CENTER FOR TRANSPORTATION RESEARCH

Energy (& Emissions) Implications of Self-Driving Vehicles

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MOTIVATION

- **Connected & (fully-) automated vehicles (CAVs)** will **change travel patterns.**
- Experts **unsure whether** CAVs' will have **positive or negative energy & emissions impacts.**
- **This paper** estimates **CAVs' energy impacts** under **best, worst, & expected-cases** for **U.S. passenger travel**, with **sensitivity analysis** (using randomized inputs) for expected outcomes, under **0% & 100% battery-only** electric-vehicle (**BEV**) **futures.**

ENERGY IMPACTS BY CATEGORY

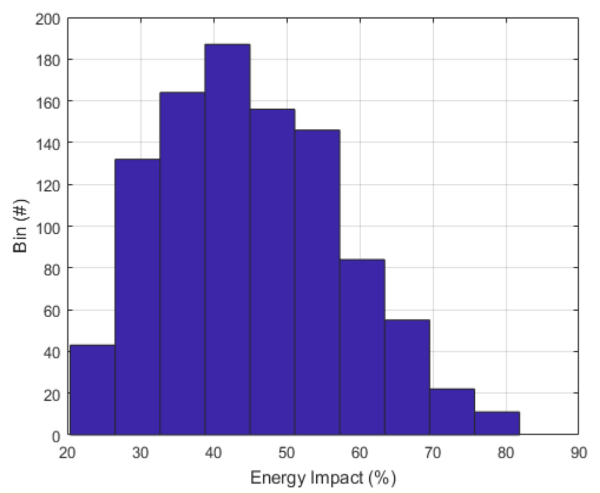
Category	Automation Level	Impact Type	Description	Energy Impacts
Travel	Level 3	Enhanced Route Choice	Route choice based on real-time traffic data from connected environment	-5% to -20%
		Long-distance Travel with CAVs	Longer distance travel caused from lower driving task of CAVs	6% to 18%
		Newly Induced Trips from Underserved Population	Newly induced trips caused from lower driving task of CAVs	10% to 14%
Driving		Smoother Driving Cycle	Smooth & fuel-efficient driving cycle	-10% to -20%
		Shared Automated Vehicles – Enhanced Fuel Efficiency	Fuel-efficiency from vehicle right-sizing & dynamic ride sharing (DRS)	-5% to -12%
	Level 4	Computation system for CAV	Energy required for control, navigation, infotainment system of CAV	4% to 15%
		Faster Travel from Improved Driving Skill	Fast & throughput-efficient driving cycle	7% to 30%
		Shared Automated Vehicles – Increased VMT & Empty Driving	Frequent use & driverless driving of SAVs	6% to 14%
Oper-ations		V2V & platooning	Vehicle-to-vehicle connectivity & platooning	-2% to -19%
		V2I & Smart Intersection	Vehicle-to-infrastructure connectivity & smart inter-section	-6% to -30%
Energy Source	BEV	Electric & Hybrid Vehicles	Change in drive train from gasoline to electricity	-30% to -70%

- **4 Categories of Energy Impacts**:
  Driving Impacts — From vehicle-performance changes
  Travel Impacts — From traveler choices (destination, mode, route, etc.)
  Operations — Interactions among vehicles & infrastructure
  Energy Source — Electric vehicles may become much more common
- **Added car use & travel** will **use more energy**, resulting in **greater emissions**.
- **But operational & energy-source advantages** will **save energy**, thus **reducing emissions**. V2X communications & higher fuel economies will **increase energy savings**.

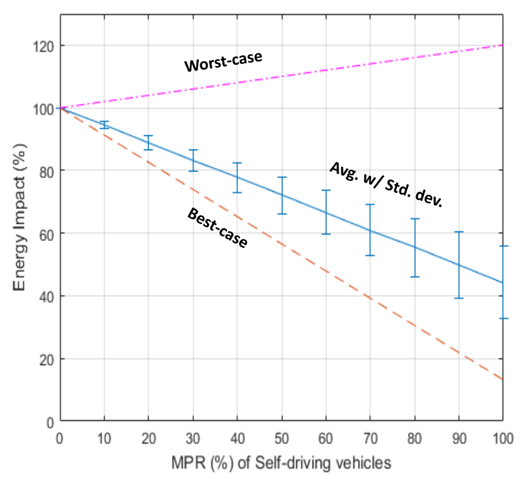
SCENARIO ANALYSIS—Penetration Rate of CAVs

- Each impact's energy consumption effect was **randomly sampled from uniform distributions** to reflect cumulative uncertainties. **Averages of 1000 samples suggest lower energy use.**
- 100% value implies 'business as usual' scenario, while lower or higher value implies a change in energy consumption.
- **Rising market penetration rates (MPRs)** of CAVs expected to **reduce energy** consumption, on average.

Random Sampling w/100% MPR



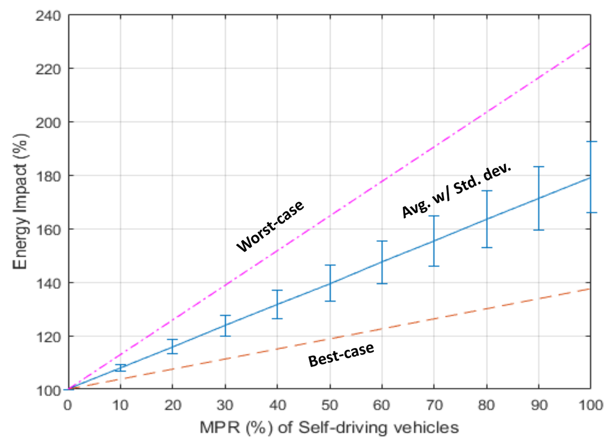
All Impacts Considered



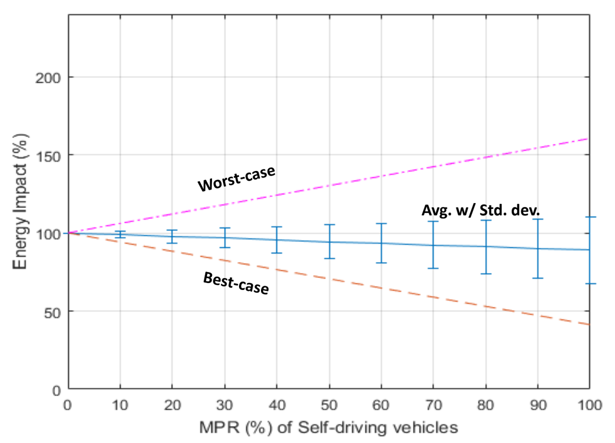
SCENARIO ANALYSIS—Energy Consumption & BEVs

- Each impact can be classified as either an **energy-using** or **energy-saving** impact. Extreme scenarios, **with & without 100% BEVs for light-duty fleet**, are shown here.
- In the **energy-using** scenario, **BEVs can offset** increased energy consumption & lower overall emissions. In the **energy saving** scenario, **BEVs enable greater energy savings**.

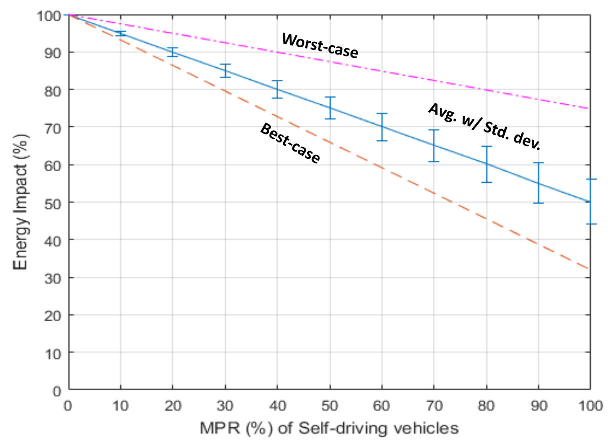
Energy Use + 0% BEVs



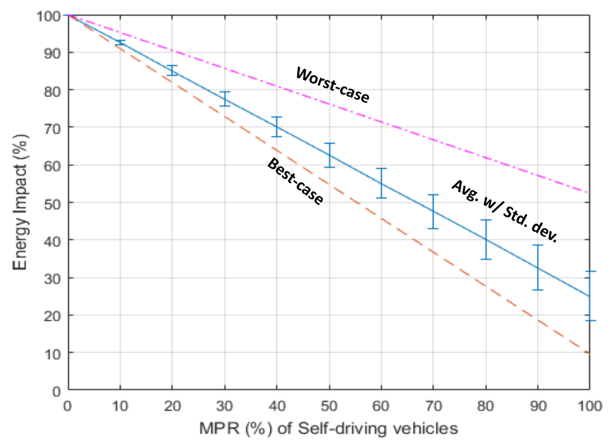
Energy Use + 100% BEVs



Energy Savings + 0% BEVs



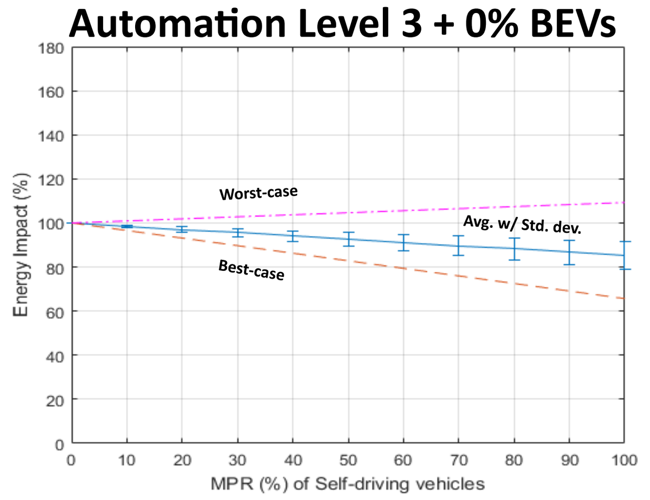
Energy Savings + 100% BEVs



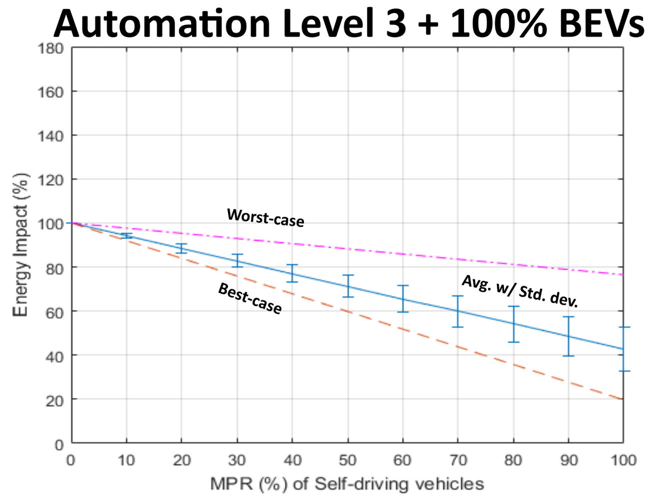
SCENARIO ANALYSIS—Automation Level & BEVs

- Automation Level 3 still requires **drivers' attention**, but a driver may disengage from **safety -critical functions**. Driver attention is not so critical in Level 4.
- Energy impacts vary by Level 3 vs. 4 automation. Here, they are analyzed **with & without BEVs**.
- Level 4 results in much **wider range between optimistic & pessimistic** scenarios than Level 3, but **difference in average energy expectations** between Level 3 & Level 4 is **relatively minor**.
- Each impact might **negate** each other when Level 4 is applied. **Riders with Level 4** CAVs would ex-perience **greater convenience without additional energy consumption**.

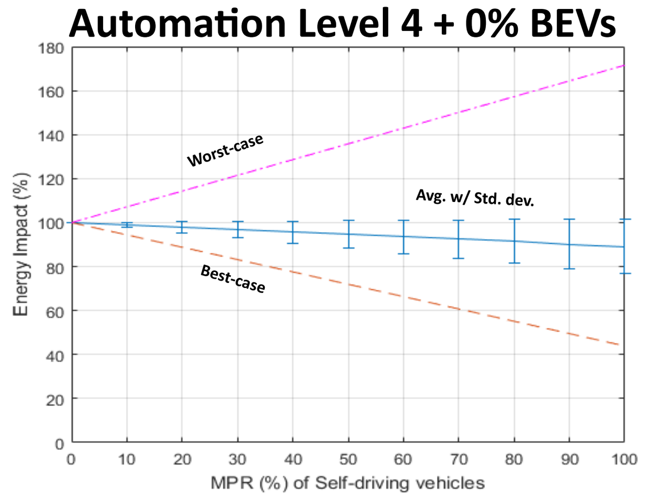
Automation Level 3 + 0% BEVs



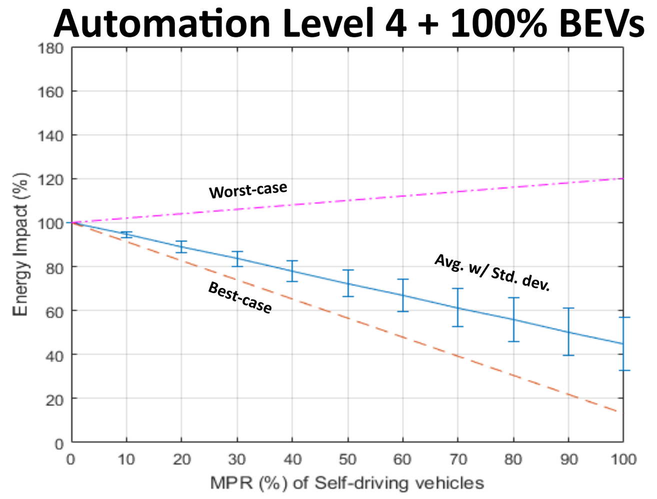
Automation Level 3 + 100% BEVs



Automation Level 4 + 0% BEVs



Automation Level 4 + 100% BEVs



CONCLUSIONS

- **BEV technology will be KEY.** Only **BEV adoption** (**or strong road tolls**) can **offset** (or moderate) CAVs' VMT impacts, enabling a net 20% to 75% **energy savings**.
- Even with **expectation of 30% more VMT** from CAVs, results still suggest **a NET REDUCTION in EN-ERGY USE by US passenger travel**: **-10% if BEVs are not adopted, & 65% if US adopts 100% BEVs**.
- **Level 3 vs. Level 4** automation futures offer **little difference** in energy use, but **Level 4 provides safer travel & great traveler convenience**.
- **Range between best** & **worst case scenarios is widest in Level 4** settings, due to uncertainty in predicting future trends.
- **Adoption of CAVs *with* BEVs** should deliver notable **energy & emissions savings**, enabling a less unsustainable future transportation system.

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