Environmental Science & Technology

Viewpoint

pubs.acs.org/est

The Environmental Impact of Autonomous Vehicles Depends on Adoption Patterns

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Autonomous vehicles (AVs) have the potential to transform our transportation system. The forces that will influence the environmental impacts of large-scale AV adoption are identified to help determine necessary future research directions. It is too early to determine which of these forces will dominate the system and dictate whether AV adoption will result in net reductions or increases in greenhouse gas (GHG) emissions. The environmental research community must develop a better understanding of the disruptive forces of AVs to help develop a strategy to reduce transportation emissions. Particular emphasis is needed regarding how AVs will be adopted and used, as these patterns may ultimately dictate the environmental impacts of AVs. Without better integration of engineering, social science, and planning disciplines to model future adoption scenarios, important opportunities to steer markets toward sustainable outcomes will be lost.

MAJOR FACTORS THAT AFFECT ENVIRONMENTAL IMPACT OF AVS

Increased Efficiency and Effectiveness. From an environmental point of view, the intrinsic technical attributes of AVs appear to be largely favorable.[1] Fuel economy improvements are likely to result from light-weighting vehicles due to reduced collisions, reduced traffic congestion due to optimized vehicle operation, "platooning" AVs together in close proximity, and intelligent transportation systems that enable smart communication between vehicles and infrastructure;[1] however, reduced risk of collision and congestion may lead to increased travel speeds, increasing GHG emissions.

Travel Behavior Patterns. The effect of AV adoption on consumer travel patterns may have greater influence on environmental impact than technical attributes; however, the forces associated with these behavioral dynamics are less consistently favorable. It is plausible that AVs could become more efficient and GHG emissions could decrease on a functional unit basis (i.e., per-passenger-mile), while overall transport-related GHG emissions increase as vehicle miles traveled (VMT) increase. While difficult to estimate, the behavioral aspects of AV adoption are largely unexplored. A better understanding of the relationship between anticipated travel behavior and different AV adoption models is needed to estimate the environmental impact of AVs.

Unlike the current paradigm where drivers must be engaged in the act of driving throughout the duration of a trip, passengers within AVs are free to participate in other pursuits during a commute, reducing their personal value of travel time.[2] The reduced aggravation associated with commuting may lead to an increased acceptable commuting radius, increasing overall VMT and inducing additional GHG emissions related to urban sprawl. Similarly, traditional public transportation alternatives may become less appealing since AVs possess many of the advantages of public transit while still providing privacy and point-to-point service.

The ability of AVs to provide mobility services to elderly and disabled populations is beneficial for societal reasons, but likely to constitute an additional increase to overall VMT. Further, additional VMT may be incurred due to unoccupied travel miles where the vehicle is moving without passengers. For example, a scenario where AVs drop passengers in densely populated areas and travel unoccupied to city outskirts for cheap and available parking before returning for pickup would effectively double the VMT from the current model. Other societal transformations, such as the use of AVs as mobile dwellings or luxury overnight sleeping compartments in lieu of higher density long-distance modes of travel, such as planes and trains, are also feasible scenarios that would increase GHG per passenger-mile.

Not all potential AV-related behavioral shifts are environmentally unfavorable. AVs have increased potential for ride-sharing and lend themselves toward business models that shift personal transportation from individually owned vehicles toward shared-use mobility services (i.e., on-demand or "e-hailing" taxi alternatives such as Uber and Lyft), which have the potential to reduce transportation GHGs. Fagnant and

Received: May 18, 2016
Published: June 10, 2016

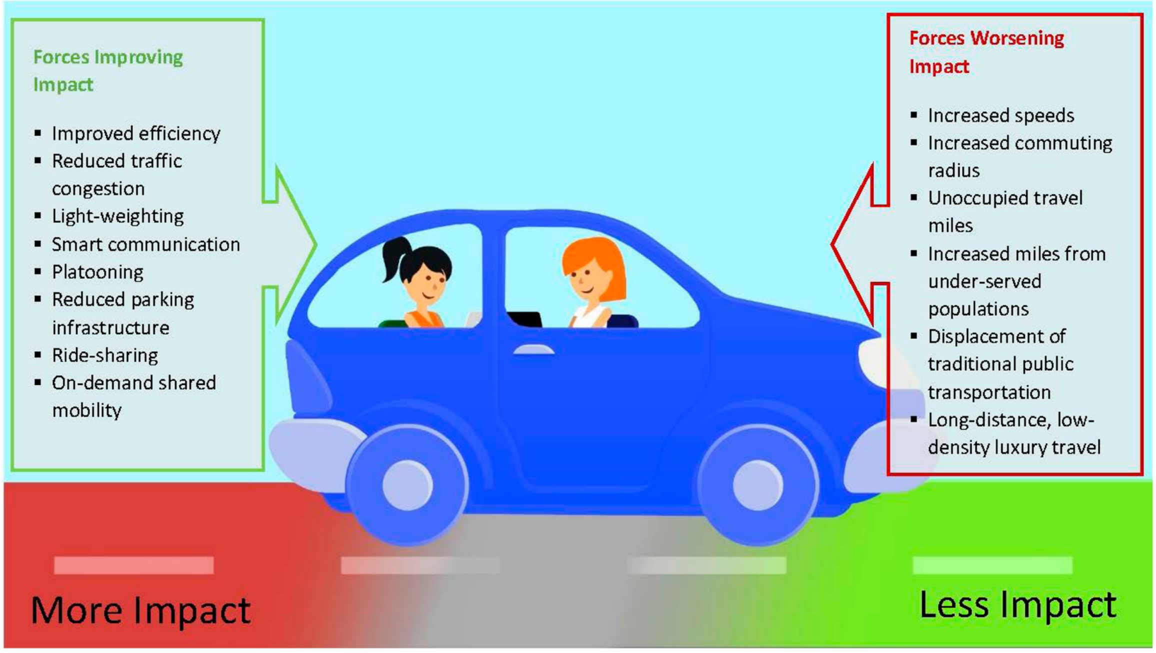

Figure 1. Major forces likely to increase or decrease energy use and GHG emissions associated with fully automated transportation.

Kockelman show that AVs deployed via an on-demand business model can reduce transportation-related emissions through reduced number of vehicles, reduced congestion, increased proportion of lower emission vehicles, reduced parking spaces, and reduced vehicular emissions due to fewer cold engine starts.[1] Meanwhile, if individually owned vehicles continue to dominate the transportation sector or if AVs are deployed within less favorable geographies, AVs may increase transportation-related GHG emissions. Therefore, adoption patterns such as ownership models can dictate whether AVs will increase or decrease overall VMT and the resulting GHG emissions.

Infrastructure Effects. Irrespective of ownership models and other adoption patterns, full-scale adoption of AVs will reduce the footprint of parking since they can double-park themselves in smaller spaces. Whether AVs are in nearly continuous operation via an on-demand business model or whether they travel unoccupied to the outskirts of a city, the need for downtown parking in densely populated areas is diminished, potentially increasing urban density and some of the associated environmental benefits. The dynamics of AV adoption on reduced parking infrastructure has not been sufficiently explored and represents a research area ripe for collaboration.

Changes to infrastructure flows can be dynamic and adaptive in a fully autonomous transportation system, allowing travel demand to dictate the number of freeway lanes moving in each direction.[3] While the congestion-related energy may decrease with such a transition, overall VMT may increase given the lack of disincentives for avoiding traffic.

DISCUSSION

Figure 1 depicts the complex and competing forces on the environmental impact of AVs. With the exception of on-demand mobility and ride-sharing, the forces likely to reduce environmental impact are generally technical in nature. Meanwhile, the forces likely to increase environmental impact are generally related to societal adoption and interaction with AVs. The environmental research community tends to focus on the technical aspects of emerging products,[1−5] as these elements are easier to quantify; however, behavioral adoption patterns have the potential to cancel the benefits of technical advances and are therefore equally as important to address in environmental analyses.

If the environmental research community continues to focus predominantly on the technical aspects of AVs, environmental impact estimates of AVs are likely to be overly optimistic. Research is needed to model the complex and dynamic nature of AVs, integrating technical, behavioral, and transportation design elements.

Recent evidence suggests that the Millennial generation is less car-oriented and more inclined toward on-demand mobility, ride-sharing, and living in dense urban environments. Nevertheless, AV-related travel demand management may be necessary to ensure that overall AV adoption will have favorable outcomes. The environmental research community must better engage the social science and urban planning communities to study this critical, yet relatively unexplored research area of induced changes to travel behavior due to AVs. Modeling behavioral elements may be as simple as constructing "what-if" cornerstone scenarios to define plausible ranges of outcomes or may extend to complex agent-based models to create reasonable prospective scenarios of technology deployment and envision potential designs that will reduce transportation related emissions. The research community is likely to neglect critical details that can change the overall sign of environmental impact on the transportation system if adoption patterns are not adequately taken into account.

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Notes

The authors declare no competing financial interest.

DOI: 10.1021/acs.est.6b02490
Environ. Sci. Technol. 2016, 50, 6119−6121

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DOI: 10.1021/acs.est.6b02490
Environ. Sci. Technol. 2016, 50, 6119−6121