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Can shared autonomous vehicles become a sustainable mode of mobility in the future? Insights from a practice-based study of urban dwellers in Norway

Tom Erik Julsrud, Steffen Kallbekken and Marianne Aasen

CICERO Center for International Climate Research, Oslo, Norway

ABSTRACT

Shared autonomous vehicles (SAVs) represent a rapidly growing technological field with features believed to potentially support the development of more sustainable mobility systems in city regions. To succeed as a sustainable mode of mobility, however, many current car owners must replace their private vehicles with SAVs. Based on a survey of citizens in Oslo and 12 other Norwegian cities, as well as in-depth interviews with citizens living in a location where SAV is tested, this study explores the relationships between people's everyday mobility patterns and their future interest in using SAVs. The study located six different mobility practices and found a positive interest in the use of SAVs among people who adhere to a shared mobility type of practice, while the resistance was strongest among people who adhere to different car-based mobility practices. Also, those whose current mobility practice involves the use of electric cars had little interest in replacing their cars with SAVs. The study points to some paradoxes and challenges that are critical to handle if an upscaling of SAVs is to be part of a future sustainable mobility mode.

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Autonomous vehicles; social practice theory; shared mobility; sustainable mobility; social acceptance; mixed-method

1. Introduction

Self-driving autonomous vehicle (AV) technologies have for a long time been heralded as an innovative field of technologies that can have a strong impact on future mobility systems (Litman, 2022; Ribeiro et al., 2022). When implemented as part of a service-based interconnected mobility plan fuelled by electric energy and powered with artificial intelligence (AI), they are believed to propel a new paradigm for sustainable transport (Brimont et al., 2017; Fraedrichs et al., 2015). Bansal et al. (2016, p. 1) state that AV technology represents 'the biggest technological advances in personal transport that the world has seen in over a century', and Ribeiro et al. (2022, p. 620) state that 'there is no question that self-driving AV powered by AI are going to change how we travel in the near future and will dramatically change the paradigm of future mobility'. A fully automated driving system is one of the predominant visions pursued by the automotive industry and academic and public sector groups, and among its expected benefits are less traffic injuries, reduction in traffic jams, improved mobility services for the elderly and people with health problems, and a reduction in per capita CO_2 emissions (Burns, 2013; Chan, 2017; Pettigrew et al., 2019).

From the perspective of sustainable urban development, however, a growing concern is that private AVs may bolster the current transport system, leading to increased demand for road construction and congestion (Dolins et al., 2021; Fraedrichs et al., 2015; Fulton et al., 2018; Thomopoulos & Givoni, 2015). Such an outcome will not only cause problems in already congested areas, but there could also be long-term implications for urban sprawl, worsened socio-economic stratification and a sharp decrease in public transport ridership as

CONTACT Tom Erik Julsrud tom.julsrud@cicero.oslo.no CICERO Center for International Climate Research, 0349 Oslo, Norway

well as biking and walking. In this scenario, AV will enhance the development of an urban mobility system, where traditional low-emission transport modes are oppressed by 'smart' mobility solutions for those who can afford it (Gaio & Cugurollo, 2022). Hence, an alternative, and presumably better solution, is to develop automated transport that is collectively shared, with a higher capacity to carry more people, reduce the number of cars on the street and help to solve the last-mile challenge. *Shared autonomous vehicles (SAVs)* hold the promise of making transport services more accessible for the elderly and people with transport impairments, supporting multimodal transport and being a solution for last-mile problems (Cohen & Shirazi, 2017; Merfeld et al., 2019). Various forms of SAVs are currently being trialled based on different variations of technologies and business models.[1] Main forms include autonomous buses following a fixed route and on-demand applications where vehicles can be ordered to the user's location, so-called 'automated mobility on-demand' (AMOD).

Even though most product development and public attention remains on AVs for private use, systems for SAVs have received increasing attention over the last few years. Several studies foresee an opportunity for the emergence of SAVs as the most prevalent and dominant mode of road transportation (Bansal et al., 2016; Fagnant & Kockelman, 2015; Menon et al., 2019). Pilot trials with SAV schemes are increasingly conducted worldwide, including in Switzerland, Singapore, England and Norway promoted by transport providers, technology companies and various industrial partners (Ainsalo et al., 2018; Nordhoff et al., 2018).

In a best-case scenario, shared autonomous zero-emission vehicles will replace many trips that are made today with fossil-fuelled cars and complement existing public service options (Fulton et al., 2018; Golbabaei et al., 2021; Kaufman, 2020). To be implemented on a larger scale, however, this must be attractive to a significant number of citizens, particularly if this is going to replace private car driving and ownership on a more permanent basis (Golbabaei et al., 2021; Kaufmann, 2002; Merfeld et al., 2019). This is a challenge that should not be underestimated; creating a shift from individual to shared mobility has long been recognised as a wicked problem with multiple lock-in mechanisms (Hårstad et al., 2022; Ivanova et al., 2018).

Numerous user-oriented studies have been conducted in the last decade to define critical factors that can improve the acceptance of AVs in the population.[2] These studies have provided a long list of drivers and barriers that are prevalent in various populations and are relevant to consider when promoting this as a new mode of travel. As for SAVs, the small number of studies restrains the conclusions that can be drawn on user preferences and interests. Also, most studies conducted on SAVs, as well as AVs, have addressed technological and economical features driving interest in purchase, while social, symbolic and cultural factors have been largely overlooked. Hence, there has been a call for studies that can provide a more holistic understanding of the underlying drivers, barriers to and future developments of SAVs (Bissel et al., 2020; Merfeld et al., 2019). Studies that analyse how technologies are taken into use or rejected through active social processes are largely absent. However, a large body of literature has documented that new social technologies in transportation always depend on how they are based on processes of social adaptation and interpretation (Anable & Gatersleben, 2005; Lyons, 2015; Sheller & Urry, 2000). Moreover, although like AVs, SAVs have a distinct profile, since they involve the sharing of car space with other passengers, more like car sharing and public transport. In the form of AMOD, it is also likely to involve more interaction with digital technology than in the use of public transport, taxis and private cars today. This suggests that the experiences and findings from research on AVs may have less relevance for SAVs.

In this paper, we apply *social practice theory (SPT)* to understand the premises and opportunities for an upscaling of SAVs as a sustainable mode of mobility. The point of departure for this theoretical grounding is an understanding that people in most situations act under certain socio-material structures and routines rather than purely rational choices or plans. Following an SPT approach, SAVs are recognised as more than just a new type of transport service for consumption, but as socio-technological artefacts that, to succeed, must become parts of people's everyday lives, habits and lifestyles. To succeed, SAV must become a distinct mobility practice, and this can be analysed as a socially based process establishing this as a configuration of meaning, skills and materiality (Hargreaves, 2011; Hobson et al., 2018; Julsrud & Denstadli, 2020; Røpke & Christensen, 2012; Shove et al., 2012). Although increasingly applied in transportation research, as well as in a wide number of consumer studies, to the knowledge of the authors, there are no empirically based studies using an SPT approach in the field of AVs or SAVs. By addressing how the potential future use of SAV

technologies can be approached as the establishment of distinct mobility practices, this study provides a more critical perspective on the challenges related to the future uptake of SAV. It supplements a few recent studies that have found that peoples every travel activities are important predictors for their assessment of AV/SAV (Krueger et al., 2016; Nazari et al., 2018), although putting this in wide more socio-technical framing. As such, it also complements a small but growing AV-literature-based sociotechnical transition, which has given little attention to this so far (Fraedrichs et al., 2015).

Drawing on an SPT framework, the following research question is raised: *How can SAVs become a sustainable mobility practices among citizens in urban regions?* This question builds on the understanding that SAVs have not yet taken hold as a mobility practice; so far, they are mostly an 'image' or idea that may (or may not) become a part of people's mobility practices in the future (Beers et al., 2010; Huxley et al., 2019). It is also based on the premise that, to become a sustainable mode of transport, they must replace mobility practices based on the use of private cars. We will answer this question in three main steps: After a description of the existing literature, our theoretical approach and methodology, we will present results from a quantitative analysis of 865 urban dwellers in Oslo and 12 other cities in Norway. In this analysis, we locate six different mobility practices and analyse whether there are differences in the interest in using SAVs in the future among individuals that adhere to these practices. In the next step, we present results from a series of qualitative interviews with households, giving additional knowledge on travel practices and how the informants imagined their own future mobility practices, possibly including SAV. Finally, we will discuss how SAVs can develop as a new sustainable mobility practice in the future and how policies can be developed to support such development.

2. Literature overview

2.1 Studies of AV use

Numerous user-oriented studies of AV users have been conducted in the last decade, trying to unpack the acceptance of this technology, the interest in different purchasing business models, and how the technology can be further developed.[3] Given the huge interest in this topic, research has been conducted across different disciplines, drawing on divergent methodologies and approaches. One important strand of research is *technology adoption studies,* which address people's intention to use AVs on the basis of attitudes and perceptions of potential benefits and risks. In these works, 'classic' behavioural frameworks are applied, such as the theory of planned behavior (TPB) (Ajzen, 1991) and the later technology acceptance model (TAM) (Davis, 1989). Recent studies of user adoption of AVs using the TAM approach include Kyriakidis et al. (2015), Madigan et al. (2017), Raj et al. (2020) and Nordhoff et al. (2018). These studies have identified several individual factors that are important in predicting the adoption of AVs, such as trust, attitudes towards technologies and perceived usefulness, often combined with socio-demographic factors. As for demographic characteristics, several studies in this field have found that men tend to be more favourable towards AVs than women and less concerned about possible risks related to accidents (Haboucha et al., 2018; Hohenberger et al., 2016; Kyriakidis et al., 2015; Menon et al., 2019). At least two studies have found that technology-savvy men are particularly positive towards purchasing and using AVs (Bansal et al., 2016; Zmud & Sener, 2017). Regarding age, however, the findings are inconclusive. A literature review found that in 6 out of 10 survey-based studies, young people were more positively oriented (Becker & Axhausen, 2017). However, Nordhoff et al. (2018) found that older people were likelier to intend to use driverless vehicles and were more positive towards the vehicle characteristics, but gave lower ratings to the effectiveness of the vehicle.

Second, a huge amount of literature has emerged using *choice experiments* and econometrical techniques to predict the likelihood of uptake and willingness to purchase AVs, comparing different groups of users (Haboucha et al., 2018; Nazari et al., 2018; Pakush et al., 2018; Zmud & Sener, 2017). These studies have supported many of the key findings related to demography and attitudes, but they have further revealed divergence in preferences for different forms of AV and the inclusion of travel behaviour aspects. Drawing from a stated preference survey in the state of Washington, Nazari et al. (2018) provide evidence that those with longer commute times were positive to AVs for commuting, while persons associated with higher daily vehicle-miles travelled were less so. This suggests

that it is not only distance that is important for the interest in using AVs but also the type of trips that are involved. This study also found that safety concerns hinder public inclination towards AVs, whereas technology savviness and green travel patterns can promote interest in AV technology. The modest interest in taking a full step towards SAVs was confirmed in a web-based survey of people in small-and medium-sized metropolitan areas in the US (Saeed et al., 2020). This study found that the interest among drivers to switch from private cars to forms of shared vehicles was low and it suggested that individuals in the older segment were likelier to use a traditional vehicle rather than adopting AVs, and that this was less attractive for people in rural areas.

Third, a handful of studies have analysed the uptake of AV technology as part of a *sociotechnical transition* in the transport system, pointing out premises for change and possible transition pathways (Cugurullo et al., 2021; Fraedrichs et al., 2015; Hess, 2020; Marletto, 2019; Milakis & Müller, 2021). These studies address how automated driving not only depends on consumer preferences, but interconnected changes in policy development, multiple technological innovations and response of institutional actors. Fraedrichs (2015) developed three alternative transition scenarios for a fully automated transport system, and Marletto (2019) depicted three pathways towards automated driving, each led by different groups of innovators.

2.2 Studies of SAV use

The literature on SAVs is scattered, although it is growing fast. The bulk of studies utilize choice-based approaches, exploring responses to scenarios for the development of configurations of AVs and SAVs. Bansal et al. (2016) used the stated preference model to investigate user groups based on pricing scenarios in a sample of users in Texas, USA. Based on this study, only 13% of the respondents indicated that they may be willing to relinquish personal vehicles and rely completely on SAVs at a cost of 1 USD/mile. In a study of five metropolitan areas in Australia, Krueger et al. (2016) analysed the relationship between the intention to use SAVs in the future and respondents' current travel behaviour, including their current type of car. In this study, they distinguished among modality-style clusters based on the frequency of use of different transport modes. A clustering of respondents by their current modal split showed that young people and those who used multiple modes of transportation were likelier to choose SAVs. In an experimental study conducted in Israel and the USA, Haboucha et al. (2018) found that most people would prefer to use a regular car for their commute rather than AVs or SAVs. Even if the SAV services were to be completely free, only 75% of individuals would be willing to use SAVs.

In addition to these experiment-based studies, a handful of studies have used qualitative approaches. In a Delphi study involving 40 international experts, Merfeld et al. (2019) located key drivers and barriers for the development of SAVs as well as potential future developments. This study found that a mix of technological, consumer acceptance and legislative issues was most important for shaping the future development of SAVs. Based on focus groups with representatives from different social groups, Etminani-Ghasrodashti et al. (2021) found service accessibility, flexibility and reliability to be the factors that most strongly influenced the demand for existing transportation services. A group of people with disabilities indicated that they would adopt the SAVs if service planners provided a supportive environment, such as access to sidewalks, ramps and curb cuts in the pick-up and drop-off locations.

As a social and technical innovation, the SAV is still at an embryonic stage, with very limited numbers of actual users, and most studies rely on people's assumptions about future behaviour under different technical and economical scenarios. Existing studies are usually also based on nonrepresentative samples with an overrepresentation of US-city regions. In the user-oriented research on AVs and SAVs, there has been a prevalence for demographic, attitudinal, economic and technical factors in predictions of SAV uptake, while symbolic, cultural or lifestyle issues have been largely ignored. Studies suggest that the interest in replacing the private car with a shared autonomous one is on a low level, but the underlying causes for this reluctance, as well as the preconditions for change, has so far not been a prominent theme in the literature.

3. Theoretical approach

This study builds on social practice theory (SPT), a theoretical perspective that builds on sociological theories of human actions forwarded by Giddens (1984) and Bourdieu (1977). Social practice theories have gained

increased recognition during the last decades as a framework for sustainability research and policy (Shove et al., 2012; Spaargaren, 2011; Warde, 2005). In the field of transportation, it has proved to be useful in explaining issues related to the adoption of private cars, bikes, electric cars and forms of shared cars (Dowling et al., 2018; Julsrud & Farstad, 2020). However, to the knowledge of the authors, there are no empirically based studies using a social practice approach in the field of AVs or SAVs.

Social practices are relatively routinized and sustained ways of enacting a set of elements, and everyday practices are anchored by multiple overlapping ties to the social, technical and cultural fabric of everyday life. At a general level, social practices can be described as 'blocks' of interconnected actions, involving socially constructed meaning, joint knowledge, bodily movements and the use of tools and materiality (Reckwitz, 2002). Shove et al. (2012) suggest that practices can be described as routinized actions that include interlinked elements of *meaning, competence and materiality*. In this context, materials refer to things, technologies, tangible physical entities and the stuff of which objects are made; competence refers to 'skill, know-how and technique and meanings include symbolic meanings, ideas and aspirations' (p. 14). On an analytical level, the establishment of a practice is understood as the creation of links between new and pre-existing elements so that these constitute each other and change through the process of integration (Ibid., p. 42). Cycling, for instance, is a practice that entails a specific technological artefact and the ability to use it, as well as certain meanings and understandings that can vary across time and place. Following Shove et al., it is the making and breaking of these links that are crucial for practices to emerge, stabilize, transform or decay.

Social practices are not static or timeless entities – they are part of practices that can emerge, stabilize and break down. Shove et al. describe the formation of practices as depending on the integration of pre-existing elements, which have histories and futures independent of the practice, but which can be transformed by it. As for a shift from ordinary private cars to SAVs, this may challenge the practice of car driving along any of the elements: it requires new skill; the technologies and its infrastructure are different, and the meaning of cars and driving is certainly in flux. Still, the elements that emerge are not all new, but usually relate to a plethora of elements integrated in other practices. Elements of a new practice are not necessarily unique or innovative, but are extracted from earlier practices or cultural ideas and representations (Shove et al., 2012). Together with numerous other social practices related to travels, leisure activities, consumption of food, etc., they form bundles that in sum constitutes certain 'lifestyles' (Spaargaren, 2011).

Viewed through the lens of practice theory, a shift from the use of a private car to sharing autonomous ones with others is therefore not primarily a question of positive attitudes or a general willingness, but about whether this, through everyday experimentation and trials, can be configurated as a new practice. To take hold, it is necessary that elements of meaning, skills and handling of materiality can form interlinked units that are stabilized in a community over time. This is a process that usually involves periods in which the constellations of the elements are unstable; it can form 'proto-practices' that may become more established in the future or fade away (see Figure 1).

Leaping from current practice to a new, however, often involves some form of idea or imagination related to the affordances of a new technology and how it might be used in the future (Gaver, 1991; Orlikowski, 2000; Strengers et al., 2019). As described in the sociology of expectations, peoples 'expectations and stories about the future' constrain how they act (Brown & Michael, 2003). In SPT, it has repeatedly been underscored how individuals' imaginations are important for transformations and disruptions in social practices (Castoriadis, 1987; Giddens, 1991; Ortner, 2006). Hence, in the forthcoming qualitative analysis, we will highlight informants' current mobility practices as well as how they imagine that they could use SAV in the future.

4. Data and methodology

The dynamic nature of social practices, where their meaning develops in close relationships with artefacts and bodily enactment, makes qualitative methodologies a first choice in most studies in this field. The strength of a quantitative approach, however, is that it opens for an overview and description of general structures in larger samples, providing evidence of the sharedness of certain constellations. As argued above, practices are routinized types of behaviour that form natural groups or 'blocks' of activities that are connected in time and space,

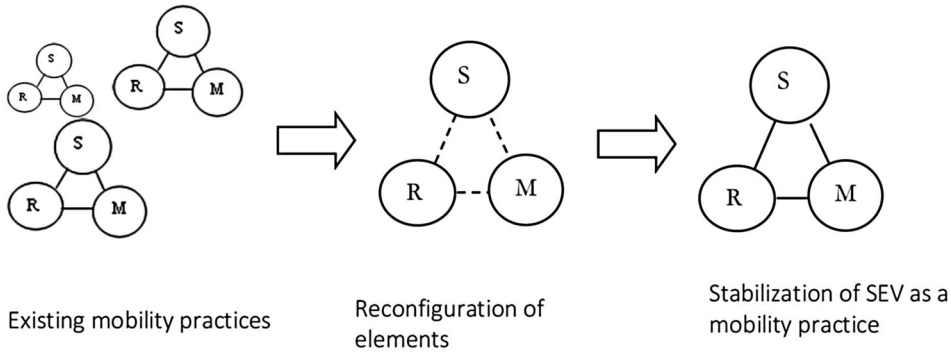

Figure 1. Steps in the establishment of SAV as a new mobility practice (M = meaning, R = Resources, S = skills).

and there are quantitative techniques that are appropriate to detect such items. The ambition of this paper is to explore some dominant constellations of elements related to car-based mobility drawing on a combination of quantitative and qualitative data and methodologies. Through a two-step process, we will first apply multivariate statistics to locale distinct constellation of elements indicating current social practices, and secondly explore these further with qualitative data. Our work adds to a small but growing body of research on social practices that make use of quantitative methods, either alone or in combination with qualitative (Guillen-Royo, 2022; Julsrud & Farstad, 2020; Mattioli et al., 2016; Southerton et al., 2012; Uteng et al., 2019).

4.1 Survey data

The survey included citizens in Oslo, the capital of Norway with over 600,000 inhabitants and 12 other cities in Norway. An on-line questionnaire was distributed with assistance from OBOS, one of the largest housing developers in Norway, with over 500,000 members.[4] Respondents were recruited through the organization's newsletter at their web pages from December 2020 to February 202.

The data include 865 respondents, and it has a well-balanced distribution of age and income, although with a bias of female informants. A total of 78% of the respondents reside in Oslo and 22% from eight other cities. Compared to a national average, there is also a slightly higher representation of retired, students and unemployed (Table 1). A large majority live in flats or semi-detached houses located in closeness to city regions. As shown in Table 2, informants have better access to public transport than in the municipality of Oslo and the national average, although with less access to private cars. A significantly higher number are also registered as member of a car sharing scheme. This is most likely due to that OBOS has made agreements with car sharing companies, located close to some of their housing areas, giving the members special offers and reduced prices.

The survey collected information on issues capturing key dimensions of shared vehicles as a social practice based on the framework suggested by (2012). Items addressing the three elements of practice were captured (Table 3), although for the purpose of our analysis, we used the terms 'actions' and 'resources' instead of 'knowledge' and 'materiality'. This could, for instance, be experiences of co-driving in the neighbourhood. The questionnaire included questions on sharing practices, including car sharing, SAVs, travel behaviour before and during the pandemic and socio-demographic issues. In this study, we include only questions relating to car sharing, SAVs and socio-demographic issues.

As a strategy to identify structures representing social practices, we used *exploratory factor analysis*, which is an inductive technique for modelling observed variables and their covariance structure, in terms of a smaller number of underlying unobservable (latent) 'factors' (Watkins, 2018). A principal component analysis with Varimax rotation located six main loadings that were used for further regression analysis. By including aspects of meaning, skills and resources, we sought to locate latent structures that integrate these dimensions, indicating that there are linkages holding them together. The dimensions were operationalized using a set of

Table 1. Sample characteristics.

	N	Percent
Age		
<30	121	14
30–44	312	36,1
45–60	203	23,5
60<	152	17,6
n/a	77	8,9
Sum	*865*	*100*
Income (1000 NOK)		
<250	42	4,9
250–499	136	15,7
500–749	202	23,4
750–999	103	11,9
1000–1449	163	18,8
1500<	63	7,3
n/a	156	18
Sum	*865*	*100*
Gender		
Male	257	29,7
Female	581	67,2
n/a	27	3,2
Sum	*865*	*100*
Status		
Employed	615	71
Student	60	6,9
Unemployed	79	9,1
Retired	89	10,3
Other, n/a	23	2,7
Sum	*865*	*100*

Table 2. Access to transport resources in the OBOS-survey compared to Oslo municipality, the county of Viken and Norway. Percent.

	Municipality of Oslo*	Viken County*	Norway*	OBOS-survey
Private cars in household				
No car	34	9	14	42
One or more	67	91	86	58
Distance to nearest publ. transport hub				
< 500 m.	55	38	45	48
500 m–1 km	23	20	19	49
1 km <	22	42	36	3
E-car ownership (% of car owners)	17	15	13	15
Member of car a sharing scheme	3	1	0	11

*Source: Ruter/PROSAM, 2022.

questions and statements. *Resources* were indicated by the availability of mobility resources (cars, public transport, etc.), *meaning* through a set of value-laden statements. *Activities* were captured by registering the types of activities that individuals are engaged with, linking up to an activity-based approach to learning in which people build skills through their everyday actions (Daniels, 2010).

As a dependent variable, we relied on a simple question asking about the interest in using SAVs on their daily travels on a five-point Likert scale. A brief explanation of the SAVs was given to the informants before presenting this question.

4.2 Qualitative data

The second dataset consists of 20 in-depth interviews with informants living in Ski, a community on the western side of Oslo. The qualitative data was gathered as part of a project where a public transport operator ran local

Table 3. Key variables mean values on a five-point scale (1 = not interested, 5 = highly interested).

	Scale	Mean	St d.
Resources (Materiality)			
Petrol or diesel cars in the household (number)	4	0,43	0,69
Electric or hybrid cars in the household (number)	5	0,18	0,46
Distance to the closest public transport service (km)	7	1,74	0,90
Meaning			
In the future I want to live without owning a car	5	3,12	1,41
Cars and motorsport are an important hobby for me	5	1,58	1,01
Travels with private cars have little impact on the climate	5	2,26	1,21
It is impossible to manage without a car where I live	5	1,93	1,22
I like to drive cars	5	3,33	1,27
I have a lifestyle that demands owning a private car	5	2,16	1,40
Biking is an important leisure activity for me	5	2,80	1,42
I try to avoid using fossil fuelled vehicles	5	2,95	1,24
I like taking long walks in the neighbourhood	5	4,11	1,01
Activities (Skills)			
Use of car to/from leisure activities	4	3,81	1,35
Use of car to/from work	4		
Participation in informal activities during the week	4	2,96	0,67
Participation in formal activities during the week	4	3,35	0,97
Picking up/deliver children in kindergarten or at school	4	3,36	1,35
Co-driving with people in the neighbourhood	5	1,06	0,34
Use of car sharing services	5	1,37	0,82
Future use of SAVs			
Interest for using SAVs on daily travels	5	3,18	1,57

trials with SAV in the area. Respondents were recruited through a prior survey[5] addressing the general interest in implementing an SAV bus route in their neighbourhood. Interviews were conducted in the homes of the informants or through MS Teams and lasted approximately an hour.[6] The interviews were recorded, transcribed, coded and analysed using appropriate software (NVivo). A combination of deductively and inductively based pattern coding, was used in the analysis starting with a thematic list of social practice dimensions, elaborating sub-categories subsequently (Miles & Huberman, 1994). These practice dimensions were then matched with the practice clusters located by the quantitative analysis. The sample of informants was well balanced when it comes to gender and age, and includes a mix of employed, retired and students (see Table 4).

The combination of quantitative and qualitative data follows a logic where survey data is used to define groups that are investigated in more detail and depth with the qualitative data. Three cases will be highlighted in the next section, representing practices that we found to be particularly important for the interest in using SAV in the future. The intention is to provide a better understanding of the routines, meanings and material environments constituting the mobility practices identified, show how they are interlinked and in what way this informed their (expected) future mobility needs.

Both datasets involve citizens in the Oslo region, and they were conducted at approximately the same time. Yet, there is no direct link between them. None of the informants for the in-depth interviews are included in the survey. Our premise then is that certain general mobility patterns exist in this area independently of the data sets.

5. Results

5.1 Survey results

As indicated in Table 5, the interest in using SAVs on future daily travels was, on average, modest. Males were more positive than females and younger persons were more positive than older, but the differences across income groups were less clear.

The results from the factor analysis displayed in Table 6 indicate that six factors (components) had eigenvalues above 1 and cumulatively explained 52% of the variation. Only to a limited degree did adding more

Table 4. Informants' characteristics.

No. #	Gender	Age	Status
1	F	26	Student
2	F	30	Employed
3	M	45	Employed
4	F	70	Retired
5	F	45	Employed
6	M	77	Retired
7	M	35	Student
8	F	64	Unemployed
9	M	52	Employed
10	F	50	Unemployed
11	F	36	Employed
12	M	67	Retired
13	M	72	Retired
14	M	83	Retired
15	M	64	Employed
16	F	21	Employed
17	F	29	Student
18	F	55	Employed
19	M	36	Employed
21	M	55	Employed

Table 5. Interest for using SAVs on future daily trips. Mean values on a five-point scale (1 = not interested, 5 = highly interested).

	Mean	St.d.
*Age****		
<30	3,6	1,4
30–44	3,4	1,5
45–60	3,0	1,6
60<	2,8	1,5
*Income**		
<250	3,3	1,5
250–499	2,9	1,6
500–749	3,2	1,6
750–999	3,4	1,6
1000–1449	3,3	1,5
1500<	3,3	1,5
*Gender**		
Male	3,3	1,5
Female	3,2	1,6

*Chi Square < 0.05.
***Chi Square <0.001.

components improve the explained variance. Bartlett's test of sphericity was significant (sig = .000), confirming that all correlations are different from zero and that the data are suitable for PCA. The Kaiser-Meyer-Olkins measure of sampling adequacy is above 0.75, which indicates that the data are useful for further analysis.

The first and strongest component, labelled *Car dependent,* contained three variables that reflects a user practice highly dependent on traditional fossil-fuelled cars. Leisure activities as well as work travel dominated car use. A long distance to public transport services indicates that access to such resources was limited, while multiple cars were common. The second component, named *Car culture*, focuses on the joy of driving and its value as a leisure activity and hobby. While the former practice seemed to be dependent on cars for doing errands or getting to work, this practice was characterized by enthusiasm for driving, and the understanding of traditional cars as negative for the environment was doubted. The third component, *Electromobility*, is characterized mainly by using electric and hybrid cars for commuting and other assignments. Although not doubting of the negative aspects of fossil cars, there was little interest in living without a private car in

Table 6. Sorted component score matrix.

	Factors					
	1 Car dependent	2 Car culture	3 Electro mobility	4 Active leisure	5 Bike and walk	6 Shared mobility
Petrol or diesel cars in the household (numbers) (M)	**0,698**					
I try to avoid using fossil fuelled vehicles (M)	**−0,674**					
Use of cars for to/from leisure activities (A)	**0,544**		0,496			
In the future I want to live without owning a car (M)	−0,493	−0,219	−0,408			0,212
Cars and motorsport are an important hobby for me (M)		**0,688**				
Travels with private cars have little impact on the climate (M)		**0,637**				
It is impossible to manage without a car where I live (M)	0,375	**0,589**	−0,262			
I like to drive cars (M)		**0,571**	0,317			
I have a lifestyle that demands owning a private car (M)	**0,553**	**0,56**				
Electric or hybrid cars in the household (R)			**0,762**			
Use of cars to/from work (A)	0,459		**0,623**			
Participation in informal activities during the week (A)				**0,777**		
Participation in formal activities during the week (A)				**0,738**		0,228
Picking up/deliver children in kindergarten or at school (A)		−0,245		−0,466	0,217	0,366
I like taking long walks in the neighbourhood (M)					**0,742**	−0,261
Biking is an important leisure activity for me (M)					**0,694**	0,231
Distance to the closest public transport service (R)	0,298					**0,513**
Use of car sharing services (A)	−0,323					**0,511**
Co-driving with people in the neighbourhood (A)						0,381

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in eight iterations.

M = Meaning, A = Activity, R = Resources.

the future. The fourth component, *Active leisure*, is characterized by active engagement in activities during the week, although with less frequent use of cars. This has a very low loading on delivering/picking up children and is likely to involve singles and young persons that are less established. The fifth component involves frequent *walking and biking* and low use of cars, while the final component consists of *shared mobility* activities characterized by involvement in co-driving and car sharing, as well as a willingness to live without cars in the future. This is a dimension that involves some skills that are relevant for SAVs and they also have an intention of replacing the use of cars with other modes.

Hence, this analysis points out three different car-based factors, of which two involve traditional (fossil fuelled) vehicles and one hybrid/electric one. Three other factors were evolving around active and more local leisure trips without cars, biking and walking and use of share mobility services as part of daily travels. We interpret this as indicators of the general mobility practices that exist in the sample.

Figure 2 illustrates how the factor loadings are distributed among different age groups. As could be expected from earlier studies, car-based practices were most prominent among people older than 45 years of age, and dedicated car use was particularly prominent in the oldest category. Active leisure was mostly a practice related to those below 30 years of age and shared mobility for people 30–35 years old. This reflects a significant variation in everyday mobility practices between age groups.

Table 7 shows results from a stepwise regression where the level of interest in using SAVs on daily travels in the future is a dependent variable. The first step included three key demographic variables, while significant mobility practices were added in the subsequent steps. The analysis shows that these six factors impact the interest in taking up SAVs in the future differently. As expected, interest was significantly higher among the young respondents, while gender and household income had no predictive value. As for the social practice variables, the two first car-based factors – card dependent and car culture – have a significant *negative impact*, indicating that those who were involved in these practices were not likely to use SAVs in the future. The same is true for electromobility, although to a much lesser degree. The shared mobility practice, on the other hand,

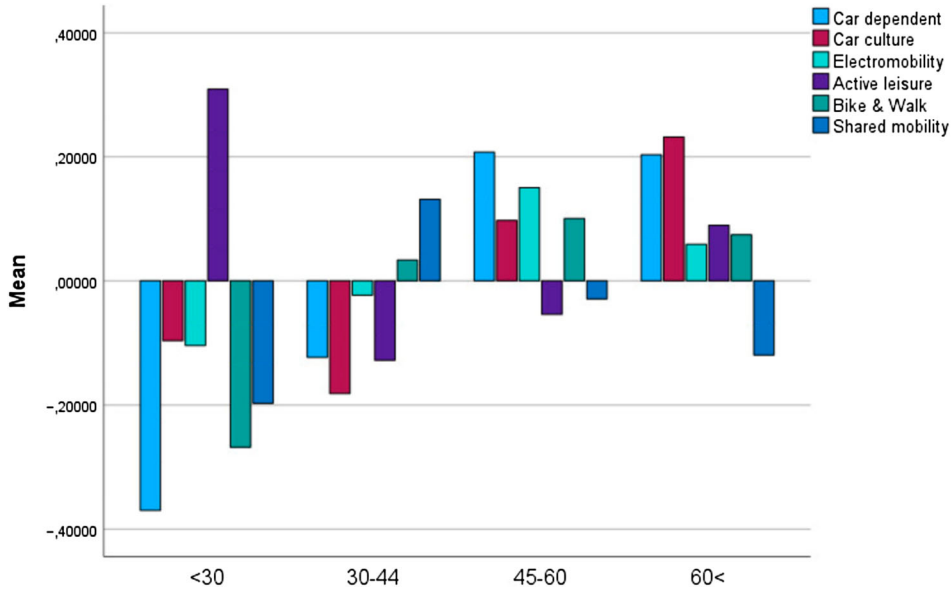

Figure 2. PCA component scores and age groups. Mean.

has a *positive impact*, whereas the last two factors (Active leisure and Walk & bike) were unsignificant and not included in any of the models. This final model was significant, (F = .7461, sig = < .001) even after controlling for gender, and it accounted for approximately 59% of the variance in the dependent variable.

Hence, findings indicate that having car-based mobility practices was negative for an interest in using SAVs in the future while having experiences and skills from using other shared travel modes was positive. This indicates that people's perception of their future interest in SAV can be related to their current mobility practices, involving elements of learning, meaning and access to transport resources.

5.2 Results from qualitative analysis

The inductive quantitative analysis located six constellations of elements, representing outlines of mobility-based social practices. To get a better understanding of how these compilations of elements were sustained as a distinct mobility practice we turn to the qualitative data. As we saw above, three constellations of elements (practices) were significant as promoters or barriers to an interest in the future use of SAVs. We will explore these social practices further and highlight how they promote or prohibit potential shift in mobility routines. For the sake of simplicity, we treat the two car-based practice forms in combination here, since they appeared to be relatively similar in the way the elements link up together.

5.2.1 Car dependent/Car culture

Fredrik (#3) is a man in his 50s with higher education, living together with his wife and two children aged 11 and 13. Both adults work full-time and commute in different directions. He usually takes the train to the city, while she uses the family's diesel car for her work some 20 km away. The car is also much used for driving the two kids to sports and culture activities in the district in the evenings, and for shopping at the local shopping centre. An important activity for the family is trips to their cabin in the mountain. He says that this requires a good car, and possibly also an electric one.

> For a family like ours the alternative is to buy a new car, not to live without one. It is about big shopping, the famous cabin-lives, and several other things. When we want to go the forest we need a car to get to new locations. No, living without a car is out of the question as long as we have a good economy.

Table 7. Stepwise regression predicting general interest* for using SAVs on daily travels in the future.

	Step 1		Step 2		Step 3		Step 4		Step 5	
	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.
Demography										
Age	-.274	<.001	-.232	<.001	-.201	.001	-.200	.001	-.187	
Gender (Male =1)	-.135	.277	-.157	.203	-.210	.091	-.192	.123	-.225	
Household income	.006	.858	.012	.721	.000	.946	-.001	.964	.009	
Mobility practices										
Car dependent			-.197	<.001	-.201	<.001	-.202	<.001	-.206	<.001
Car culture					-.165	.005	-.165	.005	-.167	.005
Shared mobility							.130	.024	.127	.027
Electromobility									-.126	.029
F-Value	7.853	8.442	8.373	7.869	7.461					
Adjusted R2	0.26	0.40	0.49	0.54	0.59					

*Level of interest was measured on a 5-point likert scale.

Fredrik says the family tries to make choices that can limit their environmental footprint, although they sometimes feel 'guilty' for not doing enough. Yet, he thinks it is difficult for them to stop driving, and admits that they really don't want to make changes that may reduce their quality of life.

> We don't really need a cabin, but we have a cabin. It is because we think this is nice, it is not climate friendly to have one, but it gives us fantastic nature experiences. So, I do find this complicated. But we rarely make climate choices that reduces on our quality of life.

As for a potential implementation of SAV in the neighborhood, he is reluctant. This is not only because the technology is poorly developed, but also because he believes it will be risky and unnecessary. He foresees various situations where this would be difficult or cumbersome:

> I can imagine a heavy, wet winter day with jacket and rucksack and boarding a crowded bus where people are getting on and off. That is something I would avoid, and rather try to walk the distance.

Except for his use of public transport, neither he nor his family have much experience with sharing vehicles or other items. In his view sharing of items is more suitable for those with little money.

> Sharing is for people with less money than what we have. I am 50 and my wife about the same and we have had solid jobs for our entire lives and have a good economy. So, I think this is mostly for those without permanent jobs or that are in difficult life situations …

In general, then the established mobility practice is driven by activities that depends on the use of a car, and it is hard for him to imagine how their mobility needs in future can be met with SAVs. The private car is integrated as a premise for living the life that they do today and there is little willingness to make significant changes in their current lifestyles.

5.2.2 Shared mobility

Linda (#17) is a female student, living together with a partner and child in an apartment a bit outside the city center. She is currently on a maternity leave but plans to take up studies afterwards. The couple have recently exchanged their fossil car for a small electric car that her husband uses to and from the campus where he studies. During a normal day, Linda takes the local bus to deliver her daughter to kindergarten, to meet friends or to take part in different activities. During weekends and holidays, they often use the car to travel to places where they can hike in the nature, and to their cabin in Sweden. Linda considers herself a dedicated public transport user, and she likes sharing trips with her daughter.

> … I rather take the bus than a car, because then I can sit beside her and we can talk all the way, avoid that she is sitting in the back complaining and those kind of things

She says that she and her partner are 'beyond average' concerned about the environments and have taken different actions to reduce their climate footprint. In addition to replacing their older fossil-fueled car with

an electric, they have switched to a vegetarian diet and try to reduce unnecessary shopping. She believes avoidance of overspending and increased sharing is important to develop more sustainable lifestyles.

> Very often people think that, oh, I want this and that and then they buy it. But it is better to think that hey, maybe I don't really need it if I can borrow it from my neighbor instead. We should try to get back to where it was more common to share things …

They couple has occasionally used shared cars and more commonly shared a ride with neighbors, which she describes as «a little bit like using the bus». As for SAVs, Linda is enthusiastic and believes this would fit perfectly in their local environment, where there are many steep roads up and down to the bus stops. Reflecting on her own situation, she thinks that this could make it easier for her to travel with her child to the train station.

> I think this is so cool if it can be implemented in a neighborhood like ours where there are a lot of apartments and houses, and a very steep road down to the train station or nearest bus stop. (…) As for now I manage to walk with my daughter in a stroller, but she cannot walk very long distances. So when she becomes three or four, we cannot get to the train unless I place her on the back of a bike or something like that. That hill will be too hard for her until she is perhaps six or seven. So, for families with small children, I think this could be very useful to avoid taking the car …

Hence, her current public-transport based mobility pattern, mainly based on public transport, makes it easy for her to imagine how SAVs could be useful for her in the future, in many ways as a continuation of her present routines. The meaning of SAVs was framed as an innovation that could help her manage without a car, which she really didn't like to use, as well as a possible step toward greener local mobility.

5.2.3 Electromobility

John (#13) is a retired insurance worker, living close to the centre of the community together with his wife. There are two cars in the household, one full electric smaller car used by the wife, and a larger four-wheel drive hybrid car that he usually drives. His wife, working as a home-nurse, uses the electric car on a daily basis. He says that she doesn't feel safe on public transport due to negative experiences in the past. The hybrid car is mostly used for trips to family and friends, their seaside cabin, as well as shopping. They are planning for a longer car trip in Norway during the summer.

Their main motives for adopting electric cars were convenience and economy, and not to cut their transport emissions. On the contrary, John is member of the 'climate realists', an organisation that aims to be 'a counterweight to the dominant scientific perception of climate change'.:

> I must say that this climate issue has become hysterical. But the reason why me and my wife moved from gasoline to electric cars was simply because they are more comfortable to drive, quieter and also cheaper.

Hence, the idea that green car drivers are more concerned about the environment is refuted in this case. Neither has the family any ambition to manage without a car in the future.

> Living without a car is not an option, we have so much to do with our grandchildren, and where they live there are no direct public transport routes and it takes too much time. Always being available for the grandchildren is important, and then we have the cabin …

As for a possible implementation of SAVs in their community, John is in general negative. He believes that these cars are unsafe and that the technology itself is immature. As a former insurance worker, he also thinks that there are several legal obstacles that need to be tackled before this can be taken into use.

Even if it would become more common in the future, he cannot see that this would represent anything but 'a new type of bus' without a driver. Since there already are bus lines serving the community SAVs are not really necessary even when he gets older and loses his driver license.

> To me it really doesn't matter if the bus has a driver or not, or how it works, as long as it gets me where I want to go. (…) In a couple of years, I might not be able to use my legs as I do today so I might be more dependent on the bus. But as I said, it doesn't matter as long as it goes frequently and that I can trust it.

All in all, John is generally negative to SAVs but he doesn't totally close the door for it in the future if it will be like a 'regular bus'. However, making changes in any of his current car-based mobility habits is not something

he is willing to do. In sum, this case shows how electric cars are used as an alternative to other cars, not for environmental reasons, but for economic reasons and convenience. It also illustrates the generational split, where older people hold significantly more negative views of SAVs than younger people, along the dimensions of meaning and activities/experiences.

6. Discussion

Building on a social practice perspective, our study has shown how resistance is strongest among people who adhere to different types of car-based mobility practices, while a positive interest was found among people who had experiences from shared mobility and positive meanings related to sharing and co-driving with others. We also found that current e-car users tend to have little interest in replacing their cars with SAVs. As for demographic variation, we find that young people are more positively oriented than older people, but that gender and household income had little impact. Given the higher interest in using SAVs among practitioners of shared mobility, this study also supports some earlier contributions indicating that environmental attitudes can be positive for an interest in using SAVs (Acheampong & Cugurullo, 2019). In line with several other studies, our results also show that there is much scepticism and reluctance to give up the private car for shared and autonomous ones (Haboucha et al., 2018; Hudson et al., 2019).

6.1 Scepticism and support as embedded in household practices.

Why does current mobility practices have an impact on the interest in using SAV in the future? The qualitative cases have displayed how people reflect on their future transport needs based on their current life situation and mobility routines. Current travel routines were related to deeper held meanings, sustained by access to resources and infrastructure that often was a result of investments (i.e. expensive cars, second homes) or important life choices (where to live). Together with other practices, they formed recognizable lifestyles and identities, that SAV needed to be adaptable to be seen as relevant. When the perceived gap between current practices and imagined future use was too wide, people tended to be sceptical.

For instance, the *meaning* of sharing transport resources was in the car dependent case seen as mostly relevant for poorer households, while in the shared mobility case was approached as something that was smart and good for the environment. Similarly, the meaning of using (fossil fuelled) private cars for a daily travel was in the electromobility-case seen as unproblematic while in the second case was seen as threatening to the environment. These divergent symbolic meanings of sharing vehicles and using private cars were decisive for how attracted they were to the idea of using shared autonomous vehicles on their daily travels in the future. Elements of meaning, however, were 'materialized' in a wider *material environment*, including ownership of private cabins, valuable new cars, membership in car sharing clubs, etc. Such elements of meaning were similarly also connected to patterns of *everyday activities* as well as the skills acquired using different technologies and applications. Thus, having experiences and skills in using shared cars and public transport networks made it easier to imagine autonomous cars as part of their daily lives in the future, than if this required new skills.

Hence, while a few recent earlier works have indicated that people's current mobility behaviour are important predictor for their future interest in AVs and SAVs in the future (Krueger et al., 2016; Nazari et al., 2018), this gives a more complete picture of how such behaviour is related to certain practices and lifestyles. We should note, however, that while the survey outlined overarching structures in the data, practices 'on the ground' will not necessarily fit directly into these categories. This was evident in the electromobility case above, where the informant expressed reluctance to accept the impact of fossil cars on climate, a meaning that was most salient for the Car culture practice.

6.2 Solving the paradoxes of SAV

Our findings point towards some major paradoxes that haunt the implementation of SAVs as part of a zero-emission transport system. First, to become a sustainable mode of mobility, SAVs should recruit users from

segments that currently use non-sustainable modes, particularly privately owned fossil cars. As we have seen, however, this group is not very likely to do so, at least not without much regulation and financial support. Second, the groups of users that often are believed to have most use of SAVs – older people – seem to be mainly negative. Although this group often has high need for local mobility, they also have a high affinity for cars and probably public transport, walking and biking. There are good reasons to believe that many older people find it less relevant to imagine themselves as part of futuristic transport innovation, given the limited number of remaining living years. If this group is to reap the benefits of SAVs, they need to be explicitly invited to take part in pilot trials, etc., and addressed by appropriate communication (Pettigrew et al., 2019). Third, it appears that the fast uptake of e-cars in the population has established mobility practices that are negatively related to the use of SAVs. Many current e-car users do not see themselves as users of SAVs in the future. Hence, the heavy investments in policies to support the purchase of electric private cars in Norway may have bolstered mobility practices that make the use of SAVs less relevant. One of the qualitative cases exposed here (Electromobility) illustrated well how a 'private car logic' can be sustaining for the purchase and use of low-emission cars, unrelated to any environmental motives. This points to the fact that the configuration and implementation of SAVs as a new mobility practice can compete with other sustainable modes, such as e-mobility as well as biking and walking.

Automated vehicles, in combination with AI and smart city applications, will clearly redefine and transform urban mobility in the future. Unless the paradoxes above are addressed, however, there are reasons to doubt on whether this actually will become a mode of transportation that contributes to the development of a low-emission transport system.

6.3 Configurating SAV as a new mobility practice

The practice-based approach suggested in this paper can guide policymakers aiming to include SAVs as part of a strategy to build smart and sustainable cities. One strategy could be to nurture mobility practices that currently seem to be the most compatible with sustainable SAV practices, such as the shared mobility type. This can be done by addressing all practice elements – skills, mobility resources and meaning – and the configuration of them as a sustainable mobility mode. For instance, enabling the development of skills to use these can be based on small-scale pilots in communities, giving different groups of people an opportunity to use SAVs over some time. It is particularly important here to recruit groups that currently are reluctant, such as the elderly and impaired, but also for people adhering to car-based mobility routines. Situations disrupting 'normal' routines, such as the COVID-19 pandemic and rapidly increasing energy costs, may be important windows of opportunity for this (Greene et al., 2022). As for the resource dimension, policy developers should put emphasis on making SAVs easily accessible where people live and choose technological interfaces that are easy to use for all groups. There must also be public transport services so that it is convenient and cost-efficient to live without cars outside city centres. Making car sharing services available in local communities and residential areas (as was done by OBOS) makes it easier for people to manage without cars and provides opportunities for learning how to share transport resources. Focus should also be given to build up the identity of SAVs as part of an environmental lifestyle, making living without private cars a real option for a larger number of people. For example, one should pay attention to how the use of AV/SAV can release time aboard for work and free time activities if applied in accordance with individual and social needs (McCarroll & Cugurullo, 2022). Over time, these efforts may help cultivate SAVs as a practice that can contribute to the development of a zero-emission transport system.

6.3 Limitations

This paper has used a rare combination of quantitative and qualitative techniques to explore mobility practices and the way these are related to the use of SAV in the future. Still, the definitions of the practices, using inductive multivariate techniques, have only been able to capture some of the social practice dimensions that could be relevant. Some forms of mobility in the households have been less covered in the design, such as the use of

different public transport services. Hence, the set of practices outlined in this study is far from extensive or complete. Second, the dependent variable used here implies that the actual use of SAV in the future is (or will be) a rational decision, an assumption that may appear to be at odds with the basic premises behind practice theory. We argue, however, that people's expected future behaviour can work as an indicator of general interest, although it is likely that socially embedded factors will constrain what they do in the future. Insights about what people think about new technology today are undoubtedly valuable as information about potential resistance and barriers to the development of new practices, even though it does not give a comprehensive answer (Axsen & Sovacool, 2019). Third, the nature of the survey-data relied on here may have produced results that deviates from a larger and fully representative sample. The high number of car-sharing members among the OBOS-members may have made this variable more important than it would have been in a larger sample of the population on the region.

7. Conclusion

SAVs represent a rapidly growing technological field with features that can support the development of city regions with more sustainable mobility systems based less on private vehicle ownership. It is frequently promoted as an innovation that can improve safety, accessibility, and equity among travellers. However, there is a risk that the same technology can bolster current unsustainable mobility practices by improving the attractiveness of private cars instead of making public transport more relevant and accessible. In this dim vision, autonomous mobility will exacerbate suburban sprawl and fossil fuel usage and further diminish public transit and active travel modes. To reap the benefit of SAVs and avoid what Sperling (2018) describes as a 'hell scenario' for automated vehicles, it is necessary that citizens actually change their travel practices by moving away from private fossil fuelled cars.

This study suggests that there are deeply held mobility practices evolving around the fossil car that obstruct a shift to SAVs as part of a sustainable transport system, although we also see that this may become adopted by people adhering to sharing practices and sustainable lifestyles. Private cars are currently a crucial part of the mobility system and many social practices are centred around the car as a material artefact and cultural symbol (Bissel et al., 2020). Thus, an automatic shift from private car-based mobility forms to SAVs is unlikely to happen without policy measures and actions that actively engage people to change their mobility practices and constrain unsustainable behaviour. Simply informing about the negative impact of private cars and encouraging sustainable forms of mobility have, in this respect, proven to be insufficient. A navigable way forward may be to develop and frame SAVs in ways that make them attractive and useful for people who currently adhere to green social practices. If green mobility practices can be demonstrated, with beneficial outcomes for individuals, communities and cities, this may spur a further upscaling of SAVs as a sustainable mode of mobility.

Notes

1. In this paper, we use the term SAV for all type of shared autonomous vehicles.
2. For an overview, see Axsen and Sovacool (2019).
3. For more detailed overviews, see Becker and Axhausen (2017) and Golbabaei et al. (2021).
4. OBOS is the largest developer of residential areas in Norway operating as a cooperative with over 500,000 members. https://nye.obos.no/dette-er-obos/english/.
5. This project run a population survey, where respondents could indicate whether they could also be contacted for participation in a qualitative interview.
6. The field work took place during the COVID-19 pandemic, and most informants preferred to be interviewed through digital media rather than face-to-face.

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Declaration of interests

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Notes on contributors

Dr. Tom Erik Julsrud holds a PhD in sociology and an MBA in communication studies from the University of Oslo. He currently works as a Senior Research Scientist and Research Director at CICERO Center for International Climate Research. His research interests include social practice theory, sustainable consumption, socio-technical innovation theory, trust and collaborative consumption. He has recently published the book; Trust in network organizations, at Fagbokforlaget (2020).

Dr. Steffen Kallbekken is Research Director for the Climate Economics group at CICERO. His research has focused on climate policy instruments, international climate agreements. pro-environmental behavioural change, long-term climate targets, and the mitigation of short-lived climate forcers. He uses surveys, lab and field experiments in his research. His current research is focused on mitigating the climate impact of aviation and on enabling the green transition in Norway by developing deeper insights into the public response to new climate technologies.

Dr. Marianne Aasen is a senior researcher at CICERO Centre for climate research and holds a PhD in institutional economics from the University of Life Sciences, Norway. Her research focuses on public responses to climate change and climate policies and she is trained in both qualitative and quantitative methods. She is Contributing Author to the Intergovernmental Panel on Climate Change Working Group 3 for its Sixth Assessment Report (IPCC WG3).

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