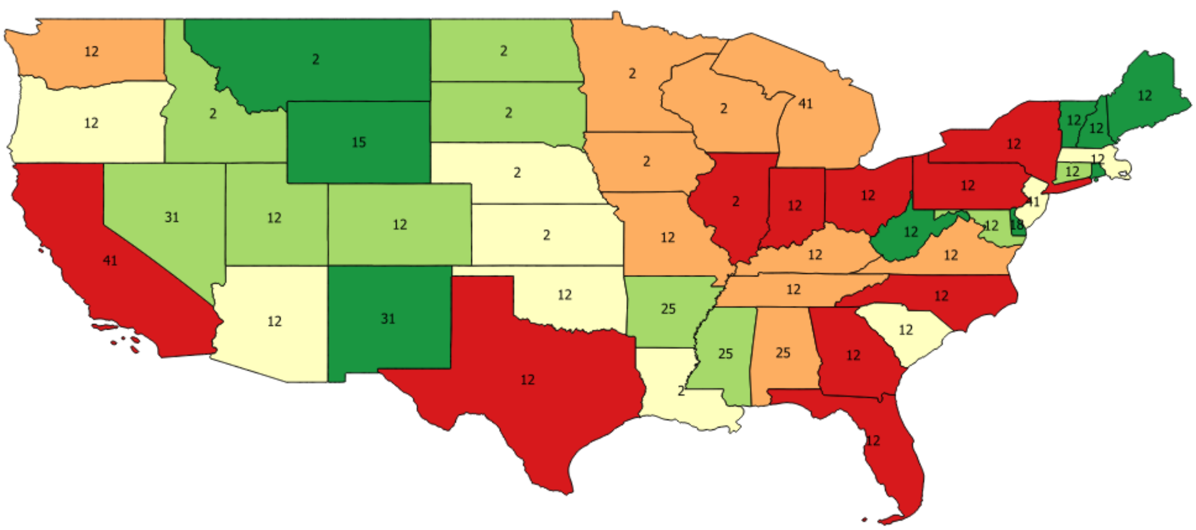

Figure 4: Total freight flow weight (green to red) by quintile and highest tonnage commodity (label)

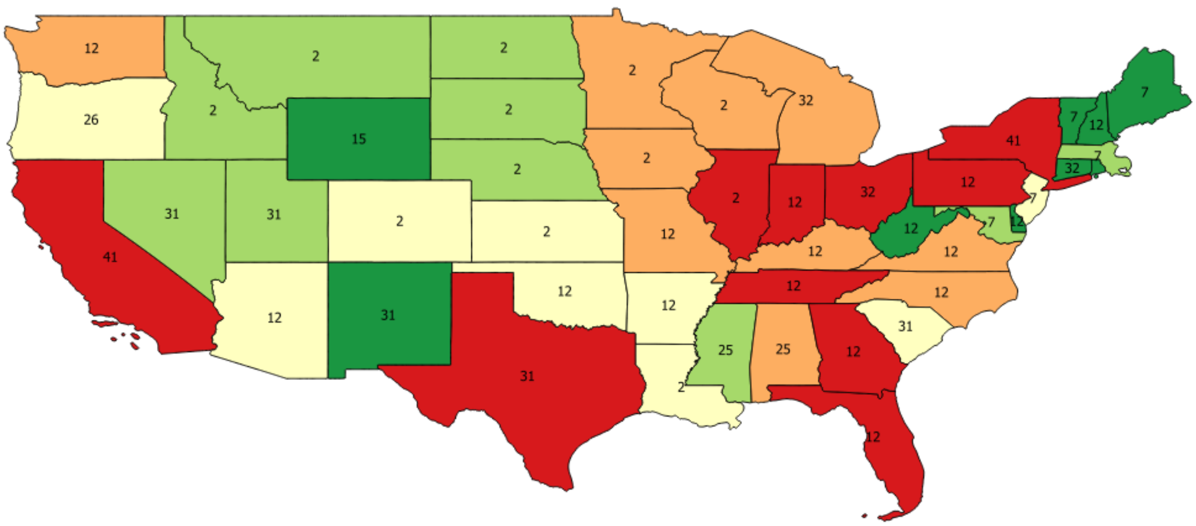

Figure 5: Total freight flow weighted distance (green to red) by quintile and highest weighted distance commodity (label)

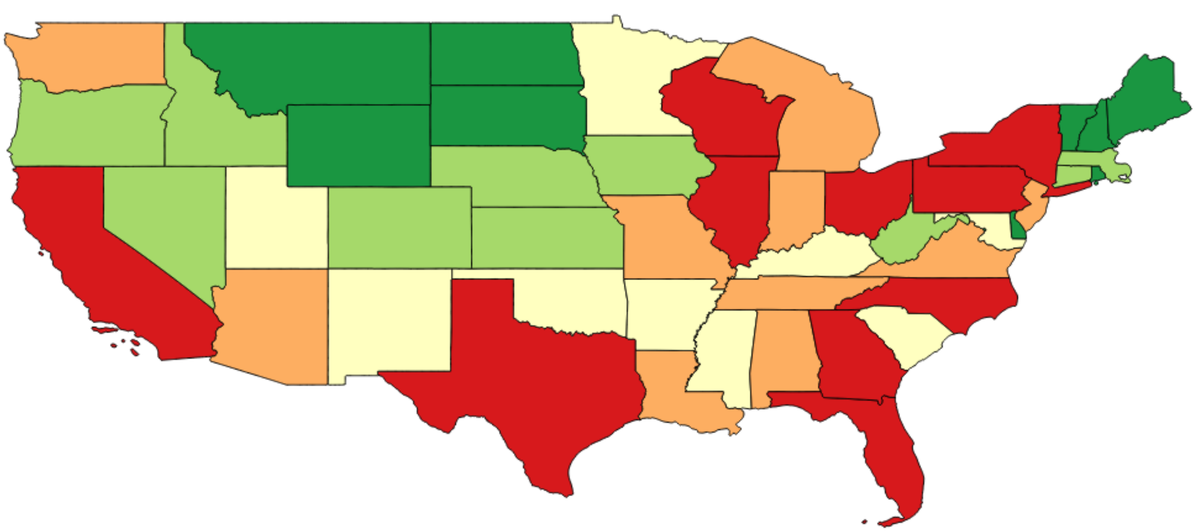

Figure 6: Total truck VMT (red to green) by quintile

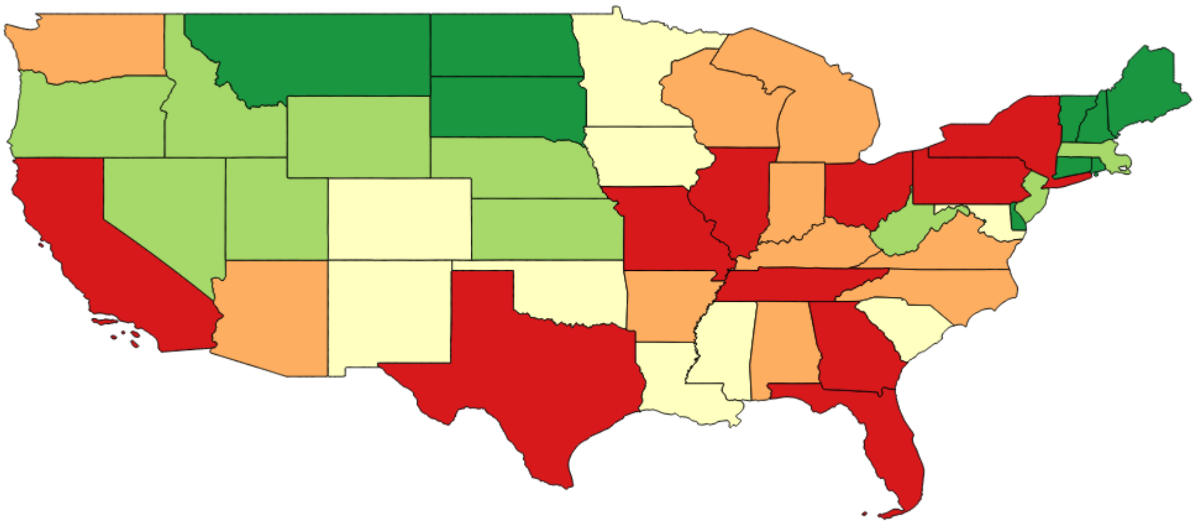

Figure 7: Total truck NO_x emissions (green to red) by quintile

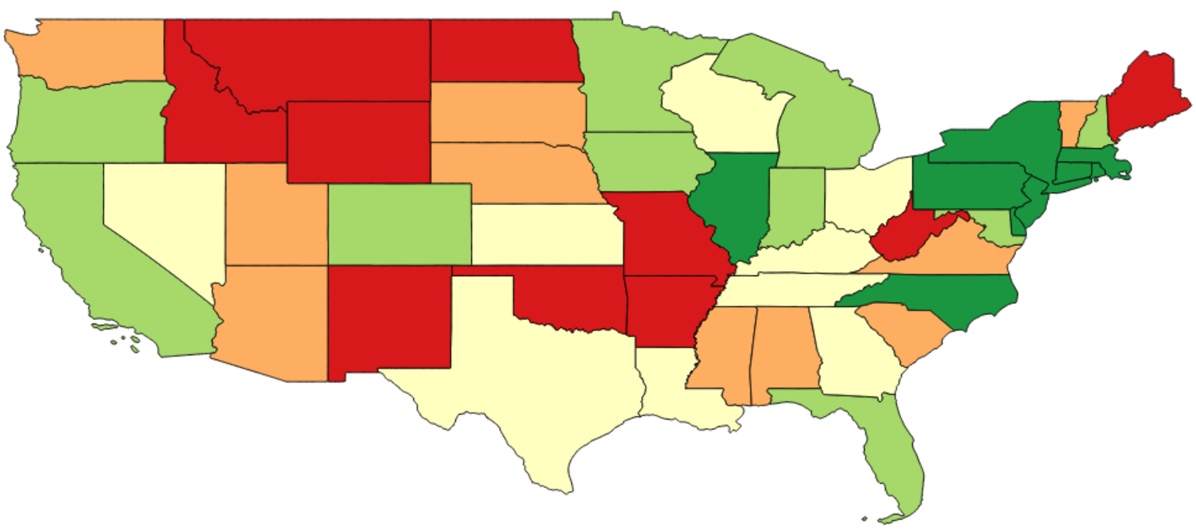

Figure 8: Truck NO_x emissions rate per value (green to red) by quintile

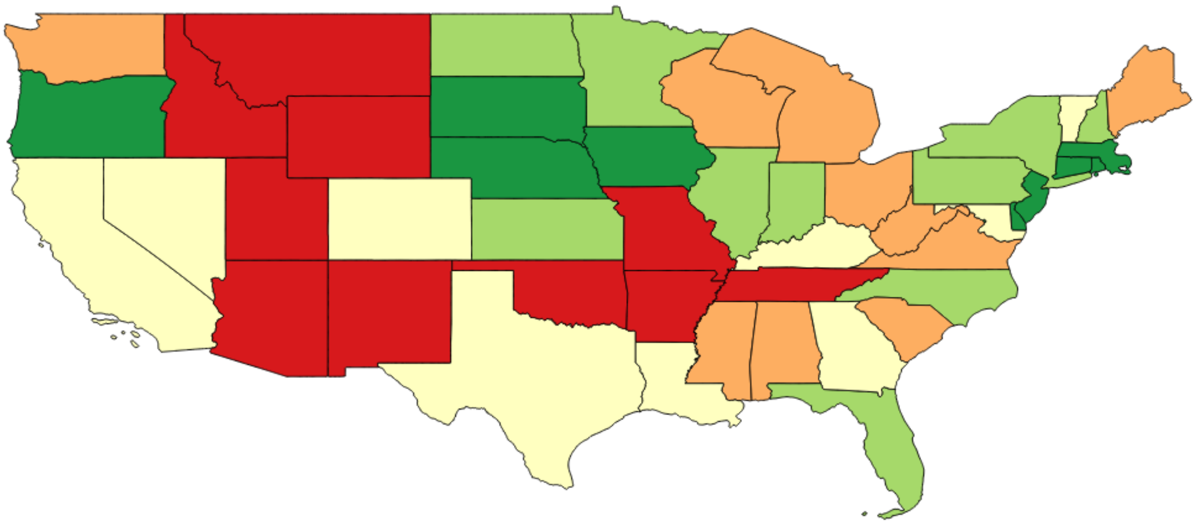

Figure 9: Truck NO_x emissions rate per ton (green to red) by quintile

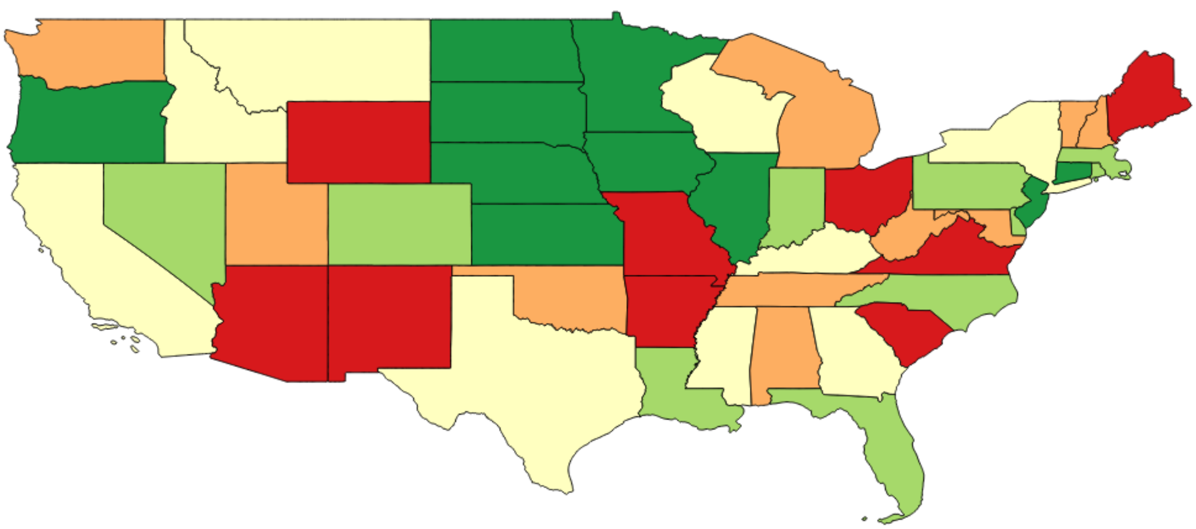

Figure 10: Truck NO_x emissions rate per ton-mile (green to red) by quintile

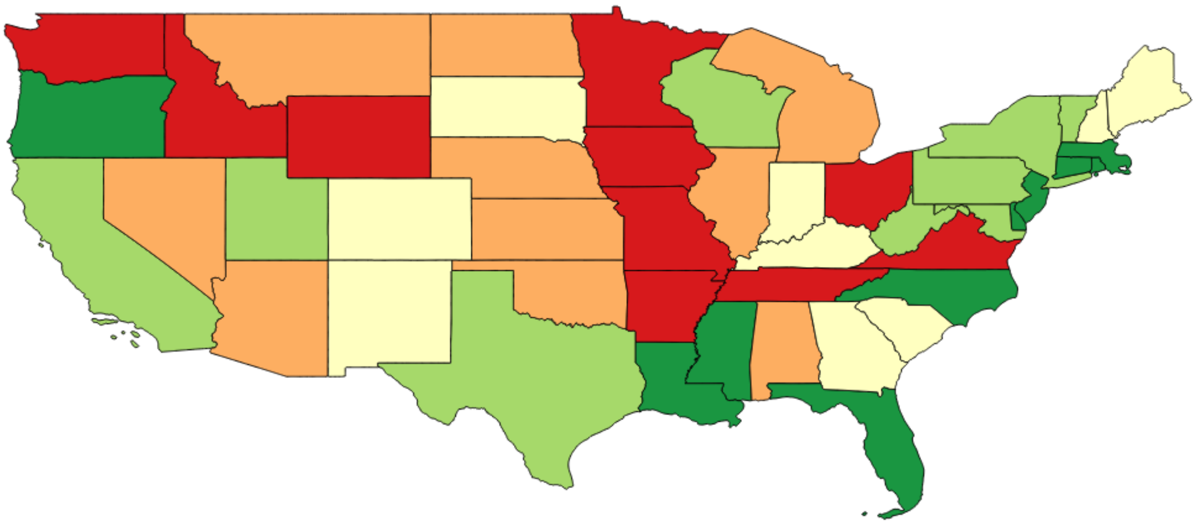

Figure 11: Truck NO_x rate per distance (green to red) by quintile

Discussion

The figures above indicate that there are differences in where absolute values are the highest and where intensities are the highest. California, Texas, and states along the Great Lakes all have the highest absolute values with respect to freight, traffic, and emissions. However, the Great Plains, Midwestern, and states along the Mississippi River have the highest emissions intensities.

The differences between figures showing absolute values and those showing ratios of values indicate a disparity between freight activity and emissions. In part, this is due to the freight activity data not accounting for travel through states which are neither the origin nor the destination of flows. Having commodity flows by road segment would account for this, and would be more useful in addressing the research questions posed above.

Conclusion

In conclusion, this work suggests that freight flows and emissions are linked, that it may be useful to target specific commodities for modal shift, and that a regional approach will probably have to be taken in developing policy. The results showed that the areas with the highest freight activity also had the highest truck NO_x emissions, indicating that there is a connection between freight and emissions. Also, there are clear patterns to the types of commodities that contribute the most to freight flows. Additionally, the commodities that dominate freight flows seem to be clustered in specific regions of the U.S.

This work also suggests the need for further data collection and research in this area. More comprehensive and geospatially explicit data could help find the most effective routing of freight flows to manage tradeoffs between transportation economics and environmental and public health impacts. Specifically, understanding how freight is routed through states which are neither the origin nor destination of shipments would provide useful insight into developing more effective policies.