Targeted Electric Vehicle Procurement Incentives Facilitate Favorable Abatement Cost Outcomes

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Transportation emissions are the largest of any sector

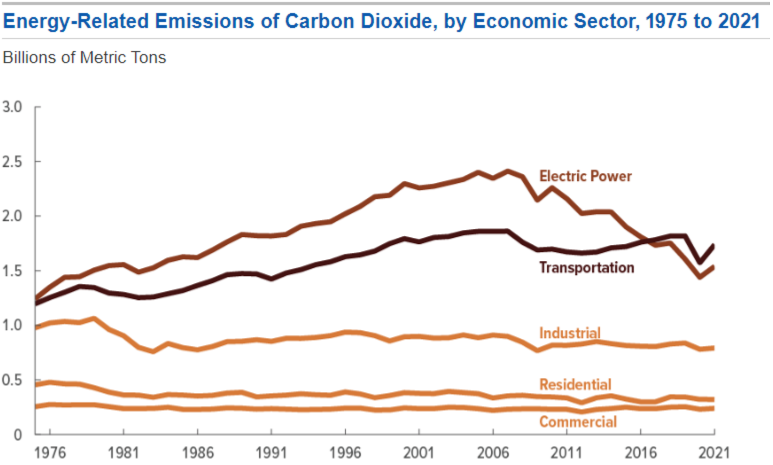

Figure 1: Source: International Energy Agency

Light-duty vehicles are the largest source in the U.S.

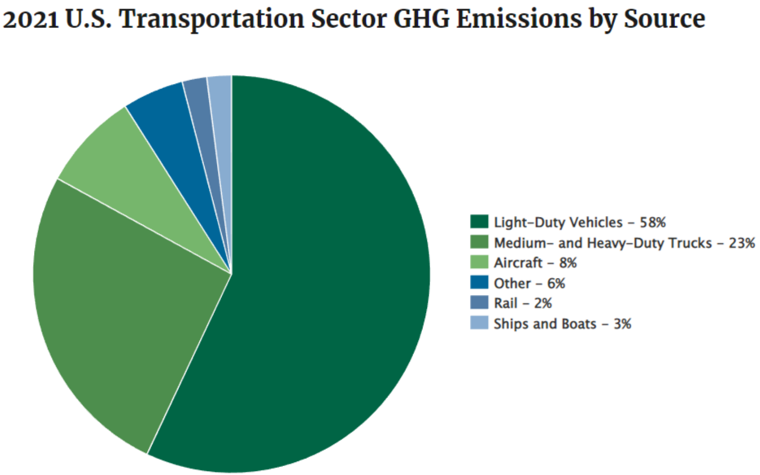

Figure 2: Source: U.S. EPA

EVs represent a potential path forward (albeit w/ caveats)

- Zero tailpipe emissions & lower overall emissions from utilization (but higher vehicle manufacturing emissions)
- Potentially cheaper to operate and maintain (but higher upfront costs)

Public policy response

- Federal govt. offers subsidies to offset high upfront costs of new EVs. Up to $7,500 in the U.S. Similar programs exist abroad
- Policy's goal: incentivize fleet electrification $\Rightarrow$ fewer carbon emissions & less fossil fuel dependence

Short- versus long-run benefits

- Argument for long-run benefits: EV procurement incentives $\Rightarrow$ increased short-run EV demand $\Rightarrow$ economies of scale and technological advancement $\Rightarrow$ improved long-run environmental and/or financial prospects for EVs
- This is plausible. However, there are potential limits on EV procurement incentives' long-term provision:
  1. public resistance to subsidies
  2. finite governmental spending

Short- versus long-run benefits

- Additionally, if policy's main goal is promoting future innovation (rather than maximizing near-term emissions reductions), supply-side policies may be more effective
- In short, near-term policy efficacy also warrants investigation. Ideally, govt. should seek to maximize carbon emissions reduced per dollar spent (relative to other policies)

A key driver of EVs' advantage over ICEVs:

Relative to ICEVs, EVs are:

- Costlier upfront
- More polluting to manufacture
- Potentially cheaper to operate
- Cleaner to operate

Thus, ceteris paribus, greater **aggregate vehicle utilization** $\Rightarrow$ larger and cheaper EV emissions benefits.

Research questions

Focusing on mid-sized light-duty vehicles in the U.S., we ask:

1. What aggregate utilization is required s.t. EVs realize cost-competitive emissions reductions relative to alternative policies?
2. How effective are current new EV subsidies?
3. How might future improvements to electric grids affect EVs' requisite aggregate utilization thresholds?

Existing literature

- Earlier work focuses solely on either EVs' cost or emissions profiles, rather than both
- More recent literature compares vehicles of different types and/or driving range or excludes key factors such as upfront vehicle costs
- Many efforts do not consider requisite battery replacements. Nascent literature finds newer EV batteries retain 80% capacity through 100,000 miles, but this ignores calendar aging, a dominant source of capacity fade

Our approach

Using public data and parameter estimates from existing literature, we:

- Conduct a life-cycle analysis of EVs' and ICEVs' carbon emissions profiles
- Model EVs' and ICEVs' Total Cost of Ownership (TCO)
- Calculate the "cost" of EVs' emissions benefits (defined in $/ton CO_2e reduced)

In doing so, we account for various factors including requisite battery replacements while standardizing vehicle size and driving range

Key vehicle model assumptions

	EVs	ICEVs
Purchase Price ($)	36,620	23,645
Vehicle Manufacturing Emissions (tons CO_2e)	13.6	8.0
Fuel Efficiency (MPGe)	114	34
Fuel Production Emissions (g CO_2e/MJ)	121	19
Fuel Usage Emissions (g CO_2e/MJ)	0	73
Average Fuel Costs ($/kWh and $/gal.)	0.149	3.19
Internal Volume (ft^3)	115	117
Battery Size (kWh)	85	-
Annual Utilization (mi./year)	11,300	11,300
Resale Value (% of previous year's value)	95	95

Table 1: Note: sensitivity tests conducted on all parameters

Life-cycle analysis (ICEVs)

$$E_{PM} = \frac{((e_{vm} * 1,000,000) + e_{vd} + e_{mr})}{au} + \left(\frac{1}{FE}\left(\frac{e_{fp}}{MJ_e} + \frac{e_{fu}}{MJ_e}\right) * EC_G\right) \quad (1)$$

where:

- E_{PM} is emissions per mile (g CO_2e/mi.)
- e_{vm} is emissions from vehicle manufacturing (tons CO_2e)
- au is aggregate utilization (miles)
- FE is fuel effiency (MPGe)
- $\frac{e_{fp}}{MJ_e}$ is fuel production emissions (g CO_2e/MJ of energy)
- $\frac{e_{fu}}{MJ_e}$ is fuel usage emissions (g CO_2e/MJ of energy)

Life-cycle analysis (EVs)

$$E_{PM} = \frac{((e_{vm} * 1,000,000) + e_{vd} + e_{mr})}{au} + \left(\frac{1}{FE}\left(\frac{e_{fp}}{MJ_e} + \frac{e_{fu}}{MJ_e}\right) * EC_G\right) + \left(\frac{au}{BatLife(\frac{AnnVMT}{12})} - 1 * BatSize * Bat_e * 1,000\right) \quad (2)$$

where:

- $BatLife(\frac{AnnVMT}{12})$ is battery lifespan (miles) as a function of annual utilization
- $BatSize$ is battery size (kWh)
- Bat_e is emissions from battery replacement (kg CO_2e/kWh)

Life-cycle analysis

$$E_{PV} = \frac{au}{1,000,000} * E_{PM} \tag{3}$$

where:

- E_{PV} is emissions per vehicle (tons CO_2e)
- E_{PM} is per-mile emissions (g CO_2e/mi.)

$$ED = E_{PV,ICEV} - E_{PV,EV} \tag{4}$$

where:

- ED is the emissions difference b/t ICEVs and EVs (tons CO_2e)

TCO modeling (ICEVs)

$$TCO_{ICEV} = MSRP_{ICEV} + \left(MSRP_{ICEV} * \frac{Tax}{100}\right) + TitleFee \tag{5}$$
$$+ \left(\sum_{k=1}^{n} \frac{((Gas\$ * \frac{AnnVMT}{MPG}) + AnnFees + AnnInsur_{ICEV} + (MR_{ICEV} * AnnVMT))}{(1 + DiscRate)^k}\right)$$
$$- \frac{(MSRP_{ICEV} * DepRate^n)}{(1 + DiscRate)^n}$$

where:

- TCO_{ICEV} is ICEVs' TCO (\$)
- $MSRP_{ICEV}$ is ICEVs' upfront cost (\$)
- $Gas\$$ is average cost of gasoline (\$/gal.)
- $DepRate$ is remaining resale value (proportion relative to previous year)
- $DiscRate$ is annual discount rate

TCO modeling (EVs)

$$TCO_{EV} = MSRP_{EV} + \left(MSRP_{EV} * \frac{Tax}{100} \right) + TitleFee \tag{6}$$
$$+ \left(\sum_{k=1}^{n} \frac{((Elec\$ * \frac{AnnVMT}{MPK}) + AnnFees + AnnInsur_{EV} + (MR_{EV} * AnnVMT))}{(1 + DiscRate)^k} \right)$$
$$- \frac{(MSRP_{EV} * DepRate^n)}{(1 + DiscRate)^n} + \left(\frac{AnnVMT * n}{BatLife(\frac{AnnVMT}{12})} - 1 * BatSize * BatCost \right)$$

where:

- TCO_{EV} is EVs' TCO (\$)
- $MSRP_{EV}$ is EVs' upfront cost (\$)
- $Elec\$$ is average cost of electricity (\$/kWh)
- $DepRate$ is remaining resale value (proportion relative to previous year)
- $DiscRate$ is annual discount rate

TCO modeling

$$TCOD = TCO_{EV} - TCO_{ICEV} \tag{7}$$

where:

- $TCOD$ is the TCO differential b/t ICEVs and EVs (\$)

Calculating cost of EVs' emissions benefits

$$FinalCost = \frac{TCOD}{ED} \tag{8}$$

where:

- *FinalCost* is the cost of EV procurement policy's emissions benefits (\$/ton CO_2e reduced)

Results - life-cycle analysis

Relative to ICEVs, EVs' per-mile emissions decrease as a function of aggregate mileage. Greater aggregate utilization $\Rightarrow$ more favorable emissions outcomes for EVs.

- EVs realize emissions advantage after approximately 28,000 miles*

    *assuming annual utilization exceeds 1,200 miles per year. Otherwise, a battery replacement may be required owing to calendar aging, raising the aggregate utilization threshold to 49,000 miles.

Results - TCO

- Given annual utilization rates of 11,300 miles/year, EVs' TCO is ∼\$6,900 greater than ICEVs' after 6 years.
- After 12 years, EVs' TCO is ∼\$9,700 greater than ICEVs' owing primarily to a greater loss of resale value (which is a function of higher upfront purchase prices).

Results - TCO

- Based on sensitivity tests, declining electicity prices and rising gasoline prices offer inelastic declines to EVs' TCO differential (elasticities: 0.35 and 0.73, respectively)
- But ceteris paribus, lowering EVs' upfront cost differential from $12,975 to $1,173 enables TCO parity in a 6-year ownership period
- Alternatively, higher annual utilization rates improve EVs' financial prospects
  - E.g., Increasing from 11,300 to 20,000 miles/year decreases EVs' TCO differential from $6,906 to $3,625 over a 6-year period

Results - cost of EVs' emissions benefits

- Under current utilization and ownership patterns, the implied "cost" of reducing CO_2 emissions via EV procurement incentives is \$801/ton if only considering \$7,500 government expenditure
- But EVs' TCO differential may exceed (or subceed) \$7,500...

Results - cost of EVs' emissions benefits

- How far would an EV need to travel to realize a \$7,500 TCO differential? Our model suggests $\sim$60,000 miles. Yet such a policy is still unlikely to be ideal.
- Accounting for emissions from vehicle manufacturing and utilization, an ICEV travelling 60,000 miles only generates 27.2 tons of CO_2 emissions.
- What if an EV were to produce zero emissions from cradle to grave?
  - The implied cost of a \$7,500 procurement incentive would still be \$276/ton CO_2e reduced.
    This exceeds the cost of alternative policies such as gasoline taxes (\$47/ton CO_2e reduced) or reforestation (\$11/ton CO_2e reduced), as well as the social cost of carbon (\$51/ton CO_2e reduced according to the Biden administration)

Results - cost of EVs' emissions benefits

- Yet based on current utilization patterns and ownership trends, EVs' emissions advantage is 7.93 tons CO2e. Suggests a target of $50/ton CO2e reduced is possible were EVs' TCO differential lowered to $397
  - This could occur if EVs' upfront costs were reduced to $2,244 more than ICEVs' (e.g., via economies of scale or improved technology)
- Put simply, the issue is not that EVs need to get cleaner. Rather, EVs' emissions benefits currently come at too high a price

Near-term policy solutions

- How might these costs be reduced? Greater aggregate utilization raises EVs' emissions benefits and lowers TCO differential
- Electrifying high utilization vehicles (e.g., taxis) is more likely to produce cost-competitive emissions reductions
  - E.g., our model estimates that EVs travelling 157,000 miles over a 6-year period (464,000 miles over a 12-year period) can realize a cost of $50/ton CO2e reduced
- Policies that instead offer utilization-based incentives (e.g., subsidized vehicle maintenance fees) may be similarly effective

Long-term policy solutions

- Future decarbonization of the electric grid is likely insufficient to realize cost-effective emissions reductions.
- Rather, incentivizing the development of more affordable, financially-competitive EVs likely better optimizes emissions reductions per dollar spent.

Summary

- Even after accounting for battery replacements and standardizing for vehicle size and range, EVs can offer emissions reductions relative to ICEVs. But, the magnitude of these reductions largely depends on utilization
- A $7,500 incentive is unlikely to be efficient, as ICEVs do not produce enough emissions for EVs to offset at a low cost (relative to alternative policies).
- Holding constant annual utilization rates, longer ownership periods produce worse TCO differentials for EVs. Instead, emphasizing high-utilization vehicles can maximize near-term emissions reductions
- In the long run, making EVs more affordable (rather than sustainable) may better enable cost-competitive emissions reductions