The roles of users in electric, shared and automated mobility transitions

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Abstract

This paper synthesizes insights from 19 peer-reviewed articles published in this Special Issue on the roles of users in shared, electric and automated mobility. While many researchers and stakeholders remain inspired by the potential low costs and societal benefits of these innovations, less is known about the real-world potential for uptake and usage. To better understand the likelihood and impacts of widespread uptake, we explore the perceptions of actual and potential *users*, including drivers, passengers, owners, and members, as well as other stakeholders such as pedestrians, planners, and policymakers. The Special Issue examines a range of cases, including plug-in electric vehicles, car-share and bike-share programs, ride-hailing and automated vehicles. For each innovation, we organize insights on user perceptions of benefits and drawbacks into four categories. Much of the research to date focuses on the first category, private-functional perceptions, mainly total cost of ownership (e.g., $/km), time use and comfort. Our synthesis however spans the other three categories for each innovation: private-symbolic perceptions include the potential for social signaling and communicating identity; societal-functional perceptions include GHG emissions, public safety and noise; and societal-symbolic perceptions include inspiring pro-societal behavior in others, and the potential to combat or reinforce the status quo system of "automobility". Further, our synthesis demonstrates how different theories and methods can be more or less equipped to "see" different perception categories. We also summarize findings regarding the characteristics of early users, as well as practical insights for strategies and policies seeking societally-beneficial outcomes from mass deployment of these innovations.

Keywords: automated vehicles; shared mobility; electric vehicles; car-share; ride-hailing; consumer behavior

Research Highlights

- We synthesize user insights from 19 studies on shared, electric, automated mobility
- User perceptions span private, functional, symbolic and societal dimensions
- Different theoretical frameworks better "see" different user perception categories
- In some cases, characteristics of early users are consistent across innovation types
- User insights can help to anticipate innovations' adoption, usage, and societal impacts

Abbreviations and acronyms

ACES – automated, connected, electric and shared

AV – automated vehicle

BEV – battery electric vehicle

GHG – greenhouse gas

Km – kilometers

MaaS – Mobility as a Service

P2P – peer-to-peer

PEV – plug-in electric vehicle

PHEV – plug-in hybrid electric vehicle

TCO – total cost of ownership

VKT – vehicle km traveled

1. Introduction and background

This article provides a synthesis of insights from the 19 peer-reviewed articles published in this Special Issue, entitled: "The roles of users in low-carbon transport innovations: Electrified, automated and shared mobility." We first provide a brief introduction to the status quo system of transportation ("automobility'), as well as the innovations that could change it, and make the case that users will play a central role in determining the likelihood and societal impacts of widespread uptake of these innovations. The following sections then delve into the Special Issue and the insights that it yields.

The sociological concept of automobility describes the continued, self-reinforcing dominance of privately-owned, petroleum-powered vehicles used primarily by single occupants (Urry, 2004). While our present (automobility-based) transportation systems provide numerous benefits, the negative societal impacts are enormous. Globally, the transportation sector is responsible for almost one-quarter (23%) of total energy-related carbon dioxide equivalent emissions (IPCC, 2014), while road traffic is a major contributor to fatalities and injuries, and in many countries a leading cause of death among young adults (WHO, 2018b). In numerous cities and developing countries, vehicles remain a major source of criteria air contaminants that cause significant health impacts, especially among children and elderly populations (WHO, 2018a). Despite decades of progress for alternative and low-carbon fuels and technologies, and some incremental improvements taken up in the mass market, most countries remain locked-in to petroleum-powered automobility (Melton et al., 2016; Sperling, 2009).

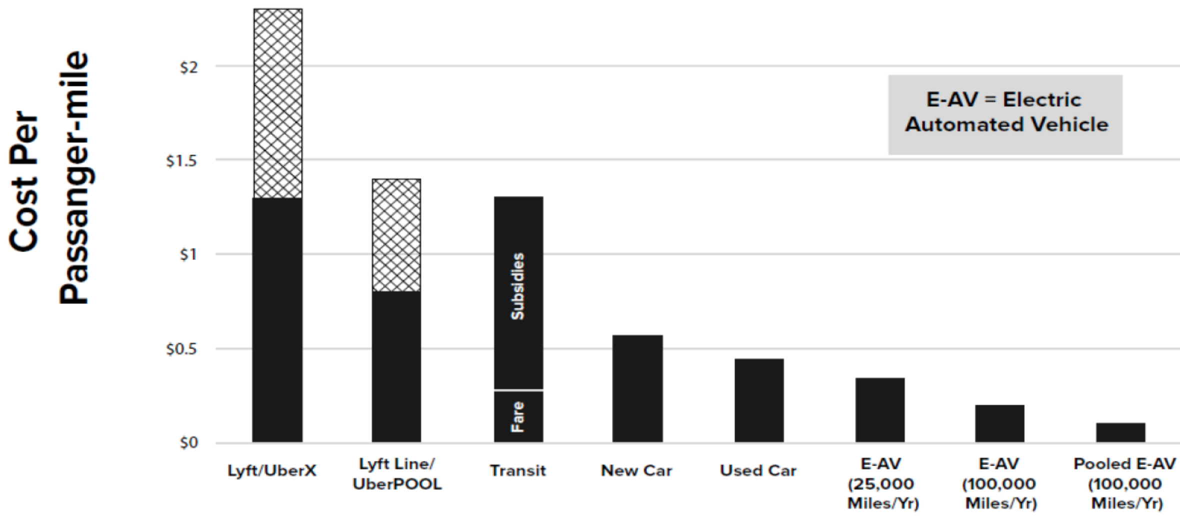
Policymakers and other stakeholders have therefore explored and supported efforts to transition towards more sustainable forms of mobility. Sustainability is typically defined based on a need for deep reductions in greenhouse gas (GHG) emissions and air pollutants, while also being affordable and accessible to the full population – sometimes including goals for the health benefits associated with active travel modes (see Litman's (2017) broad collection of sustainability definitions). In recent years, hope for sustainability has been attached to three particular categories of innovation: electric vehicles, automated vehicles and shared mobility. These have been collectively called the "Three Revolutions" (Sperling, 2018) as well as "New Mobilities" (Sheller and Urry, 2016), among other terms (e.g., automated, connected, electric and shared, or ACES). For this article, we simply refer to them innovations. As we will discuss, a socio-technical transition (that is, involving substantial technical and social changes) to one or some combination of these innovations could indeed play an important role in achievement of sustainable transportation goals – substantially impacting the environment, energy use, and social well-being.

However, there remains considerable uncertainty about the likelihood of widespread deployment, uptake and usage of these innovations, and the ultimate magnitude and direction of societal impacts. Several modeling studies have shown the dramatic potential for positive impacts resulting from a fleet of shared, automated, electric vehicles, which for example could cut GHG emissions (per km) by 87-94% compared to conventional vehicles, even with substantial increases in vehicle travel, average speed and vehicle size (Greenblatt and Saxena, 2015). Similarly, Viegas et al. (2016) use detailed travel data from Lisbon, Portugal to show that such a fleet could meet travelers' requirements with 97% fewer vehicles, 95% less parking space, 37% fewer vehicle km, and much lower operating costs. In another modeling example, Alonso-Mora et al. (2017) find that 98% of New York taxi demand could be met with 15-20% of the vehicles (if shared and automated) with no projected negative service impact.

While such visions and scenarios of shared, electric and automated vehicles are inspiring, they should be viewed as a type of boundary analyses – in these cases as attempts to anticipate the potential extreme positive outcomes of such technological transitions. While such idealized scenarios can provide useful thought experiments, arguably too little of the research in this field has focused on behavioral realism – that is, understanding what users actually want, why, and how that might change and develop over time. Instead, the above modeling studies simply assume that all travelers adopt and use the new technology system as idealized and modelled by the researchers.

Others take a purely financial costs approach, such as total-cost of ownership (TCO) calculations that condense purchase price, depreciation, and ongoing costs (fuel, maintenance, insurance, etc.) into a total cost per passenger km travelled (e.g., Bösch et al., 2018). Sperling et al. (2018a) provide a particularly compelling analysis (Figure 1), where shared, automated, electric vehicles could reduce TCO by over 80% (per km) compared to a conventional new car. While the calculations are informative, some researchers and stakeholders mistakenly interpret these results to mean that consumers will naturally select the option with the lowest financial TCO – seeming to forget that in most countries, the lowest TCO travel modes (transit, active travel, and small, efficient cars) have the lowest market share. Clearly, users are motivated by more than just financial considerations – a realization that is increasingly taking hold among energy modelers as well (McCollum et al., 2017).

Figure 1: Comparative costs of travel by different means in the United States. (Sperling et al., 2018b)



Notes: Cross-hatched bars indicate the range of costs due to length of trip (longer is cheaper per mile) and variation across cities. Numbers based on cost analysis by Aditi Meshram and Daniel Sperling, based on numbers from the Internal Revenue Service, the BLS Consumer Expenditure Survey, APTA's 2016 Public Transportation Fact Book, and unpublished sources

To avoid undue optimism, we must also consider the potential negative societal impacts of such innovations. Wadud et al. (2016) provide a particularly useful analysis of boundary conditions for automated vehicles (including scenarios with sharing and electrification), finding that calculations of energy use and GHG emissions impacts could range from half to double present day emissions, depending on consumer uptake and usage of the technology. Milakis et al. (2017) provide a broader, three-order framework to organize qualitative thinking and estimates of automation impacts, broken down as: i) day-to-day usage impacts (travel costs and choices), ii) impacts to long-term decisions (vehicle ownership, sharing, residence choice), and iii) overall societal impacts (energy, environment, equity and health). Sperling et al. (2018a) simplify the possibilities into two extremes for future transportation systems. The "Heaven" scenario improves safety, accessibility and equity among travelers, who forgo private ownership, and willingly subscribe to a system of shared, automated, electric vehicles that slash energy use and GHG emissions. In stark contrast, the "Hell" scenario exploits automation to further entrench private vehicle ownership and increased vehicle use (including "empty" miles or "deadheading", when the AV drives with no humans), exacerbating suburban sprawl and fossil fuel usage and further diminishing public transit and active travel modes.

To understand which of these scenarios are more likely, we believe that we must better understand the users. Many questions remain unanswered, for example: how many consumers would buy electric vehicles and/or automated vehicles? What level of automation would they prefer? How many would give up vehicle ownership? Who is willing to share rides with strangers, and under what conditions? How will all these decisions then impact housing choices, traffic patterns, and societal expectations for travel and transport systems? And importantly, what practices and policies can support the most societally beneficial outcomes for mass deployment of such innovations? The user-focused research published in this Special Issue (as well as elsewhere) can start to provide answers to these questions, which in turn can help us to inform policymakers, planners and other stakeholders how to positively support such transitions.

The next section provides more details of the Special Issue, and Section 3 provides terminology and frameworks to help organize insights from the diverse set of studies. Section 4 then organizes insights regarding user perceptions of electric, shared, and automated mobility (providing more specific definitions of case technologies). Section 5 summarizes insights on the characteristics of actual and potential adopters of these innovations. Section 6 attempts to tease out practical insights from this synthesis, and Section 7 concludes.

2. The Special Issue: The roles of users in transitions to low-carbon innovations

The goal of the Special Issue is to acknowledge and explore the complexity of users in the cases of transitions to shared, automated and electric mobility – including the individual innovations and combinations thereof. The intention is to build insights beyond the idealized positive (or negative) potential of these innovations, and beyond a sole focus on financial implications. We employ the term "user" in a broad sense, including adopters such as households and fleets (companies), and direct users such as drivers, operators and passengers. As we will explain, more comprehensive theoretical perspectives (e.g., socio-technical systems) extend the term user to encompass a broader set of actors, including intermediaries, citizen groups, and policymakers.

The full realm of possible innovation cases and combinations is interminable, where Table 1 presents a subset of more likely cases (given our present understanding). Bolding and asterisks indicate the cases that are covered in this Special Issue. We invited manuscripts to include all transportation sub-sectors, including: light, medium- and heavy-duty vehicles; passenger, fleets and freight; land, marine and air; as well as active-travel and public transit. As is common for literature in this area, the submissions and realized collection focuses entirely on land-based passenger travel, and mostly on motorized travel. The exceptions are two studies that focus on fleets (rather than individual or household users), and two that focus on active travel (bike-share programs). None of the 117 submitted abstracts addressed marine or aviation applications. Of the four abstracts submitted relating to freight, one was invited for submission but later declined to submit a manuscript. Aviation, marine and freight are all commonly understudied sub-sectors for low-carbon transitions.

Table 1: The variety of "cases" of shared, automated or electric mobility (coverage of Special Issue noted in bold and double asterisk)

	Passenger	Fleets and freight
Electric mobility	**Light-duty vehicles****	**Light-duty vehicles****
	Transit vehicles	Medium-duty vehicles
	Bicycles**	Heavy-duty vehicles
	Scooters	Train
	Marine	Marine
	Aviation	Aviation
Shared mobility	**Car-share (2-way, station-based)****	N/A
	Car-share (1-way, floating)**	
	Car-share (peer-to-peer)**	
	Ride-hailing (single user)**	
	Ride-hailing (pooled)**	
	Bike-share**	
	Scooter-share	
	Transit integration	
	Mobility-as-a-Service (MaaS)	
Automated vehicles	**Light-duty vehicles****	Light-duty vehicles
	Transit	Medium-duty vehicles
	Aviation	Heavy-duty vehicles
		Marine
		Trains
		Aviation

The goal of this paper is to synthesize insights from the 19 articles published in this Special Issue to generate a broad perspective. As noted, our initial call resulted in 117 abstract submissions, which the guest co-editors (and authors of this article) independently rated according to novelty, quality of methods, and breadth of coverage. Of the 26 author teams that were invited to submit manuscripts, 19 have followed through and successfully worked through the peer-review process (Table 2). As will be discussed, the papers vary considerably in focus, theoretical framework, and methods. To summarize the coverage of this Special Issue:

- In terms of innovation case: 5 studies focus on electric vehicles (but another 7 include electrification); 8 studies focus on shared mobility (addressed by another 3); and 3 focus on automation (also addressed by another 3).

- Geographically, the studies focus on North America (5), the United Kingdom (2), continental Western Europe (7), and Nordic countries (4). The only exception is a study of China (1). As is common in this literature, we miss other continents and especially developing countries.
- In terms of methods: 7 studies collected data using large quantitative surveys, 7 used interviews (or focus groups), 3 used literature review or case studies, while more unique approaches included simulations with a transportation and land-use model, as well as analyses of social media "tweets" and travel data. As will be noted in section 3.2, surveys and interviews varied in their target population (e.g., early users, potential users, or general population).

Table 2: Summary of the 19 studies published in this Special Issue

Focus	Authors	Specific focus (type, sector)	Theory/framework	Region	Target population	Methods (data collection, analysis)
Electric	(Daramy-Williams et al., this issue)	Passenger PEVs	Multiple adopter-focused approaches	International	Owners and trial participants	Systematic literature review, content analysis
	(Anfinsen et al., this issue)	Passenger PEVs	Domestication theory	Norway	EV owners	Semi-structured interviews (n=30), coding and grounded theory
	(Kanger et al., this issue)	Passenger PEVs	Societal embedding	USA and Netherlands	N/A	Case studies, literature review
	(Skippon and Chappell, this issue)	Fleet PEVs	Thematic analysis of motives	UK	"Early adopter" car and van fleets	Multiple semi-structured interviews with 4 fleets, thematic analysis
	(Valdez et al., this issue)	Passenger and fleet PEVs	Sensemaking, imaginaries	Milton Keynes, UK	Users, business adopters, policymakers	Document analysis, organizational interviews (n=13), thematic analysis
Shared	(Burghard and Dütschke, this issue)	Car-share (and PEVs)	Diffusion of Innovations	Germany	Car share users, EV users	Survey (n=947), bivariate statistics
	(Coulombel et al., this issue)	Ride-hailing	Rebound effects	Paris, France	Travelers	Simulation with integration transportation land-use model
	(Sprei et al., this issue)	Car-share (free-floating), and PEVs	Time use	Europe and USA cities	Car-share members	Car-share travel data, plus Google maps estimates
	(Dowlatabadi et al., this issue)	Car-share (one-way and two-way)	Demographics and motivations	Vancouver, Canada	Car-share members	Member survey (n = 4010), statistical comparisons, regression
	(Hess and Schubert, this issue)	Electric-cargo bike sharing	Demographics and functional considerations	Switzerland	Members and non-members	Mixed-methods survey, multilevel regression, qualitative coding
	(Yin et al., this issue)	Dockless bike-share	Value formation and destruction	China	Bike share members	Social media analysis (twitter, over 8000 tweets), thematic coding

	(Uteng et al., this issue)	Car-share (cooperative, peer-to-peer)	Mobility biographies and social practice theory	Oslo, Norway	Car-share members	Web-based survey of two car-sharing groups (n=2841), multivariate analysis
	(Sopjani et al., this issue)	Light electric vehicle sharing	Users in transitions, user roles, user motivation and involvement	Sweden	Members and non-users	Vehicle telematics (n=178 registered users), interviews and surveys (n=51), thematic coding
Automated	(Pudāne et al., this issue)	Driverless vehicles (level 5)	Time-geography, activity-travel behavior	Netherlands	Daily commuters (car/transit)	Focus groups (n = 27), thematic analysis
	(Blyth, this issue)	Automated mobility	Phronesis, techno-politics, socio-technical systems	Finland	“Intermediary” stakeholders	Semi-structured interviews (n=31), thematic coding
	(Hardman et al., this issue)	Automated vehicles	Diffusion of Innovations, attitude theories	USA	Electric vehicle owners	Survey (n = 2715), statistical analysis, cluster analysis
Multiple	(Stoiber et al., this issue)	Shared automated vehicles	Choice analysis	Switzerland	Households	Web-based survey (n = 683), choice experiment, regression analysis
	(Spurlock et al., this issue)	Automated, ride-hailing, car sharing, PEVs	Motivations, demographics, personality	San Francisco Bay Area, USA	Households	Web-based survey (n = 1,046), descriptive and regression analysis
	(Whittle et al., this issue)	Automated, shared, electric and reduced mobility	Social psychology, multi-level perspective	International	N/A	Literature review, expert interview (n = 11), thematic analysis

3. Organizing insights: Innovations, users, perceptions and frameworks

To help us organize insights from this Special Issue, in this section we outline the complexity of concepts concerning innovations, users, perceptions and theoretical framework.

3.1 Innovations with (potential) societal impacts

In marketing literature, new technologies relating to electric, automated and shared mobility can be referred to as "innovations", meaning technologies or practices that are perceived as new by individuals or relevant stakeholders (Rogers, 2003). Others differentiate innovations by the degree of novelty, using terms such as "disruptive technologies" (Christensen, 1997; Christensen et al., 2015), "really new products" (Hoeffler, 2003; Urban et al., 1996), among others, each having different meanings and relating to different theories. Our case innovations can also be described as "architectural innovations" in that widespread uptake could involve substantial changes not just to the consumer base, but also to industry structure (Abernathy and Clark, 1985).

Our present interest extends further to the broader societal impacts of the innovations. As noted, some sociologists look at conventional vehicles as part of "automobility" (Urry, 2004), "a system of interlocking social and technical practices that has reconfigured civil society" (Gartman, 2004). Large-scale uptake of automated, shared, or electric vehicles could weaken, maintain or strengthen different aspects of this system (Sovacool and Axsen, 2018), leading to impacts on other sectors and society more broadly. In this sense, the case technologies might be considered as "transformative" innovations (Geels, 2012; Sparrow and Howard, 2017; Weber and Rohracher, 2012), or at least they hold that potential.

For convenience in this paper, we'll simply use the general term "innovation", but note it as short-hand for "innovations with transformative potential" – meaning to include the broad range of possible impacts to consumer base, producers, and society more generally.

3.2 Types of "users"

To many researchers, the "user" can simply be defined as the people that physically use the innovation in question. Yet, even this starting point is complicated. For transportation services, does this include the owner, driver, member, operator and/or passenger? For organizations, does it include employees, sponsors, members, or others? And which of these is the "consumer" for consumer research?

A further complexity is that there can be considerable heterogeneity within any one of these user categories. For the perhaps more clear-cut case of private purchase of light-duty passenger vehicles, research shows considerable differences between the earliest buyers of a new innovation, and potential later buyers. In the case of plug-in electric vehicles, for example, where adoption makes up less than 1% of new vehicles sales, these first adopters are found to have particularly high awareness and valuation of the technology, different preferences for design, and unique demographic and lifestyle characteristics compared to "mainstream" conventional new vehicle buyers (Axsen et al., 2016). The difference between early adopter and potential early mainstream users is far from trivial – understanding the mainstream potential for a new product is considered by some to be the greatest challenge for market research (Urban et al., 1996). For more radical innovations in particular, mainstream consumers may have low awareness, high uncertainty and non-existent or unstable preferences (Bettman et al., 1998; Hoeffler, 2003). There is thus typically an inherent trade-off between studying the first adopters, who have actual experience but unique characteristics, and studying potential mainstream buyers, who are the more relevant target market, but may have unstable or unknown preferences.

In other research traditions, notably those following a socio-technical systems perspective, the notion of users becomes even more comprehensive (Oudshoom and Pinch, 2003). For example, Kivimaa and Martiskainen (2018) and Martiskainen (2017) identify "user intermediaries" as actors who influence other users or the selection environment. Expanding further, Schot et al. (2016) argue for five user categories:

1. User-producers create innovations as new technical and organizational solutions;
2. User-intermediaries shape the needs and desires of users as well as products, infrastructures, and regulatory frameworks;
3. User-citizens engage in politics of lobbying for a particular innovation;
4. User-legitimators shape the values and worldview of niche actors (those in the initially small groups that develop and test out innovations); and
5. User-consumers appropriate products and services and thus producing meaning and purpose, and testing new systems.

Much of the research summarized in this Special Issue focuses on the "user-consumer", whom we will more simply refer to as "consumers". We split empirical insights between those coming from actual adopters (buyers, owners, drivers, passengers or members) compared to insights coming from mainstream consumers that have not adopted, but are in the potential target market. We will address the other user categories as they come up, be they stakeholders, intermediaries, policymakers or non-users.

3.3 User perceptions of the innovation: Functional, symbolic and societal attributes

As noted, decisions and actions by consumers and stakeholders are typically not just driven by financial considerations, or even only perceptions of private or functional benefits. To facilitate a more comprehensive perspective, our synthesis draws from Axsen and Kurani's (2012) two-by-two typology of innovation attributes, or in this case, users' perceptions of these attributes (Table 3). The horizontal dimension distinguishes functional from symbolic perceptions, while the vertical separates private from societal perceptions. While represented as four discrete categories, the dimensions can also be thought of as continuums, with potential for overlap. This framework has been applied to consumer research on electric vehicles (Axsen et al., 2018; Axsen et al., 2017; Axsen et al., 2013; Matthews et al., 2017), green electricity programs (Noppers et al., 2014), as well as societal framing of passenger vehicles and electric, shared and automated mobility (Sovacool and Axsen, 2018).

Table 3: Conceptualization of the benefits of new mobility options (illustrative examples)

	Functional	**Symbolic**
Private	The functional benefit to the consumer, e.g.: • Save money • Convenience (e.g., time savings) • Safer for driver	The symbolic benefits to the consumer, e.g.: • Expression of self-identity (e.g., social status, gender) • Attain group membership
Societal	The functional benefit to society, e.g.: • Reduce air pollution, GHG emissions • Reduce traffic congestion • Safer for non-drivers	The symbolic benefit to society, e.g.: • Inspire other consumers • Support technology development • Send message to industry or policymakers • Challenge incumbent technology (lock-in)

Source: Adapted from Axsen and Kurani (2012)

The private-functional category addresses what the innovation does for the consumer, including financial costs or savings, performance, convenience and reliability. As noted, this category is often the major (or sole) focus of research on transportation innovations – especially the purchase price or total cost of ownership (TCO). More broadly, the category is meant to encompass all of the functional attributes that a vehicle, or a form of mobility, provides for the consumer, such as its ability to travel over distances (km driven or travelled) in a manner that is affordable, convenient, or safe for the consumer (owner, driver or passenger).

Next, the private-symbolic category acknowledges that innovations such as vehicles or new forms of mobility can express self-identity, convey personal status, or signal membership in a particular group (Heffner et al., 2007; Shove and Warde, 2002; Steg, 2005; Steg et al., 2001). An innovation can be novel in how it conveys a "different social meaning" than conventional technologies and practices (Hirschman, 1981). This could include an expression of gender, class, or other identity category. Admittedly, there are other "non-functional" perceptions that could deserve their own category, notably emotions such as pleasure from driving, or feeling good or safe from purchasing a certain vehicle or signing up for a mobility program. In this synthesis, we consider emotional attributes as being non-functional, and group them in the symbolic category – noting that future work could better explore if and how emotions ought to be best represented in this framework.

The bottom two categories of Table 3 cover societal attributes or benefits. The societal-functional category includes the innovation's direct societal impacts, including environmental impacts and energy usage, land-use impacts, and safety impacts to society more broadly (Brown, 2001; Green, 1992). Lastly, the societal-symbolic category relates to the innovation's ability to inspire other users and stakeholders (e.g., drivers, companies and governments) to engage in activities that in turn impact society more broadly, supporting further technological advancement and connectivity, or challenging conventional vehicle ownership models – or even challenging the system of automobility (Sovacool and Axsen, 2018). This category can include perceptions of contributing to formal social movements (Marwell et al., 1988), as well as less formal messaging or social negotiation of norms and values.

As this framework is based on the perceptions of users, it can be difficult to categorize a given empirical observation, and perceptions can vary widely across different users. Further, the attribute of an innovation might fit into multiple categories of perception. For example, improved fuel economy for a vehicle can be seen as saving money (private-functional), sending a symbolic message about frugality (private-symbolic), helping to reduce GHG emissions (societal-functional), and/or helping to inspire a social movement towards higher valuation or greater availability of fuel economy technologies (societal-symbolic). We are concerned with which of these potential interpretations is true for the users we study in a given context. Taken together, the framework in Table 3 is also meant to be dynamic, where perceived attributes can change over time with experience, new policy, and societal negotiation (Calef and Goble, 2007; Gjoen and Hard, 2002; Hess, 2007; Smith, 2005). As discussed next, we find that different theoretical frameworks provide different levels of insight into the categories of (and dynamics within) this two-by-two framework.

3.4. Organizing conceptual frameworks

Given the complexity of innovations, users, and perceptions, it should be no surprise that there are such a wide variety of theories and conceptual frameworks that guide user-focused research. Sovacool et al. (2018) summarize a number of ways to organize theories used in energy social science, including focus on individual decisions (agency) versus social system (structure), as well as behavioral assumptions (as examples, assumptions that users are driven by rational self-interest, attitudes, values, lifestyle, habits or social norms). The research included in this Special Issue is guided by a variety of theories, where such diversity may be necessary in order to “see” the many potential social dimensions of these innovations and their users.

Table 4 groups most of the frameworks used by studies in this Special Issue, organized according to one dimension or continuum: specific versus comprehensive. While admittedly crude, the dimension serves the present purpose of organizing theories according to the breadth of users, perceptions, and dynamics that are included in the research process, for example, the technique of data collection, analysis or modelling. The more specific frameworks focus on one type of user (typically adopters or consumers more generally), and in some cases only one or two specific perceptions categories (e.g., time use or cost), holding static the other aspects of the system. In other words, more specific frameworks are narrower in coverage, which as we later show and describe in Figure 2, can also be visually represented as the area covered or “seen” by the framework. In contrast, the more comprehensive frameworks by design aim to understand a broader set of users, stakeholders, or other dimensions. Comprehensive frameworks thus can typically “see” more types of attributes – especially in the symbolic categories. Moving down the list in Table 4, the frameworks include more elements of focus, and more dynamics in those elements.

As we will see in this synthesis, there seems to be an inevitable tradeoff in depth (or high resolution) of insight compared to breadth of insights. That is, a more specific framework on consumer valuation of time savings can provide a wealth of insight on that topic, but misses other important consumer perceptions. On the other hand, a more comprehensive framework can shed insights on a broader set of perception categories, but perhaps provides a more simplistic understanding a particular category, such as valuation of time savings. Such differences in strengths and weaknesses would argue for potential complementarity in insights offered by research guided by these different frameworks. Sartori (1970) found this to be the case in politics and political science scholarship: as one moved up from specific to comprehensive frameworks, scope, purpose and concepts change to become more complex but also more difficult to teach, operationalize and analyze.

Perhaps the most specific framework of all would be a total-cost of ownership (TCO) perspective, as depicted in Figure 1 (above). In this Special Issue, the more specific frameworks similarly focus on time use as one attribute, either alone (Sprei et al., this issue), in conjunction with changing expectations of time use (Pudāne et al., this issue), or, more dynamically, along with rebound effects in how time and cost savings can impact other travel decisions (Coulombel et al., this issue). Slightly more broad, several studies utilize aspects of Roger's (2003) Diffusion of Innovations framework to study the multiple characteristics of early adopters and potential mainstream consumers, including innovativeness and demographic details such as education and income – as applied to car sharing (Burghard and Dütschke, this issue) and automated vehicles (Hardman et al., this issue). Other studies also focus on consumers, but consider an even broader set of motivating factors that can shape their perceptions and behavior such as culture, values and attitudes (e.g., Dowlatabadi et al., this issue; Skippon and Chappell, this issue).

Table 4: Organizing conceptual frames according to specific versus comprehensive focus

Focus	Framework (examples in this issue)	Focus on			
		Characteristics of the consumer	**Characteristics of the innovation**	**Broader socio-technical system**	**Processes**
More specific (and/or static)	Time-use (activity, time-geography) (Pudāne et al., this issue; Sprei et al., this issue)	Adopters' time use, activities, expectations	Time savings (or delay)	Tends to be static, though Pudāne et al. look at changing expectations of time-use (dynamic)	Travel choices
	Biography and life or family stages (Todd et al., this issue; Uteng et al., this issue)	Life history, life events, number of children, size of household (demographics)	Static	Static	Adoption
	Rebound effects (Coulombel et al., this issue)	Elasticity of response (reaction to change in price/time)	Cost savings, time savings	Can be dynamic, e.g. system response to price/time change	Adoption, travel choices
	Diffusion of Innovations (Burghard and Dütschke, this issue; Hardman et al., this issue)	Innovativeness, demographics such as income and education	Relative advantage, compatibility, trialability, observability, complexity,	Static	Adoption or use
	Motivations (attitudes, values, lifestyle, demographics) (Dowlatabadi et al., this issue; Hess and Schubert, this issue; Skippon and Chappell, this issue)	Positive perceptions, lifestyle, high income, high education, size of family, family stages	Static	Static	Adoption or use
	Social influence, negotiation of value (Daramy-Williams et al., this issue; Yin et al., this issue)	State of awareness, learning, identity formation	Static	Dynamic among social network, but usually misses other social groups and stakeholders	Adoption, social influence, value creation
	Domestication (Anfinsen et al., this issue)	Gender roles	Potentially shaped by users and user perspective	Dynamic: negotiation of social norms (norms, lifestyle, driving practices, identity)	Negotiation of meaning
	User-based innovation and negotiation (Sopjani et al., this issue; Valdez et al., this issue)	Heterogeneous, creative, dynamic	Innovation process shaped by "imagining" of users, or learning of users		Learning, sense-making, imagining
	Techno-politics (Blyth, this issue)	Largely imagined by stakeholders	Shaped by stakeholder demands, goals, negotiation	Dynamic: negotiation of meaning among stakeholders	Power struggle
More comprehensive (and/or dynamic)	Societal embedding (Kanger et al., this issue)	N/A	Shaped by broader socio-technical system	Dynamic: co-evolution of actors, technologies, institutions, culture, policy	Embedding, co-evolution of technology and society

The more comprehensive perspectives consider a wider range of actors, including consumers, non-users and various stakeholders. These frameworks are also more dynamic in that they consider the interactions, negotiations or power-struggles that lead to development and valuation of innovations. As one example, Anfinsen et al. (this issue) apply domestication theory to explore how electric vehicles sustain or challenge gender roles. Blyth (this issue) considers power dynamics among stakeholders regarding visioning and planning for automated vehicles in Finland. Kanger et al. (this issue) take perhaps the broadest view, exploring how the history of conventional vehicles has been "socially-embedded" in social practices, expectations, norms and culture – indicating that a substantial uptake of electric mobility would have to interact with, and perhaps challenge or reinforce, such embedding. These latter frameworks are consistent with literature on "socio-technical transitions", which explores the interactions between technical and social systems when new technologies emerge (Geels, 2010).

To illustrate the potential complementarity of these different conceptual frameworks, Figure 2 maps some of them onto the two-by-two perception framework from Table 3. We do not include all frameworks in Table 4, in part because they would not easily fit. We rather depict several illustrative categories, where the "socio-technical systems" category includes the bottom four frameworks in Table 1. (We also add TCO due to its mention earlier in this paper, even though it is not included in this Special Issue.) The position of each oval is meant to convey the likely coverage of insights using that framework, while the size indicates the overall breadth of insight. To start, being singularly focused, purely cost-based and time-use frameworks have narrow coverage. The rational actor framework from neoclassical economics in theory can cover anything that matters to consumers, though in practice tends to focus on private and functional attributes. Diffusion of Innovations and other motivation-based frameworks tend to uncover more of the symbolic and societal attributes. Social (interpersonal) influence frameworks focus even more on symbolic attributes, including communication and negotiation of meaning. Finally, approaches using a socio-technical systems perspective (e.g., societal embedding or techno-politics) are the most broad, and also the most likely to uncover symbolic-societal attributes, which relates to social movements and negotiation of social meaning – something that has proven difficult to elicit directly from the consumer. At the same time, these broad frameworks can shed less light on specific details, such as consumer perceptions and valuations of particular attributes. Many of these patterns of insight from various frameworks are demonstrated next in our summary of user perceptions from the studies in the Special Issue.

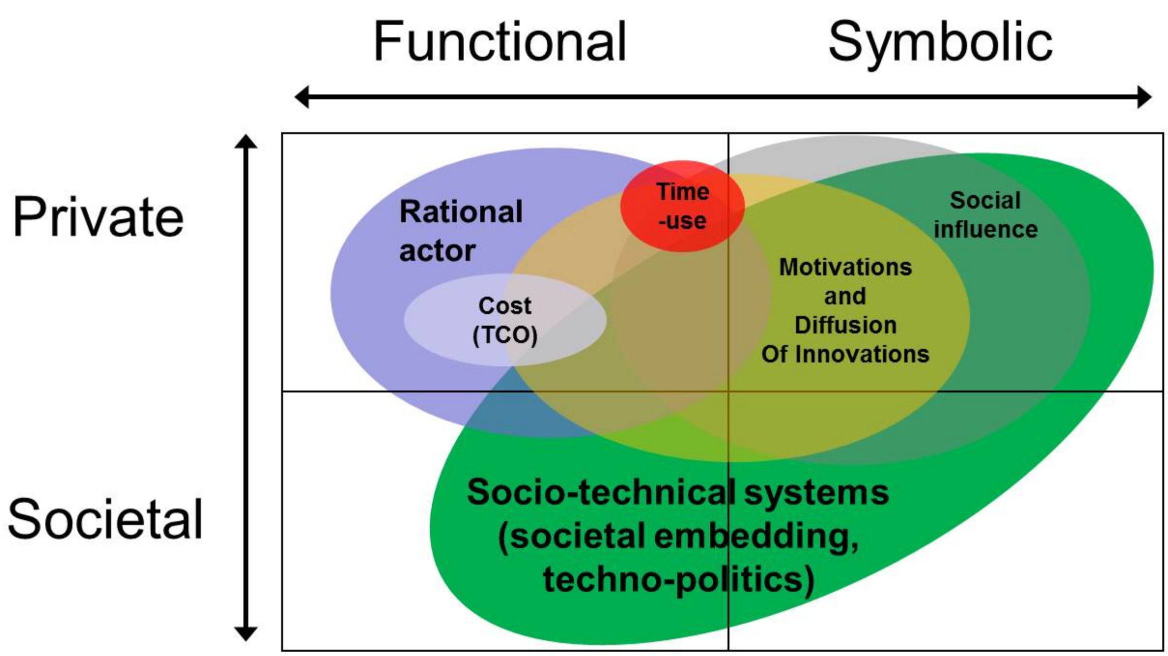


Figure 2: Illustration of how different theoretical perspectives tend to produce insights for different perceptions and attributes of innovations. (TCO = total cost of ownership)

4. User perceptions of the three innovations

This section uses the two-by-two framework to organize insights from our Special Issue regarding user perceptions of each of the three main innovations categories: electric vehicles, sharing and automation. As noted, we will see evidence of how different theoretical frameworks tend to yield insights into particular attribute categories, largely aligning with Figure 2.

4.1 Perceptions of electric mobility

Of the three innovations, electric mobility is perhaps the most frequently studied over the past few decades, having experienced several cycles of societal hype (and disappointment) (Geels, 2012; Melton et al., 2016). We use the term plug-in electric vehicles (PEV) to cover both battery electric vehicles (BEVs) that are powered only by electric motors, as well as plug-in hybrid electric vehicles (PHEVs) that can be plugged-in or powered by an internal-combustion engine (typically gasoline or diesel). These terms can apply to all vehicle types, though are most frequently applied to light-duty passenger vehicles. PEVs are often mentioned as holding potential to play a strong role in decarbonizing the transportation sector (IEA, 2017; Williams et al., 2012). Where most PEV consumer research focuses on diffusion and adoption (including four studies in this Special Issue), Daramy-Williams et al. (this issue) provide a unique perspective by reviewing studies on the usage of PEVs by adopters and trial participants.

We summarize insights from these user studies on electric mobility using the two-by-two table in Table 5. As will also be seen with the subsequent two innovations, the positive (+), negative (-) and uncertain (+/-) perceptions span all four categories. To start, the private-functional attributes include the usual suspects: cost savings (being beneficial or uncertain), practicality, electric driving range (being adequate or limited), and charging access and timing (being adequate, limited or slow). Limited availability of PEV makes and models is noted by one study (Skippon and Chappell, this issue), a supply-side issue that is increasingly gaining attention in the literature (e.g., Matthews et al., 2017; Wolinetz and Axsen, 2017; Zarazua de Rubens et al., 2018). Studies also address common perceptions of societal-functional impacts, including reduced air pollution and GHG emissions (either positive or uncertain), as well as the less studied, and seemingly varied, perceptions of noise pollution impact (Daramy-Williams et al., this issue)

Table 5: User perceptions of electric mobility ("+" is positive, "-" is a negative, and "+/-" is mixed.

	Functional	Symbolic
Private	(+) practicality [b,h] (+) cost savings [e,h] (+) adequate range [c] (+) adequate charging [c,h] (+) ease of use [g] (+/-) unsure cost savings [cd] (-) limited range [a,d,f,i] (-) slow charging [d,f] (-) lack of charging access [d,f,i] (-) lack of availability of BEV/PHEV models [d,i] (-) cost of maintenance, replacing batteries [d]	(+) belonging [a] (+) stimulate social interactions [f] (+) adventure/discovery [a,c] (+) potential for gaming [a] (+) avoiding guilt [a] (+) innovativeness [a,c,i] (+) social signaling [b,d,g] (+) green identity [b,c,d,h] (+) symbolizing pro-environmental credentials [d,g,h] (+/-) gender identity [b] (+/-) unclear signal of corporate social responsibility [d] (-) embarrassment or mockery [a]
Societal	(+) reduced air pollution [c,e] (+) reduced GHG emissions [c,e] (+/-) reduced noise [a] (+/-) uncertain lifecycle GHG impacts [d] (-) charging contributes to peak load [d]	(+) demonstrating pro-environmental credentials [d] (+) shaping international standards [c] (+/-) challenging or entrenching automobility [c]

[a] (Daramy-Williams et al., this issue)
[b] (Anfinsen et al., this issue)
[c] (Kanger et al., this issue)
[d] (Skippon and Chappell, this issue)
[e] (Spurlock et al., this issue)
[f] (Whittle et al., this issue)
[g] (Burghard and Dütschke, this issue)
[h] (Sopjani et al., this issue)
[i] (Valdez et al., this issue)

Although symbolic aspects of PEVs were considered understudied a decade ago, since the work of Heffner et al. (2007) and others there has been more attention to this category of perceptions for alternative-fuel vehicles. On the private-symbolic side, Anfinsen et al. (this issue) bring specific attention to gender identity, finding that electric mobility can appeal to men and women alike, connecting with or even avoiding different gendered narratives. Another study finds that electric mobility can connect with and signal aspects of identity such as being green or innovative, or with being adventurous (e.g., Skippon and Chappell, this issue). In some cases, electric vehicles also seem to stimulate social interactions and belongingness (e.g., Daramy-Williams et al., this issue). Kanger et al. (this issue) note that some people adopt PEVs for a sense of thrill and adventure, that is, doing something new that is fun despite possible challenges, such as limited range and access to charging. The only clearly negative private-symbolic perception was the potential for embarrassment or mockery, in cases where the PEV is seen to conflict with a set of norms or social practices seen as important to the user (Daramy-Williams et al., this issue).

As noted, societal-symbolic PEV perceptions have proven difficult to uncover in more directly adopter-focused research (Axsen et al., 2017; Axsen et al., 2013). Skippon and Chappell (this issue) provide one example, where some fleet operators see the potential for PEV adoption to demonstrate "pro-environmental credentials" that could both benefit the adopter (private benefit) and inspire others to follow (societal benefit). Kanger et al. (this issue) provide a "social embedding" perspective (one of the socio-technical frameworks more likely to observe societal-symbolic perceptions), where PEV adoption could be seen as helping to shape international standards, and to be either challenging or entrenching automobility.

While most of these studies focus on the market for light-duty passenger PEVs, we note the novelty of Skippon and Chappell's study of fleet operators in the UK – a focus that is quite rare, aside from a few cases (e.g., Boutueil, 2016; Nesbitt and Sperling, 2001). It is often hypothesized that fleet operators are likely to be more "rational" than passenger vehicles, driven by a focus on costs and perhaps other practical performance features – in short, limited to private-functional perceptions. However, Skippon and Chappell find that even among fleet operators, PEVs can be valued for symbolic attributes, including social signaling, communicating green identity, and symbolizing or demonstrating green credentials.

4.2 Perceptions of shared mobility

Shared mobility proved to be the most popular topic in our Special Issue – addressed by about half of the published studies. This may be in part explained by the large diversity of shared mobility innovations or cases, where various groups are attempting to establish a consistent terminology (e.g., SAE J3163). For this article, we split the broad concept of shared mobility between the sharing of vehicles (e.g., car-sharing or bike-sharing), and the sharing of rides (e.g., ride-hailing). Car-sharing (or a "car club" in the UK and Europe) involves the adopter paying an hourly (and/or mileage-based) rate to pick up a vehicle, use it, and return it somewhere (Cervero et al., 2007). Car-share programs vary in their requirements for parking (station-based or free-floating), and for trip structure (one-way or two-way)—Dowlatabadi et al. (this issue) compare users of one-way and two-way programs. An emerging version, peer-to-peer (P2P) car-sharing, allows individuals to rent out their personal vehicles (studied by Sopjani et al., this issue). The net societal impacts of car sharing programs are uncertain, though it is often considered as a pathway to reduce vehicle ownership (Baptista et al., 2014; Firnkorn and Müller, 2011). Similar principles apply to bike-sharing and scooter-sharing programs, with the added variation that some such programs are "dockless", with no particular parking or storage space at all (studied by Yin et al., this issue)

The second broad category of shared mobility is ride-hailing, typically defined as an app-based platform that allows users to hail a ride from a (at least semi-) professional driver—with Uber and Lyft being the most well-known service providers (Shaheen, 2018). It is common and arguably important to distinguish between: i) individual-use ride-hailing, that is, alone or with friends/acquaintances, and ii) "pooled" ride-hailing where a trip is shared with one or more strangers (aside from the driver) and generally require multiple pick-up and drop-off points. As with car-sharing, the environmental impacts of ride-hailing are uncertain, though there is some evidence that increased uptake has led to increases in vehicle travel (Schaller, 2017), and decreases in transit and taxi usage (Clewlow and Mishra, 2017; Shaheen, 2018). For this reason, Sperling (2018) argues that widespread use of pooling is essential to ensure that ride-hailing helps to reduce overall vehicle travel (even if passenger travel increases), and thus contribute to sustainable transportation goals.

Our Special Issue studies yield insights into a wide variety of user perceptions of shared mobility cases, where Table 6 combines insights in car-share, bike-share and ride-hailing. More generally, Stoiber et al. (this issue) find that almost two-thirds of Swiss travelers in their sample would prefer a shared version of an automated vehicle, rather than a privately owned one. Among the other studies, perceived private-functional benefits include lower or more predictable costs, simplicity, compatibility with lifestyle, the allowance of more travel options, and the avoidance of risks associated with vehicle ownership. There are both positive and negative perceptions relating to time use and personal safety – likely varying by user context (e.g., congestion levels, and management and reputation of shared mobility programs in the region). Negative private-functional perceptions include inconvenience, difficult access to the mode, and the potential for "contaminated" vehicles and damaged equipment from other users.

Table 6: User perceptions of shared mobility ("+" is positive, "-" is a negative, and "+/-" is mixed.

	Functional	Symbolic
Private	(+) easy, compatible with life [a,b,g] (+) reduced travel cost [d,e,h,j] (+) predictable costs [f] (+) reduced travel time [d] (+) allows more travel [d] (+) simplicity [h] (+) practicality [g] (+) avoids ownership risks [h] (+) attractive to AV users [k] (+) convenience [e,j] (+/-) safety [b,c,g] (+/-) impact on travel time [i] (-) damaged equipment [c] (-) inconvenient [b,h] (-) difficult to access [b,h] (-) contaminated by others [h] (-) too costly [b] (-) too much effort [b] (-) inconsistent demand/irregular need [b]	(+) social norms [a] (+) identity compatibility [a,g] (+) expression of extraversion [f] (+) expression of openness [f] (+) expression of agreeableness [f] (+) innovativeness [e,h] (+) expression of environmental friendliness [g] (+) more efficient lifestyle [j] (+/-) firm reputation [c] (+/-) feelings/emotion [c] (+/-) requires social trust [g] (-) loss of independence [a,h] (-) lost status as car owner [h]
Societal	(+) lower environmental impact [b,e,f,h] (+) lower energy use [h] (-) illegal usage [c] (-) vandalism/appropriation [c] (-) rebound effect (GHGs, congestion, noise, air pollution) [d]	(+/-) challenges to automobility and "lock-in" [g],[h] (+/-) requires development of institutional trust [g]

[a] (Burghard and Dütschke, this issue)
[b] (Hess and Schubert, this issue)
[c] (Yin et al., this issue)
[d] (Coulombel et al., this issue)
[e] (Sopjani et al., this issue)
[f] (Spurlock et al., this issue)
[g] (Uteng et al., this issue)
[h] (Whittle et al., this issue)
[i] (Sprei et al., this issue)
[j] (Dowlatabadi et al., this issue)
[k] (Stoiber et al., this issue)

In the private-symbolic category, use of shared mobility can be seen as positively affecting social norms, identity and the expression of innovativeness. Uniquely, Spurlock et al. (this issue) find that adoption of and interest in shared mobility can be associated with the expression of several personality traits: extraversion, openness and agreeableness. Uteng et al.

(this issue) add that car-sharing can require the development of trust and dependence on other users – a trust that has been largely avoided (and perhaps eroded) by automobility to date.

Perceptions of societal-functional attributes are particularly contentious. With the potential for reductions in cost, time use, and environmental and energy impacts comes the potential for rebound effects—that is, an increase in usage that cancels out a portion of the expected societal benefits. Coulombel et al. (this issue) in particular explore rebounds for ride-hailing, where reductions in travel costs and travel times can lead to increased societal impacts through the subsequent switching away from transit, driving longer distances and relocating of residences further from the urban center. Their simulation of travel and land-use behavior find that such effects can cancel out two-thirds (or more) of GHG reduction benefits and more than half of societal benefits in aggregate. As another, more specific example of societal drawbacks, Yin et al. (this issue) explore perceptions of the illegal usage and vandalism associated with dockless bike-share programs.

Two studies provide insight into societal-symbolic perceptions of shared mobility. Whittle et al. (this issue) assert that if such programs reduce vehicle ownership, they can represent a challenge to the system of automobility more generally (and associated lock-in), including all the entrenched interests and patterns relating to vehicle ownership. Uteng et al. (this issue) note that whether car-sharing entrenches automobility or not depends on the particular type of program: some members become "serious" sharers, doing it consistently, whereas others are more experimental and "playful," only doing it occasionally.

4.3 Perceptions of automated vehicles

We use the term automated vehicles (AVs), while acknowledging that the terms autonomous and self-driving vehicles are often used synonymously (Sperling et al., 2018b).

There are a number of frameworks used to define different levels of automation, and terms tend to be used inconsistently across AV studies. We use the 5-level SAE system (J3016), where Levels 1 and 2 include automated features that are already available in the market (e.g., adaptive cruise control, self-parking, and lane changes). Level 3 automation can fully drive itself, though the driver needs to be ready to take over on short notice (typically keeping their hands on the steering wheel). Levels 4 and 5 require no driver attention – a Level 4 AV cannot drive in all possible conditions (e.g., extreme weather, traffic emergency), while a Level 5 AV can. We refer to Level 4 and 5 as AVs ("fully automated"), which are not currently available for sale, though many companies (automakers and others) have announced plans to introduce full AVs to the market in coming years (ranging from as early as 2020 to 2040 or beyond). As noted in Section 1, widespread AV uptake could profoundly impact society in a number of ways (Milakis et al., 2017), with a wide range of positive and negative scenarios for GHG emissions and energy impacts (Wadud et al., 2016).

Table 7 summarizes a breadth of user perceptions of AVs. Private-functional benefits include improved safety and reliability, as well as accessibility for those that are unable to drive conventional vehicles (e.g., people with disabilities). Pudāne et al. (this issue) focus on the potential positive attributes of time savings, time that can then be spent on other activities – along with the potential drawback of increasing societal expectations of how to spend that free time (e.g., working, interacting with others), which we've listed as both a private-functional and societal-symbolic perception. Other private-functional drawbacks include higher purchase price (Hardman et al., this issue), potential for motion sickness (Pudāne et al., this issue), and threats to privacy and hacking of the vehicle (Blyth, this issue; Whittle et al., this issue).

Table 7: User perceptions of automated vehicles ("+" is positive, "-" is a negative, and "+/-" is mixed.

	Functional	Symbolic
Private	(+) safety [a,c,e] (+) comfort [a,b] (+) save time [b] (+) time for other activities [a,b] (+) reliable [b] (+) accessibility (for those unable to drive) [c,e] (-) purchase price [a] (-) increased expectations for time use [b] (-) motion sickness [b] (-) privacy [c,e] (-) threats from hackers [e] (-) reduced safety for Level 3 [e]	(+/-) connected to gender [d] (+/-) trust in technology [e] (-) isolation [b] (-) increased expectations for time use [b] (-) vulnerability [c] (-) technophobia [a] (-) anxiety [e] (-) loss of control [e]
Societal	(+) environmental benefits [a,e] (+) energy efficiency [a] (+) improved social equity [e] (+/-) uncertain environmental benefit [e] (+/-) uncertain safety for non-users [e] (-) reduced safety for non-drivers [c] (-) restricting social space [c] (-) increased alcoholism, intoxication and public drunkenness [c]	(+/-) power struggle [c] (+/-) driver agency/liberation [c]

[a] (Hardman et al., this issue)
[b] (Pudāne et al., this issue)
[c] (Blyth, this issue)
[d] (Spurlock et al., this issue)
[e] (Whittle et al., this issue)

As with the uncertainty in societal impacts noted in the academic literature, two studies identify a mix of positive societal-functional perceptions of environmental and energy impacts from AVs (Hardman et al., this issue), as well as uncertainty in these same benefits (Whittle et al., this issue). Blyth (this issue) brings attention to perceptions of other negative impacts, including the potential reductions in safety or restrictions in social space for non-users of AVs. Blyth also warns that AVs could promote and condone alcoholism (in the case region of Finland) since there would be fewer restrictions on "heavy intoxication". Relatedly, Blyth explains how the combination of automation and alcoholism could change perceptions of safety, providing the example of a woman that no longer feels safe using a driverless public transit vehicle because there would be no human driver to protect her from inebriated and heckling riders.

AVs inevitably have symbolic attributes as well, where studies in our Special Issue tend to uncover negative perceptions. AVs have been found to resonate more with men than woman, suggesting an important limitation in how the technology connects with gender identity (Spurlock et al., this issue), as has been explored in other studies (Hohenberger et al., 2016). The widespread usage of AVs could also stimulate or exacerbate feelings of isolation (Pudāne et al., this issue) and vulnerability (Blyth, this issue), as well as loss of control and fear of technology (Whittle et al., this issue).

Blyth's (this issue) study of techno-politics provides a particularly broad and dynamic perspective on AVs, including societal-symbolic perceptions. The author finds that AV technology emphasizes the way that drivers (and indeed, society as a whole) may lose some of their agency and power. For instance, algorithms embedded in AVs could restrict where those vehicles drive or park (perhaps for safety or other reasons). Further, the processes of negotiation regarding the different potential goals and visions for AVs could itself represent and reinforce a power struggle among different stakeholders and intermediaries in society – where those in power are able to shape AV development to support their own priorities.

5. Characteristics of present and potential future adopters

In addition to uncovering different categories of user perceptions (summarized above), a number of studies provide insight into the characteristics of those who have adopted the case innovations (sometimes called "early adopters" or "innovators"), or those who might adopt in the future (the potential early mainstream). Eight of the 19 articles in this Special Issue utilize an adopter-focused perspective, and thus can provide insights into adopter characteristics for their case innovation – or all three innovations in the case of Spurlock et al. (this issue). Table 8 compiles these insights into four innovation categories (separating car- and bike-share from ride-hailing), according to demographic characteristics, travel patterns, and motivations (identity, personality, and beliefs).

Table 8: Characteristics of early adopters and potential mainstream consumers

	PEV	Car-share (and bike-share)	Ride-hailing (single and pooled)	Automated vehicle
Demographics				
Income	(+) higher [c]	(+) lower [e,f] (-) higher [c,f]	(+) higher [c]	(+) higher [a,c]
Age	(+) middle age [c]	(+) younger [f,g] (+) middle age [d,f,g]	(+) younger [c]	(+) middle age [a] (+) younger [c]
Gender	(+) male [c]	(+) male [c,d,g] (+) female [e]		(+) male [a,c]
Education	(+) higher [c]			
Other details		(+) has young child [d]		
Travel patterns (context)	(+) longer commutes [c] (-) lack of home charging [h]	(+) walkable residence [c] (+) cyclist (bike-share share only) [g]	(+) walkable residence (pooled only) [c]	(+) people unable to drive [e]
Motivations				
Identity, personality	(+) agreeableness [c] (-) conscientious [c] (+) pro-enviro. identity [c]	(+) opennness [c] (-) risk-loving [c] (+) pro-enviro. [e] (+) innovators [e]	(+) extraversion [c] (+) agreeableness (pooled only) [c]	(-) technophobes [a] (-) low trust in tech. [e]
Priorities, beliefs	(+) enviro. impacts [c] (+) low costs [c]	(+) cost savings [e,f] (+) environmental impacts [f] (+) convenient[f] (+) higher social trust (peer-to-peer only [d] (-) lack of safety (bike-share only) [g]	(+) predictable costs [c] (+) enviro. impacts [c]	

[a] (Hardman et al., this issue)
[b] (Burghard and Dütschke, this issue)
[c] (Spurlock et al., this issue)
[d] (Uteng et al., this issue)
[e] (Whittle et al., this issue)
[f] (Dowlatabadi et al., this issue)
[g] (Hess and Schubert, this issue)
[h] (Skippon and Chappell, this issue)

Across studies, interest (a term we'll use to refer to both adoption and potential adoption) in the innovation tends to be associated with higher household income, aside from two cases of car-share programs (Dowlatabadi et al., this issue; Whittle et al., this issue). Interest is also associated with being younger or middle age (all four innovations), and typically with being male (aside from ride-hailing). Higher education was found to be related to PEV ownership. Uteng et al., (this issue) consider the life stage of users, finding that having young children was positively associated with membership in a conventional car-sharing program.

Findings concerning user travel patterns (and household context) were more varied – and seemingly unique to the innovation type. PEV interest is positively associated with longer commutes (Spurlock et al., this issue) and negatively associated with lack of home charging (Skippon and Chappell, this issue). Both car-sharing and pooled ride-hailing adoption are positively associated with living in a walkable neighborhood (Spurlock et al., this issue). Interest in AVs is thought to be higher for those that are unable to drive (young, elderly, people with disabilities) (Whittle et al., this issue).

We also observe several patterns in motivations that are associated with user interest in the innovations. Interest in both electric and shared mobility is associated with having a pro-environmental identity, and belief that the innovation will positively impact the environment. PEV and car-share interest is associated with perceptions of cost savings, while ride-hailing interest is associated with predictable costs. Interest in car-sharing is associated with innovativeness (Whittle et al., this issue), while interest in AVs is negatively associated with "technophobia" (Hardman et al., this issue) and low trust in technology (Whittle et al., this issue). Research exploring personality factors is particularly unique, finding that PEV and pooled ride-hailing interest is associated with agreeableness, both single and pooled ride-hailing are associated with extraversion, while interest in a car-share program is associated with openness.

In short, there is evidence that some adopter characteristics carry over multiple innovations (e.g., income, age, gender, environmental orientation), while many are relevant only for particular innovations (e.g., life stage, travel patterns and personality types).

6. Reaching "Heaven" rather than "Hell": Recommendations to stimulate adoption and improve sustainability impacts

In the Introduction we noted that while boundary analyses have helped to determine the best and worst case scenarios (what Sperling calls "Heaven" and "Hell") for the societal impacts of these innovations, user research is needed to better anticipate which scenarios are more likely, and how technological, policy, or social conditions can shape such transitions. In other words: whether electrified, shared, and automated mobility is sustainable, or not, is indeterminate, and users will play important roles in shaping these transitions (and if transitions occur at all).

Here we start to extract practical insights from our synthesis – supporting opportunities for societal benefit while avoiding or mitigating the negative impacts or barriers. Such insights could inform the strategies of policymakers, planners and stakeholders seeking to realize sustainable transportation goals, including deep GHG reductions, improved social equity and access, and improved health. This discussion is meant to be illustrative and speculative, drawing from evidence where available, but more intended as generating hypotheses and directions for future research to examine. In particular, we are not presently able to authoritatively evaluate or comprehensively compare the potential magnitude of impact these different solutions might offer. In short, we call them insights, but hold back from making firm recommendations – as we do not have the evidence to comment on their relative effectiveness in achieving different sustainability goals.

As summarized in Table 9, we distinguish between two broad goals: i) adoption, or stimulating uptake of the innovation, such as purchase, membership or usage, and ii) sustainability, or assuring societally beneficial impacts from that uptake and usage. Following our two-by-two framework, the two private categories of perceptions are most likely to relate to adoption potential – as examples, innovations that offer cost savings (private-functional benefit) or improved social status (private-symbolic benefit) will likely enjoy higher market share. The two societal categories relate to broader sustainability goals, including GHG emissions reduction (societal-functional) or inspiring a social movement towards higher valuation of climate abatement (societal-symbolic). While this summary is not meant to be exhaustive, we include a variety of insights that were brought up in this Special Issue and our synthesis of it.

Table 9: Illustrative insights to improve the adoption and sustainability of electric, shared and automated mobility

Challenge	Potential solution
i) Adoption: How to increase uptake	
Private- functional strategies	
Costs	● Electrification lowers fuel and operating costs. ● Automation can avoid driver costs (e.g., for ride-hailing and public transit). ● Shared mobility can avoid ownership costs. ● Shared mobility can help lower operating costs for transit (e.g., Mobility as a Service, or MaaS). ● Government subsidies (or taxation) can improve the relative prices of these innovations.
Convenience	● Automation can make PEV charging more convenient. ● Automation can make car-share pick-up/drop-off more convenient. ● PEVs offered in car-share program can better match diversity of user needs. ● Innovations matched with transit (MaaS) can address "last-mile" or "first mile".
Personal safety	● Strict safety standards and testing can improve safety for all innovations ● Public engagement can improve perceptions of safety. ● If the high safety potential of automation is realized, it could improve safety of ride-hailing (or other modes).
Private-symbolic strategies	
Identity needs	● More pro-environmental users could be reached by improving certainty of environmental benefits (e.g., pair "green electricity" with electrification). ● Marketing and framing should move beyond just "pro-environmental framing" to include pro-technology, practicality and other motives. ● Offer wide-variety of innovation options (e.g., styles, models, membership packages) to reach wide variety of user groups.
Social learning	● Induce social learning and interpersonal engagement to help "normalize" new modes, while also supporting learning of functional details (e.g., how to use car-share, ride-hailing or PEVs).
Personal trust	●For pooling, develop credible systems for safety ratings and user profiles

Challenge	Potential solution
ii) Sustainability: How to improve social impacts	
Societal- functional strategies	
GHG emissions	● Carbon pricing (and subsidies) improve the relative price of using low-carbon versions of these innovations. ● Regulations can reduce the carbon intensity of fuels, e.g., a low-carbon fuel standard, or renewable portfolio standard. ● Vehicle regulations improve the fuel efficiency of vehicles, or development and availability of PEVs, e.g., a zero-emissions vehicle mandate.
Congestion/VKT	● Carbon pricing, congestion pricing or vehicle km travelled (vkt) charges can mitigate rebound effects.
Safety/damage	● Careful design and piloting of new shared mobility systems can avoid or minimize societal damage (e.g., vandalism, dangerous use).
Societal- symbolic strategies	
Social resistance	● Explicitly framing innovation deployment and supportive regulation as part of sustainability and climate goals can inspire changing social values. ● Careful engagement and demonstration can increase public buy-in to these initiatives.
Automobility	● Increase mobility options to challenge automobility, including the norm of private vehicle ownership. ● Complement active travel and public transit, rather than compete with it.

The private-functional category includes the challenges of cost, convenience and personal safety. We encompass several technology-focused solutions, in particular by pointing out the potential for the combining of these innovations in ways that exploit the different benefits and drawbacks of each. As a partial list:

- For ride-hailing, using AVs can avoid the costs and potential safety concerns of a human driver.
- For car-share programs, using AVs could avoid the inconvenience of finding and accessing the vehicle.
- Including PEVs in the car-share fleet can allows users to match the potentially limited range vehicle to their purposes for a particular trip (rather than needing a PEV designed for every type of trip).
- Inclusion of PEVs in shared vehicle fleets could also provide users with more exposure and experience with PEVs – perhaps developing more positive valuation or at least awareness.
- For PEVs, adding automation could possibly eradicate concerns about range limitations or charging inconvenience (if the car easily finds charging for itself), while the potential for AV eco-driving and downsizing could lessen the need for a large battery.
- As depicted by Sperling et al. (2018b) in Figure 1 (above), combinations of all three innovations could potentially slash the cost of driving per passenger-km.

Relatedly, the concept of Mobility-as-a-Service (MaaS) provides one avenue to efficiently maximize the private-functional benefits of these innovations, mainly shared mobility (but perhaps automation and/or electrification as well), by integrating them with existing public transit services (Matyas and Kamargianni, 2018). For example, with a single payment, transit riders could use a car-share, bike-share or ride-hailing system to get to and from a commuter rail system – avoiding the "first/last mile" problem. A further observation that applies to most private-functional perception categories is that the continued offering of and experimentation with a wide variety of mobility options would improve the likelihood of finding a service that aligns with the private-functional needs of different segments of the population.

Improving private-symbolic perceptions can also induce adoption of these innovations. We consider the challenges of identity, social learning and trust. For shared and electric mobility, the potential motives for pro-environmental and technology-oriented (or innovative) symbolism could be supported through better framing and marketing of the innovations around these objectives. Consumer uncertainties about environmental impacts in particular could be overcome with an intentional framing of a shared, automated and/or electric vehicle program – with evaluation and credible promotion of the societal benefits, perhaps including the intentional pairing of PEVs with renewable electricity (Axsen and Kurani, 2013). Though, it should be noted that not all adopters are motivated by the stereotypical frames of environment or technology (Axsen et al., 2018; Noel et al., 2019). To that end, offering a diversity of innovation options and cases, such as different vehicle makes and models, and different usage options, could better connect with a wider variety of lifestyles and identities. Further, efforts to increase the uptake of these innovations ought to consider the importance of social influence, belongingness, and other symbolic values, where one meta-analysis find that such processes are consistently positive in supporting interest in alternative fuel vehicles (Pettifor et al., 2017). Programs could more strategically facilitate social interactions surrounding these innovations, including learning and sharing of meaning and value (Axsen and Kurani, 2014). Relatedly, efforts can be made to build trust in the technology, especially in regards to sharing rides (pooling) with strangers – for example through credible communication of safety ratings and user profiles.

While these strategies may help to induce the widespread uptake of these innovations, many stakeholders want such uptake to be consistent with various sustainability goals. In fact, the uncertainty of societal-functional impacts (notably GHG emissions) from these innovations is a major motivation for this Special Issue. The bottom half of Table 9 considers these challenges and potential solutions. Arguably, effective policy could be the most powerful mechanism to drive pro-societal outcomes. Many economists would argue that a large enough carbon tax would guide consumer and firm behavior in a low-carbon direction – supporting whatever combination of these (or other) innovations and practices that consumers prefer as climate mitigation actions (Hanley et al., 2013). Such carbon pricing could also avoid or mitigate rebound effects, that is, increased driving that could result from lower driving costs (and faster trips) provided by shared, automated and/or electric mobility. There is already evidence for such rebounds from PEVs (Graham-Rowe et al., 2012; Langbroek et al., 2018), and there is large potential for similar rebounds for ride-hailing (Coulombel et al., this issue) and automated vehicles (Childress et al., 2015; Wadud et al., 2016). But if the full social costs of energy use (be it from fossil fuels, biofuels, electricity generation or other) are internalized via taxation, rebound effects should not be a large concern. Similarly, congestion pricing or vehicle travel based taxes or insurance could serve to reduce or eliminate rebound effects (Winston and Mannering, 2014).

In reality, strong carbon or road pricing policies tend to be politically unpopular (Rhodes et al., 2017). Societal-functional benefits could also be realized by market-oriented regulations (with firm requirements but tradeable credits), such as a zero-emissions vehicle mandate (Greene et al., 2014; Sykes and Axsen, 2017) or low-carbon fuel standard (Lepitzki and Axsen, 2018; Yeh et al., 2009). Though policymakers and planners must beware that any policy (regulations, incentive or otherwise) that promotes efficient (but motorized) travel and does not address the actual usage of vehicles is likely to have a rebound effect that could substantially mitigate, if not cancel out, the societal benefits of improved efficiency or uptake of low-carbon fuels.

The final category, societal-symbolic impacts, considers aspects beyond the direct air pollution and carbon emissions or impacts of the innovations. This category describes how the impacts of these innovations might be constrained or shaped by the current system of automobility (the dominance of private, single-occupancy, fossil-fuel powered cars), or alternatively how these innovations might inspire other, broader societal benefits. Arguably, any policymaker that seeks to support shared, automated and/or electric vehicles for societal benefits ought to explicitly frame such plans around those goals. For example, Brown (2001) discusses how the framing of PEV policy can influence whether consumers (and society more broadly) prioritize private or societal benefits in their own decision-making—in effect inducing a cultural shift. Further, some believe that these innovations, particularly shared mobility options, can be used to challenge the system of automobility itself (Bergman et al., 2017), that is, providing more options and alternatives to the present "monoculture" of private cars in many countries. Bike-sharing in particular is hoped to inspire more travelers to take up active-travel, though the evidence is lacking (Hosford et al., 2018). Worryingly, car-sharing could have a negative societal effect, by promoting private vehicle use among those that otherwise would use transit or active travel (Kent and Dowling, 2013). Similarly, as noted, electric and automated vehicles can be seen as further entrenching aspects of automobility. On this last issue, it is unclear if transitions to any of these innovations should seek to work with automobility, to incrementally change it, or to radically oppose it (Sovacool and Axsen, 2018). Attempts to do all at once would be not only confusing but counterproductive, and this indeterminacy of adoption and sustainability attributes reminds us about the necessity of comprehensive policy goals and instruments that are clear in their objectives and consistent in their approaches.

7. Conclusions

While we see our synthesis as offering a number of potentially useful insights, we must acknowledge the limitations of the Special Issue from which it is drawn. While the Special Issue had extensive coverage of studies of North America and Western Europe, there is only one study on China and none from the rest of the world (other Asian countries, Eastern Europe, Africa or South America). This resulted even when we (the guest co-editors) tried to recruit a broader representation, and carefully considered abstracts submitted from "non-typical" countries. The Special Issue also has a strong focus on road-based passenger travel, with two studies addressing fleets, and no studies focused on freight, or any type of rail, aviation, or marine travel. Further, the Special Issue is not meant to be representative of all user studies on this topic, as it is not itself a systematic review or random sample (though the Issue includes three literature reviews, one being a systematic review). We do not see our synthesis and conclusions as necessarily definitive about the present and future of these innovations – but we do believe we generate a number of insights that can inform a variety of stakeholders, and perhaps guide future research efforts including further exploration, hypothesis testing and modeling.

Overall, we believe our synthesis makes a strong case for the complexity of users, and the importance of understanding them to anticipate (and potentially guide) the uptake, usage and societal impacts of shared, electric, and automated forms of mobility. Our Introduction summarized several of the more optimistic modeling exercises on the GHG and congestion impacts of a fleet of automated, shared, electric vehicles (e.g., Greenblatt and Saxena, 2015;

Viegas et al., 2016), which we referred to as "boundary" analyses. While such exercises are useful, more research is needed to fill the substantial gaps in our understanding of the current and potential users of such systems: who will buy electric and automated vehicles? Who will enroll in shared mobility programs? How can suppliers, policymakers and other stakeholders make such innovations appeal to the broader market? How will these innovations be used or even mis-used? Will these innovations challenge or entrench vehicle ownership and other norms of automobility? While we still cannot provide definitive answers to these questions, this Special Issue (and our synthesis of it) provides a number of insights that contributes to the growing literature focused on the user.

First, we demonstrate the complexity of user perceptions and behavior for each of these innovations using a two-by-two typology that considers private, societal, functional and symbolic dimensions. Notably, results from the Special Issue mapped onto all four categories for each innovation. A key lesson is that users are not only concerned about costs, or the other "usual suspects" of time-savings and comfort. While these private-functional perceptions are indeed important to many users, our synthesis finds added intricacy even within this category, such as user concerns about reliability, privacy threats and concerns for personal safety. There were also ample examples of perceptions in the other three categories, including a range of positive, negative and uncertain perceptions of societal-functional impacts, such as ultimate impacts on GHG emissions, air pollution, noise, and safety. There were an array of symbolic perceptions, relating to identity, belongingness, changing societal expectations, trust and anxiety. Perhaps most broad in scope (and most difficult to study), observed societal-symbolic perceptions include associating the innovation with a social movement, as well as challenging or reinforcing the system of automobility, including incumbent regimes (Sovacool and Axsen, 2018; Urry, 2004). In short, this synthesis demonstrates the breadth and complexity of user perceptions that need to be appreciated and studied in order to understand how these innovations might become embedded in society, and to improve the behavioral realism of strategies and policies seeking to support deployment of these innovations. These insights also suggest that users can behave and change in ways difficult to quantify or predict, which holds important implications for modeling exercises and how such results are interpreted, and how future transport pathways are imagined.

Second, while our coverage of theoretical frameworks is by no means exhaustive, the Special Issue includes a broad range of frameworks that we crudely organize from more specific to more comprehensive. As depicted in Figure 2 (Section 3.4), each theoretical framework is better equipped to observe different aspects of the user. On the one hand, a time-use or willingness-to-pay study might provide high-resolution (perhaps quantifiable) insights into one aspect of private-functional perceptions. At the other extreme, a socio-technical systems or transition approach will consider the broader social system, with numerous types of users (including stakeholders and non-users), a broad range of perceptions, and representation of dynamic processes such as the formation and negotiation of those perceptions and meanings amidst changes in systems, infrastructure and social structure. For this particular synthesis, we found that insights were required from this full breadth of perspectives in order to populate the two-by-two tables for each innovation. Such a finding makes a strong case for complementarity among multiple theoretical perspectives, and supports the notion that multi-disciplinarity and inter-disciplinarity are perhaps needed to better understand and anticipate the roles of users in transitions to complex innovations.

Third, and relatedly, the diversity of insights across studies makes the case for complementarity in methods. Qualitative interviews and case studies can better explore new insights, adding the potential observation of depth and unanticipated dynamics. Quantitative surveys can assess and quantify how a broad set of perceptions resonate with a representative sample. Other sources of data (e.g., tweets and driving data) can provide additional technical and social perspectives on the deployment, uptake and usage of the innovation. Models can parameterize insights from all these methods, and simulate the logical consequence of further assumptions in technological and social dynamics. Finally, literature reviews (including narrative, systematic and "synthesis" work like this paper) can assemble insights from a diverse base of evidence. In short, these methods provide different strengths and weaknesses and in some cases can build upon one another in the types of insights they yield. For example, we demonstrate the analytical power of combining confirmatory, hypothesis testing research with more exploratory, hypothesis generating research. Such complementarity thus makes the case for the use of multiple methods in a single research program, including mixed-method approaches that integrate quantitative and qualitative approaches.

Returning to practical insights for these three case innovations, we find that the attributes of these innovations, and user perceptions of those attributes, are not predetermined. There is a specificity and contextually to their adoption dynamics as well as sustainability attributes. Much as we see with the "boundary" analyses that provide extreme positive and negative societal outcomes (Sperling et al., 2018a; Wadud et al., 2016), we find that user perceptions can cover both the positive and negative potential for each innovation. In Section 6 (and Table 9) we generate a list of practical insights from this synthesis, divided between strategies that might increase adoption of the innovations (via improvements in private-functional and private-symbolic attributes and perceptions), and those that can improve the sustainability impacts of such uptake and usage (via improved societal-functional and societal-symbolic attributes and perceptions). While not meant to be definitive, these insights can be used to guide further research efforts and pilot efforts – in part to improve understanding of which strategies are most likely to be effective (and potentially efficient and equitable) in achieving which sustainability goals.

A particularly worrying theme is that any combination of these innovations that lowers travel costs (all else constant) will surely induce a rebound effect that increases overall travel, perhaps inducing more vehicle travel (if displacing public transit and active travel modes), and even vehicle ownership. Such changes would only reinforce automobility and many of its negative societal impacts (even if one sustainability goal, say reduced GHG emissions, becomes more achievable). On the other hand, it is possible that these innovations could be integrated in more ideal ways to indeed achieve a broader set of sustainability goals, including improved livability, equity of access, diversity of choice and economic resilience. As examples, development, uptake and experience of these innovations could help to support and promote shifts in consumer values, perhaps away from private vehicle ownership, towards more pooling, and even a more flexible Mobility-as-a-Service (MaaS) transportation system that better integrates active travel and public transit with shared mobility other modes.

The most likely futures are probably somewhere in the middle of the "Heaven and Hell" extremes. Future policy interventions, or major breakthroughs such as rapid reductions in cost or improvements in performance, could tilt the balance towards one of these poles. In any case, it does seem that the indeterminacy of adoption and societal impacts justifies the development and implementation of strong, coordinated policy mixes implemented by government. Carbon pricing and market-oriented regulations in particular could play a strong role in assuring the more societally-beneficial outcomes are incentivized and realized. In short, there is no evidence that a pro-societal, Heaven-like scenarios will result from transitions to these innovations – though the odds of achieving at least some sustainability goals, notably climate abatement, can certainly be increased through the implementation of stringent and comprehensive policy.

Ultimately, these three innovations, individually or in some combination, could help to transform transportation sectors – substantially impacting the environment, energy use, and social well-being. However, there remains colossal uncertainty about the likelihood of widespread uptake, and direction and magnitude of societal impacts. Our findings strongly suggest that we take a more nuanced, careful stance on whether uptake and usage of these innovations lead to more sustainable and desirable mobility futures, or lead instead to only entrench and deepen the extent of current mobility problems. We are only beginning to understand the roles of users in these potential impacts from shared, electric, and automated mobility.

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