Understanding Energy Consumption in Autonomous Vehicles: A Component-Level Analysis

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Introduction

Autonomous vehicles (AVs) rely on sensors and onboard computing that increase vehicle energy use through auxiliary power demand, added mass, and aerodynamic drag. While previous studies have examined AV hardware and emissions, comparative evidence across real-world AV configurations remains limited.

In this study:

- A total of 21 AV configurations are analyzed.
- City and rural driving conditions are compared.
- The analysis focuses on auxiliary power, drag, and mass.

Research Question

How much do AV-specific components increase vehicle energy consumption, and how does the dominant source of this increase vary with speed?

Method

Additional AV energy consumption was estimated as the sum of road load and auxiliary power, allowing the effects of sensing, computing, drag, and mass to be compared within one framework.

$$P(t)_{total} = P(t)_{road\ load} + P(t)_{aux}$$

$$P(t)_{aux} = P(t)_{sensing} + P(t)_{computing}$$

$$P(t)_{road\ load} = \underbrace{\frac{1}{2}\rho C_d A_f v(t)^3}_{\text{(Drag)}} + \underbrace{mgC_{rr}v(t)}_{\text{(Rolling)}} + \underbrace{mv(t)\frac{dv(t)}{dt}}_{\text{(Inertia)}}$$

Sensor Configurations

- Configurations compiled from literature and industry disclosures.
- Vehicles differ in sensors, redundancy strategies, and computing platforms.

Sensor and AV computer configurations
(13 of 21 analyzed vehicles shown for readability)

Vehicle	Radar	Ultrasonic	LiDAR	Camera	AV Computer
Apollo	2	–	5	2	Nuvo + 2× Orin
Brown et al. (2022)	1	–	1	2	Nuvo 7160GC
BYD Entry-Level	5	12	–	12	Gods Eye C
BYD Mid-Level	5	1	1	13	Gods Eye B
BYD High-Level	5	1	3	13	Gods Eye A
Ford Fusion	2	8	2	7	Drive PX2 (x2)
NIO ET7	5	12	1	11	ADAM
Tesla	1	12	–	8	FSD
Waymo Gen5	6	1	5	29	Driver Gen5
Waymo Gen6	6	1	4	13	Driver Gen6
Waymo Pacifica	4	–	5	9	Drive PX2 (x2)
Wayve	5	–	1	11	Snapdragon Ride
ZOOX	–	–	8	12	1

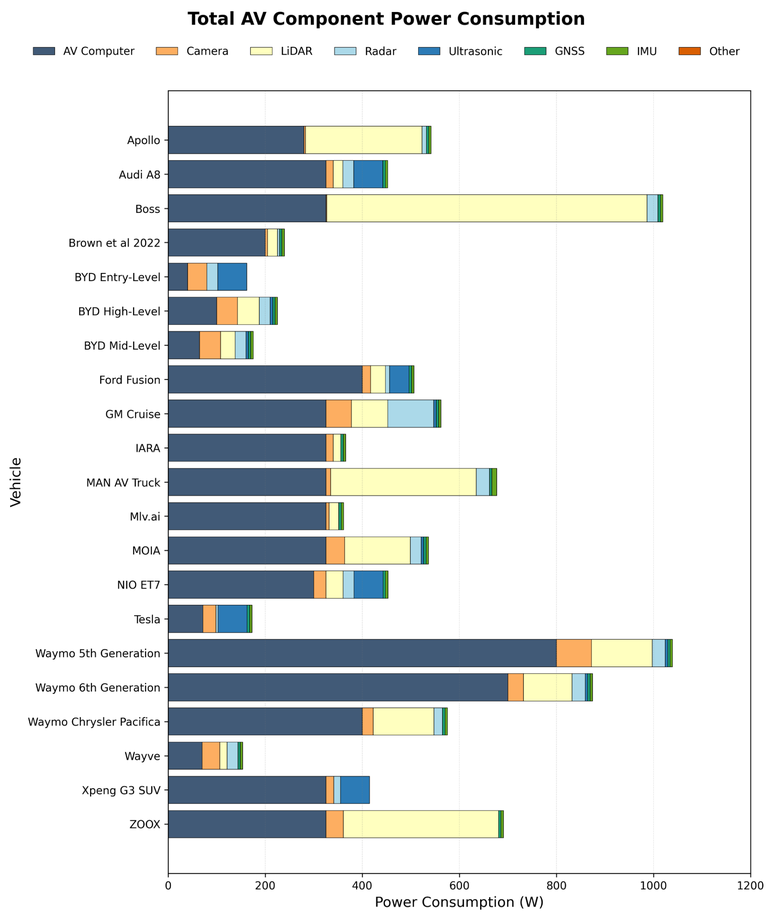
Results

The results compare the additional energy burden of AV-specific hardware across 21 vehicle configurations. The figures below highlight four aspects of this comparison:

- Auxiliary power demand
- Additional energy consumption in city driving
- Additional energy consumption in rural driving
- Sensitivity to speed and acceleration

Auxiliary Power

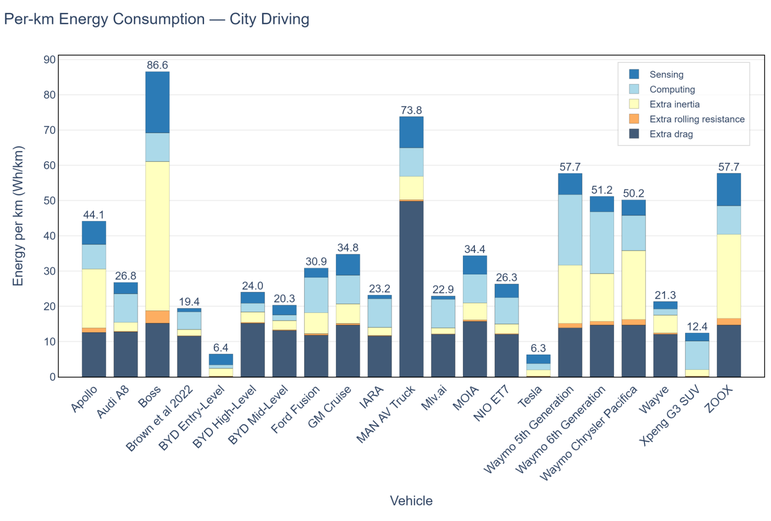
- Auxiliary power demand generally increases with sensing and computing complexity.
- It exceeds 1 kW in some AV configurations.
- LiDAR- and compute-intensive platforms show the highest values.



Auxiliary power consumption of AV components across different vehicles

City Driving

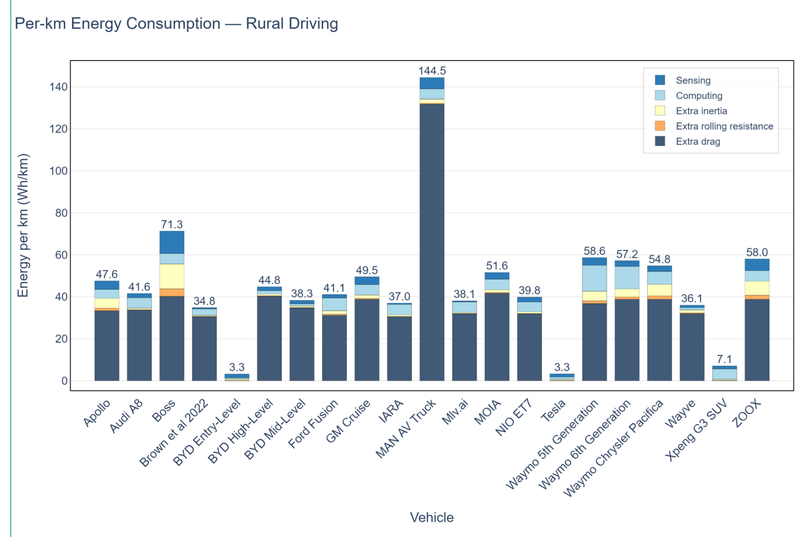
- At low speeds, sensing and computing contribute strongly to additional energy consumption.
- Higher-automation AV concepts tend to show higher values because of more demanding sensing and computing setups.
- Leaner concepts, such as Tesla, XPeng, and entry-level BYD, remain much lower.



Additional energy consumption of AVs per kilometer in city driving

Rural Driving

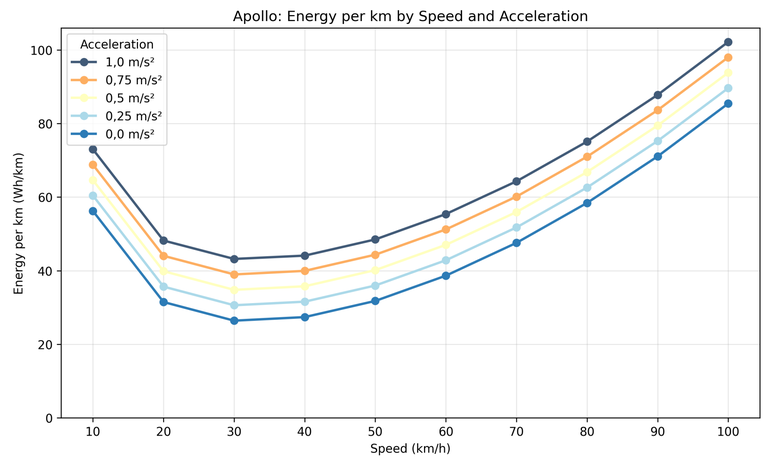
- At higher speeds, aerodynamic drag becomes the dominant source of additional energy consumption
- This effect is especially strong for vehicles with roof-mounted LiDAR because drag power increases with the cube of speed
- AVs without roof-mounted LiDAR remain near the low end of additional energy consumption



Additional energy consumption of AVs per kilometer in rural driving

Sensitivity Analysis

- Apollo was selected as a representative AV with roof-mounted LiDAR and detailed component-level data.
- Additional energy consumption shows a U-shaped relationship with speed, with a minimum at about 30 km/h.



Additional energy consumption (Wh/km) as a function of speed and accel-eration for Apollo

Discussion and Conclusions

- AV components increase energy use through auxiliary power, aerodynamic drag, and added mass.
- The dominant energy penalty shifts with speed.
- At low speeds, sensing and computing contribute more strongly to per-kilometer energy use.
- At higher speeds, roof-mounted LiDAR can make aerodynamic drag the main penalty.
- Energy-efficient AV design depends on both low-power compute and aerodynamic hardware integration.

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