SUSTAINABILITY PROSPECTS FOR AUTONOMOUS VEHICLES
ENVIRONMENTAL, SOCIAL, AND URBAN

George Martin
Sustainability Prospects for Autonomous Vehicles

The Autonomous Vehicle (AV) has been strongly heralded as the most exciting innovation in automobility for decades. Autonomous Vehicles are no longer an innovation of the future (seen only in science fiction) but are now being road-tested for use. And yet while the technical and economic success and possibilities of the AV have been widely debated, there has been a notable lack of discussion around the social, behavioral, and environmental implications. This book is the first to address these issues and to deeply consider the environmental and social sustainability outlook for the AV and how it will impact on communities. Environmental and social sustainability are goals unlike those of technical development (a new tool) and economic development (a new investment). The goal of sustainability is development of societies that live well and equitably within their ecological limits. Is it reasonable and desirable that only technical and economic success comprise the swelling AV parade, or should we be looking at the wider impacts on personal well-being, wider society, and the environment?

The uptake for AVs looks to be lengthy, disjointed, and episodic, in large measure because it faces a range of known and unknown risks. This book assesses the environmental and social sustainability potential for AVs based on their prospective energy use and their impacts on climate change, urban landscapes, public health, mobility inequalities, and individual and social well-being. It examines public attitudes about AV use and its risk of fostering a rebound effect that compromises potential sustainability gains. The book concludes with a discussion of critical issues involved in sustainable AV diffusion.

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To the memory of Peter Freund (1940–2014), collaborator, colleague, friend, and fellow walker.
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The autonomous vehicle (AV) was a challenging subject about which to write a book. It required dense use of the contingent voice (could, would, etc.) as it is an emergent technology – a moving target! Anticipating its sustainability prospects required thorough and timely judgments of new data and analysis on a daily basis. Meeting this challenge was made possible by the talented and efficient bibliographic assistance of Stan Jacobsen, a veteran editor with Nolo Press in Berkeley (and a good neighbor). His digital mining of hundreds of freshly published documents allowed me time to concentrate on writing. The work also was supported in kind through my on-going institutional affiliations: Emeritus Professor, Sociology Department, Montclair State University, Montclair, New Jersey; Visiting Professor, Centre for Environment and Sustainability, University of Surrey, Guildford; and Research Associate, Sociology Department, University of California, Santa Cruz.

The AV is a technology and a business with a laundry list of under-studied environmental and social implications bearing upon an array of weighty realms – climate change, public health, and urban transportation. I crafted its sustainability profile from the multidisciplinary perspective of an urban environmental sociologist. The prime venue for AV development and deployment is the US, and one hotspot is the San Francisco Bay Area (and its Silicon Valley), my home. I also have lived and worked in the UK, and the experience added appreciably to my grasp of the subject. In addition to the US and the UK, I judged seven countries as being most active in AV endeavors – China, France, Germany, Italy, Japan, the Republic of Korea, and Sweden. These nations comprise a group I designated as the AV9 and followed through the book. Several others were referenced in a variety of contexts – Australia, Canada, and the Netherlands – while another dozen or so were occasional sources of material.

It is my hope that readers find something here that pricks their interest and satisfies their concern and curiosity about uncertain changes in daily life that may follow on the heels of an autonomous vehicle deployment, changes of considerable consequence for the sustainability of environments, societies, and cities.
Abbreviations

AEV    Autonomous Electric Vehicle
AICV   Autonomous Internal Combustion Vehicle
APEV   Autonomous Public Electric Vehicle
APTV   Autonomous Public Transit Vehicle
ARSV   Autonomous Ride Share Vehicle
ASEV   Autonomous Shared Electric Vehicle
AV     Autonomous Vehicle
AV9    China, France, Germany, Italy, Japan, ROK, Sweden, UK, US
BEV    Battery Electric Vehicle
BFI    British Film Institute
CBD    Central Business District
CEV    City Electric Vehicle
CO₂    Carbon Dioxide
COPD   Chronic Obstructive Pulmonary Disease
EPA    Environmental Protection Agency (US)
EU     European Union
EV     Electric Vehicle
ft     feet
GDP    Gross Domestic Product
GHG    Greenhouse Gases
GPS    Global Positioning System
ha     hectare
HEV    Hybrid Electric Vehicle
ICE    Internal Combustion Engine
ICV    Internal Combustion Vehicle
kgs    kilograms
km     kilometer
lbs    pounds
LBW    Low Birth Weight
LCA    Life Cycle Assessment
mi     mile
mj     megajoule
mph    miles per hour
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>NGO</td>
<td>Non-Governmental Organization</td>
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<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicle</td>
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<td>PM</td>
<td>Particulate Matter</td>
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<td>PTOD</td>
<td>Public Transit On-Demand</td>
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<td>ROK</td>
<td>Republic of Korea</td>
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<td>ROW</td>
<td>Right of Way</td>
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<tr>
<td>SDSD</td>
<td>Social Development for Sustainable Development (UN)</td>
</tr>
<tr>
<td>SUV</td>
<td>Sport Utility Vehicle</td>
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<tr>
<td>TNC</td>
<td>Transportation Network Company</td>
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<tr>
<td>TOD</td>
<td>Transit Oriented Development</td>
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<tr>
<td>UK</td>
<td>United Kingdom</td>
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<tr>
<td>UN</td>
<td>United Nations</td>
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<tr>
<td>US</td>
<td>United States</td>
</tr>
<tr>
<td>VKT</td>
<td>Vehicle Kilometers Traveled</td>
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<tr>
<td>VMT</td>
<td>Vehicle Miles Traveled</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization (UN)</td>
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<td>WTWA</td>
<td>Well-to-Wheel Assessment</td>
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1 Setting the scene

PROLOGUE: THE AUTONOMOUS VEHICLE TAKES THE STAGE

The back story of the autonomous vehicle depicted in a drama with three acts:

- Act I reveals the backstory. Its opening scene introduces an aging antagonist: The internal combustion vehicle and its boorish and confident entourage led by hyper automobility and including super highways, super congestion, and super-sized vehicles. The second scene shifts to the present day grievances of an emergent protagonist, sustainability, representing a chorus of plaintive campaigning voices about climate change, public health, public transit, mobility equity, and green cities. Scene one of Act II introduces the autonomous vehicle (Av), a talented and hopeful newcomer with potential to resolve the conflict but who must choose between the present benefits offered by hyper automobility or the prospective opportunities afforded by sustainability. In the second scene conflict mounts. The antagonist demands a stay-the-course role for Av that maintains private automobile benefits and avoids uncertainties of change. The protagonist offers a new path with a shared mobility. Act III is in process. Its denouement will favor either the default option for Av – stepping into the internal combustion vehicle format and its personal mobility role – or choosing to premiere an electric format in a new role as a public vehicle.

1.1 Introduction: Transforming automobility’s character and role

Fantastic self-driving automobiles periodically have been imagined for public consumption. A notable example was Isaac Asimov’s *automatobile* in a 1953 short story in *Fantastic Magazine* (Asimov 1969). Today, the autonomous vehicle is moving from a role in a science fiction story to one in a reality show. The uncertainties surrounding this transition are illustrated by the range of its numerous designations, including driverless, self-driving, robotic, and automated. Here, autonomous is the chosen term. Automobiles have featured some bits of automation for a surprisingly long time. The first hydraulic automatic transmission appeared in the 1940 model year of the Cadillac and Oldsmobile cars of General
Motors (Seams 2017). Cruise control was introduced with the 1958 Chrysler Imperial (Varney 2018). In 2003 Toyota offered automatic parallel parking as an option in its Prius (Andreev 2018).

In its essence the AV is a motorized vehicle that can guide itself without hands-on human direction. Given the mass consumption of cars it is understandable that its eminent arrival commands a great deal of attention in news media. An analysis of Google searches found that interest in autonomous vehicles nearly quadrupled between 2015 and 2017 (Claypool 2017). Stimulating this curiosity is popular expectation of major changes in the everyday travel experience, changes that seem to have some promise – at least on their surface (Martin 2018).

The media attention is given a boost by the copious investments of money and time being made in autonomous vehicle development by multinational automotive and digital corporations. One result is frenetic competition to get a foot in the door of the emerging industry so as to have a piece of its future. The introduction of test AVs on public roadways has compelled a growing reach of regulatory oversight by government agencies. Moreover, civic institutions as well as businesses and governments are moving forward with anticipatory adjustments; for example, many universities in the US now factor “the autonomous vehicle thing” into their campus planning (Prevost 2017, B6).

Since Google announced in 2010 that it was beginning development of self-driving cars, a wealth of media attention has created a halo-like effect of positive expectations. Realistic and critical appraisals of possible consequences have been marginalized by the sheer scale of the favorable coverage. However, more balanced commentaries are making their way into the public arena. For example, one journalist used a religious metaphor in dividing AV potential impacts into hellish or heavenly (Chase 2014). Another journalist has used a secular version of the metaphor – utopian or dystopian outcomes (Leslie 2018).

The AV attracts such widespread attention because motorized mobility is a critical and ubiquitous feature of contemporary life. About 1.3 billion vehicles are used widely and regularly throughout the world to carry people and goods for a multitude of purposes. They are highly concentrated in more developed nations (OICA 2017a; UN 2017), and that is where motor vehicle production and use have been used as key indicators of economic development since the first decades of the 20th century. Today, more developed nations have 49 percent of the world’s vehicles with only 13 percent of its population. However, rapidly developing China has overtaken the US to lead in vehicle production and is nearly overtaking it in vehicle stocks.

Generally defined the motor vehicles examined here are mechanized, have a minimum of four wheels, and operate on roadways. This excludes two- and three-wheeled vehicles, farm tractors, etc., but includes vans, buses, and trucks. The most numerous category is the passenger automobile (or car), which represents about three-fourths of the world’s vehicles. All vehicle types are prospects for mobile autonomy, but the personal automobile is the most socially and environmentally consequential, and it is the focus of attention here.
In public discourse the benefits of AVs appear to be sound while the costs are speculative. Literature and online posts, both academic and popular, focus on the technical and business progress of their build-out and on their promise, not their peril. Reviews of writings about autonomous vehicles are in agreement with regard to this bias. Papa and Ferreira (2018) pointed out that a focus on technology makes the autonomous vehicle literature weak on broader impacts. Cavoli et al. (2017) researched the comprehensive Scopus technical database relative to autonomous vehicles and found that 61 percent of references were to engineering and computer sciences, while less than 10 percent cited social and environmental sciences.

Clearly then, the present AV discourse is deficient in addressing its broader impacts. A major reason for this is that a new technology has to be fully deployed before the whole range of its consequences is revealed. However, the course of autonomous vehicle deployment can be anticipated and to some extent predicted. Looking forward is a basis for preventing or ameliorating negative impacts rather than reacting to them down the road. Mobility technologies have major repercussions for environments, societies, and cities, as we have learned in over 100 years of living with the automobile.

Systematic attention to environmental, social, and urban prospects will cross boundaries of the natural and behavioral sciences, in which measures of impacts differ from the technological (a new tool), the regulatory (a new law), and the economic (a new investment) ones. A broadening of academic and public attention to include mobility in all of its facets is critically integral to the sustainability program for humanity: To live well and equitably within Earth’s ecological limits. Currently, motorized mobility is a prominent impediment to this program, making it important to anticipate the AV’s social and environmental ramifications. The assessment of impact here focuses on the opportunities for the autonomous vehicle to improve the wanting sustainability profile of today’s stock of motor vehicles.

As we have learned from the eventual courses taken by many technological innovations, an initial route may prove difficult to abandon or even to alter. A convenient and popular course may turn out to be damaging to environments, societies, and cities. Such path-determining choices create unanticipated liabilities for subsequent generations. Passing on inter-generational environmental burdens was the social encumbrance that brought the concept of sustainable development to the world in the Brundtland Report (WCED 1987).

In the case of automobile technology more developed nations have become dependent on it as a consumer product, casting long shadows over prospects for bequeathing socially and environmentally sustainable mobility to their progeny (Dauvergue 2008). If AVs are fitted to use internal combustion engines (ICE) and fossil fuel it will serve to darken and lengthen these shadows. However, their deployment offers an opportunity to segue to a propulsion system that enhances sustainable automobility – perhaps considerably. The perspective here is that the autonomous vehicle offers the possibility of transforming both the character (internal combustion) and the role (personal use) of the automobile.
A case is made here that an AV deployment’s best sustainability path forward is to play a role in rewriting the legacy of the personal internal combustion vehicle (ICV) rather than accepting it as is. In becoming a vehicle that is used to promote change it could be part of yet another historic stepwise transformation in automobility. According to the US National Traffic Safety Administration’s policy statement concerning automated vehicles (NHTSA 2016, 1): “Motor vehicles and drivers’ relationships with them are likely to change significantly in the next ten to twenty years, perhaps more than they have changed in the last one hundred years.” For such a change to take a sustainable turn autonomous vehicle deployment will have to deal with burdensome historical legacies. The critical analysis fashioned in this book can serve as a signposting for the directions that are available in order to turn legacy burdens into sustainability opportunities.

1.2 Legacy of environmental troubles

A legacy is something that is handed down to us by our predecessors, and here it comprises automobility’s contemporary status quo. It can be continued as is, reformed, or rejected. With regard to the historical development of the automobile, one of its best known figures, Henry Ford, commented on the nature of progress: “The remains of the old must be decently laid away, the path of the new prepared” (Ford 1922). Today, the progress required for environmental sustainability requires the laying away of the internal combustion vehicle. The autonomous vehicle will be deployed in mobility systems dominated by super-sized, greenhouse gas (GHG) emitting, passenger ICVs. The potentials for autonomous vehicles to challenge this dominance are analyzed in Chapter Two.

The internal combustion engine

Carl Benz began the first commercial production of motor vehicles with internal combustion propulsion in 1886 in Mannheim. It competed with two other power sources, steam and electricity. In the US, which became the principal locale of technological development, ICVs were only about one-fifth of sales in 1900 (Orsato and Wells 2007, 996). The competition over propulsion systems ended a few years later, in 1905, when the Ford Motor Company launched the first mass-produced vehicle with an internal combustion engine, the Model T. It rolled off assembly lines in Detroit, as well as in Manchester and cities in continental Europe (Melosi 2004).

The major reason for choosing ICE propulsion was economic – specifically a newfound availability of cheap gasoline and lubricants that was ignited by the gigantic Spindletop oil strike in southeast Texas in 1901. Assembly line mass production and cheap oil lowered the cost of making and using cars and they became widely available for the first time. In 1912 the Model T cost $US 650 ($US 16,000 in purchasing power in 2018 dollars), while competitor electric vehicles sold for about 3 times as much (Matulka 2014). It was produced until 1927, by which time its cost was down to about $US 300 ($US 4,000 in 2017 dollars).
Today’s ICE propulsion is a major obstacle to the environmental sustainability of automobility. Its GHG emissions are a substantial contributor to global climate change. We are entangled in the web of consequences of a path-deciding option chosen more than a hundred years ago (Freund and Martin 2009). An autonomous vehicle deployment has potential either to alter or to follow this path’s direction.

Super-sized vehicles

The development of superhighways (see below) prompted a substantial rise in the number of super-sized sport utility vehicles (SUVs). They are larger descendants of the station wagon in the US, the Kombi in Germany, and the estate car in the UK. In 1990 they represented only 5 percent of US motor vehicle sales; in 2004, 21 percent; in 2016, 30 percent (EPA 2017; WSJ 2017). The growth has been led by their largest models, which grew from 11 percent to 49 percent of SUV sales between 1990 and 2004 (Statista 2017). These vehicles are considerably larger and heavier than other passenger cars. They range between 4,000 and 6,000 lbs in weight, nearly double that of mid-size vehicles and more than double that of small cars (NMEDA 2011). As a result of the shift to larger vehicles, the overall industry vehicle footprint (defined as the area bounded by its tires) increased by 0.6 ft\(^2\) between 2008 and 2016 (EPA 2017).

Superhighways spurred the upsurge in sport utility vehicles by increasing traffic, which in turn posed newly perceived safety threats to drivers. As a result many Americans developed an appetite for the sense of security that larger, higher vehicles offered (Oge 2015, 105). Not just Americans, however. Popular European SUVs include the British Land Rover and the German Audi Q7. Commonly voiced reasons that consumers offer for buying them include the improved road vision provided by their height and the greater crashworthiness afforded by their mass (Davis and Truett 2000). (The additional interior space for goods and passengers is another reason given for buying them.) Sport utility vehicle popularity prods drivers of smaller cars with less roadway vision and vehicle crashworthiness to purchase them.

The upsizing of cars has had a major negative impact on environmental sustainability. Fattening automobiles is a principal reason that average fuel economy has stopped improving in the US – moving more weight against more wind resistance requires more energy and releases more emissions (Hakim 2004). Their greater mass also consumes more natural resources in the vehicle production stage and emits more greenhouse gas emissions throughout its life cycle. From an environmental perspective the SUV can be viewed as a Seriously Unsustainable Vehicle. If autonomous vehicles replicate them they will fall well short of possible environmental sustainability gains.

1.3 Legacy of social troubles

The ascendance of the automobile in post-war Western Europe and North America has left a social legacy highlighted by public health deficits and mobility inequities.