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Autonomous Vehicles Have a Wide Range of Possible Energy Impacts

Introduction

Self-driving or “autonomous” vehicles (AVs) have leapt from science fiction into the forefront of transportation technology news. The technology is likely still years away from widespread commercial adoption, but the recent progress makes it worth considering the potential national impacts of widespread implementation. This poster makes an initial assessment of the energy impacts of AV adoption on a per-vehicle basis and on total personal vehicle fuel use. While AVs offer numerous potential advantages in energy use, there are significant factors that could decrease or even eliminate the energy benefits under some circumstances. This analysis attempts to describe, quantify, and combine many of the possible effects. **The nature and magnitude of these effects remain highly uncertain**. This set of effects is very unlikely to be exhaustive, but this analysis approach can serve as a base for future estimates.

Method

Individual and combined impacts are assessed based on the “Kaya Identity,” modified for this analysis in two key ways:
(1) Populations of AVs and CVs are separated for clarity
(2) This analysis uses liquid fuel demand as the output rather than CO_2 to isolate this issue from the CO_2 intensity of electricity or other fuels.

$$Fuel\ Demand = \#Vehicles \times \begin{cases} \%AVs \times \dfrac{VMT}{AV} \times \dfrac{Energy_{AV}}{VMT} \times \dfrac{Liquids_{AV}}{Energy} + \\ (1-\%AVs) \times \dfrac{VMT}{CV} \times \dfrac{Liquids_{CV}}{VMT} \times \dfrac{Liquids_{CV}}{Energy} \end{cases}$$

The top term represents fuel use by AVs and the bottom term by CVs. We refer to factors affecting VMT/vehicles as **“use intensity” (UI)**; factors affecting Energy/VMT as **“energy intensity” (EI)**; and factors affecting Liquids/Energy (e.g. electric vehicles use no liquid fuels) as **“fuel intensity” (FI)**. This analysis uses 2030 as an example year for reference. This is predictive, but as a baseline for comparison. Each potential impact examined below is translated into one or more effects on the terms in the equations above. Where possible, we adapt estimates from other sources as they might apply to AVs. Effects are assumed to be independent for this analysis, so impacts are chain multiplied to combine. Each effect is described by:

Effect	Approach	Effect Estimate	Estimate Source
A brief description of the possible effect	How this poster estimates the impact	Estimated % change to UI, EI, FI	References used in developing the estimate

Private Ownership (Low Number of AVs)

These effects do not require strong system effects and could manifest themselves with low penetration cases where most AVs are owned by individuals. Here we assume 10% penetration.

Effect	Approach	Effect Estimate	Estimate Source
(a) **Platooning:** close following at high speed to reduce drag	Use estimates of overall savings potential from literature	-10% EI	MIT technology review (2011); Ahn, Rakha, and Park (2013); RITA
(b) **Efficient driving:** smooth start stop, some stop elimination	Use estimates of ecodriving potential	-20% to -30% EI	Gonder, Earlywine, and Sparks (2012)
(c) **Efficient routing:** traffic avoidance and most efficient route selection	Example case from Buffalo, NY	-20% EI	Sadek and Guo (2011)
(d) **Travel by underserved populations:** (youth, disabled, and elderly)	Estimate the additional miles if all people over 13 had the VMT of the highest demographic	+70% UI	Author’s estimate based on NHTS data

Shared Ownership (High Number of AVs)

In this scenario, AV use is widespread enough to make private ownership less necessary, with users instead summoning a shared use vehicle for their immediate need. Widespread adoption without vehicle sharing is also possible, but is not considered here. The effects below become possible as penetrations increase so the majority of vehicles on the road are automated. Here we assume 90% penetration.

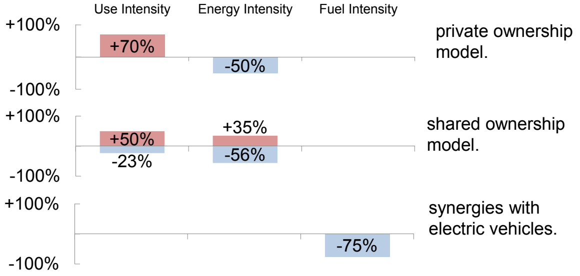
Effect	Approach	Effect Estimate	Estimate Source
(e) Efficient driving: full stop elimination and trip smoothing	Use upper bound of efficiency improvement from smooth travel	-10 to -20% EI (additional to previous estimate)	Gonder, Earlywine, and Sparks (2012)
(f) Faster travel: possible due to safe highway operation	Estimate impact on fuel economy from aerodynamic drag at 100 MPH	+30% EI	Author’s estimate based on ORNL 2013
(g) More travel: due to faster travel, reduced traffic, people may live further from destinations or travel more	Assume the current time spent travelling remains the same (so miles increase with speed)	+50% UI	Author’s estimate; Schaefer et al. (2009)
(h) Lighter vehicles: Very few crashes could enable very light vehicles for many duty cycles	Assume weight could be reduced ~75% and each 10% reduction = 6% EI reduction	-45% EI	Author’s estimate; Burns (2012)
(i) Less time looking for parking: from fewer vehicles and self parking	Assume it cuts the wasted fuel in half	-4% UI	Author’s estimate; TTI Urban Mobility Report
(j) Higher occupancy: facilitated by IT, automated carpooling	Use the upper bound estimates for "dynamic ridesharing"	-12-20% UI	Transportation Energy Futures (2013)

Synergies with Electric Vehicles

Shared AVs may be more amenable to electrification since a vehicle can be dispatched to meet a user’s specific need, only serving trips within range.

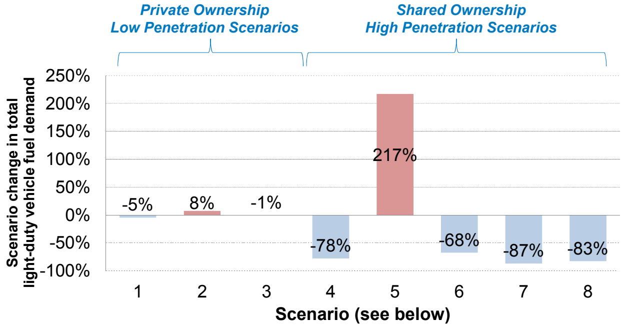
Effect	Approach	Effect Estimate	Estimate Source
(k) Electrification: deployed vehicle could be matched to user trip need	Estimate the share of vehicle trips that could be met with a 40 mi range EV	-75% FI (as a -100% FI to 75% of vehicles)	Author’s estimate; NHTS; Krumm 2012

Fuel Use Impact Ranges (Per Vehicle)



Per-vehicle potential effects range from large increases in fuel use to large savings depending on the scale and interaction of the various factors.

Total Scenario Impacts



Scenario Number	Name	Active Effects
1	Private Ownership, Fuel Savings Only	(a), (b), (c)
2	Private Ownership, Fuel Use Increase Only	(d)
3	Private Ownership, Combined Effects	(a), (b), (c), (d)
4	Shared Vehicles, Fuel Savings Only	(Scenario 1) + (e), (h), (i), (j)
5	All Identified Potential Fuel Use Increases	(Scenario 2) + (f), (g)
6	Vehicle Electrification	(k)
7	All Identified Potential Fuel Savings	(Scenario 4) + (Scenario 6)
8	All Effects	All

Other Potential Impacts

AVs would have many potential effects not covered here. Some include:

- Embodied energy benefits: Even at the peak, only 12% of vehicles are on the road (Burns 2012), so in a shared use model there could be many fewer total vehicles, leading to lower manufacturing energy use
- Economic benefits: with vehicle capital cost spread over many users in shared vehicle scenarios, transportation costs could be lower (Burns 2012)
- Social benefit of transportation access: addition of travelers increases energy use but provides valuable transportation service
- Land use benefit: with fewer, smaller vehicles on the road, cities could repurpose land from parking and potentially in transportation corridors
- Safety benefits: these would include less loss of life and injury as well as fewer vehicle replacements
- Interaction with mass transit: AVs could solve the ‘first and last mile’ problem and lower labor costs for transit, but could also make transit less competitive

Conclusion

AVs have the potential to make impacts on transportation energy use by individuals. Most possible effects on energy intensity are likely to lead to fuel savings, but many effects on use intensity could counteract this or even lead to increases in fuel use, depending on the specific scenario. **Our estimates of possible impacts range from nearly 90% fuel savings (if only energy benefits occur) to more than 250% increase in energy use (if only energy-increases are considered)**. This emphasizes the importance of considering energy impacts in AV deployment strategy.

References and Assumptions

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Baseline assumptions: 262 million vehicles, 47.2 MPG reference vehicle, 12700 miles / vehicle / year (from Annual Energy Outlook 2013).

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