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Consequences of autonomous vehicles: Ambivalent expectations and their impact on acceptance

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ABSTRACT

Connected and autonomous vehicles (CAVs) are within reach of widespread deployment on public roads, but public perceptions are ambivalent. The objective of the present research was to assess expectations about the consequences of CAV introduction. These expectations should explain CAV acceptance, but their relative importance is poorly understood. We conducted a survey with a representatively drawn panel sample ($N = 529$) from France, Germany, Italy, and the UK. The survey consisted of a large item pool of expected consequences from CAV introduction, as well as general and affective evaluation of CAVs, ease of use, and behavioral intention to use CAVs. Exploratory factor analysis revealed four facets of expected consequences: road safety, privacy, efficiency and ecological sustainability. On average, expectations were mostly positive for ecological sustainability and safety, but negative for privacy. At the same time, substantial variance existed between respondents and between countries. For safety and efficiency, improvement was expected by a third of respondents, while another third expected worsening. Respondents from Italy expected more positive consequences for safety, while respondents from both France and Germany expected more negative consequences for privacy. To different degrees, all four facets predicted the intention to use CAVs in a structural equation model, primarily via affective evaluations. For policy makers, manufacturers, and service providers, understanding the trade-offs inherent to different CAV solutions will be central to ensure citizens' needs are respected.

1. Introduction

Connected and autonomous vehicles are expected to become widespread in transportation, yet consequences of their adoption are consistently judged as ambivalent by most prominent stakeholders (Anderson et al., 2016; Hancock, 2019; Kassens-Noor et al., 2020; Sharma & Mishra, 2020). Policy makers, mobility consultants, academics and representatives of the automobile industry all have pointed out both barriers and motivators to CAV adoption, as well as positive and negative consequences depending on implementation (Kacperski, Vogel, & Kutzner, 2020). Potential benefits as well as shortcomings of connected and autonomous cars (CAVs) are evident in a variety of areas such as social inclusivity (Bennett, Vijaygopal, & Kottasz, 2020; Harrison & Ragland, 2003), sustainability (Greenblatt & Saxena, 2015; Litman, 2019), road safety (IIHS, 2010; Papadoulis, Quddus, & Imprialou, 2019), as well as

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virtual and data safety (Contissa, Lagioia, & Sartor, 2017; Parkinson, Ward, Wilson, & Miller, 2017). In addition, new infrastructure will be required for their proper functioning (Datta, Da Costa, Härri, & Bonnet, 2016). Cities will need to be adapted, as CAVs will affect other modes of transport, and potentially increase urban sprawl (Zhang, & Guhathakurta, 2017; 2018). Changes to parking infrastructure and routes will directly impact traffic, travel time and comfort (Duarte & Ratti, 2018; Noruzoliaee, Zou, & Liu, 2018).

Studying CAV acceptance by observing actual usage behavior is challenging, with very few opportunities available to make in vivo experiences (for exceptions see, Xu et al., 2018; Zoellick, Kuhlmey, Schenk, Schindel, & Blüher, 2019). However, intentions, attitudes and evaluations have been widely studied via surveys and interviews. On one hand, users report feelings of ambivalence, i.e. they see positive as well as negative aspects of CAVs at the same time (Haboucha, Ishaq, & Shiftan, 2017; Hardman, Berliner, & Tal, 2019; Kyriakidis, Happee, & de Winter, 2015; Liu, 2020), and report anticipating both benefits and risks (Liu, & Xu, 2020; Xu et al., 2018; Zhang et al., 2019). In a study on public attitudes conducted in China, more than half of the participants self-identified as ambivalent (P. Liu, 2020).

On the other hand, CAVs also polarize opinions between users, that is, some users evaluate CAVs more positively, others negatively. Research often reports on polarized opinions with a focus on demographics (Becker & Axhausen, 2017; Hudson, Orviska, & Hunady, 2019; Kyriakidis et al., 2015; Nordhoff, van Arem, & Happee, 2016). For example, on average, between 30% and 70% of respondents in surveys reviewed by Becker and Axhausen (2017) stated they would feel positive towards and be willing to adopt CAVs, while between 45% and 88% reported being scared and worried to use them, depending on the study. Exact numbers are commonly dependent on country and sample recruited, with younger, urban, male participants and participants from Asian countries reporting more positive attitudes (see also, Golbabaei, Yigitcanlar, Paz, & Bunker, 2020; König & Neumayr, 2017).

In elaboration, research has recently started to produce a more fine-grained understanding of acceptance (Golbabaei et al., 2020; Nordhoff, Kyriakidis, et al., 2019), scrutinizing drivers of acceptance. A majority of research, according to recently published literature reviews (Jing, Xu, Chen, Shi, & Zhan, 2020; Johnsen et al., 2017; Nordhoff, Kyriakidis, et al., 2019), focuses on an immediate, user-experience heavy interaction future drivers might have with CAVs, measuring such constructs as ease of use, trust, facilitating conditions to vehicle use, and compatibility with the vehicle. Specifically, the Technology Acceptance Model (TAM, Davis, 1989) and the Unified Theory of Acceptance and Use of Technology (UTAUT2, Venkatesh, Thong, & Xu, 2012) have been most commonly adopted as a starting point, with higher perceived ease of use and usefulness increasing acceptance (Jing et al., 2020; Nordhoff, de Winter, Madigan, et al., 2018; Nordhoff, Madigan, et al., 2020; Sener, Zmud, & Williams, 2019; Zmud & Sener, 2017). Trust or risk assessment have also been found to play a role in individuals' acceptance assessments (P. Liu, Yang, et al., 2019; Panagiotopoulos & Dimitrakopoulos, 2018; Zhang et al., 2020), with a large section of the literature specifically covering individuals' perceived accident risk (Bansal, Kockelman, & Singh, 2016; Hulse, Xie, & Galea, 2018; Jing et al., 2020; Montoro et al., 2019) and travel convenience (Hartwich, Beggiato, & Krems, 2018; Howard & Dai, 2014; Kyriakidis et al., 2015; Nordhoff, de Winter, et al., 2019; Site, Filippi, & Giustiniani, 2011). Finally, moral and ethical challenges have been discussed in relation with acceptance (Bonnefon, Shariff, & Rahwan, 2016). Together with risk and benefit appraisals, moral righteousness/fairness of a CAV's decision-making has been shown to influence participants' intentions to use CAVs (P. Liu & Liu, 2021).

A secondary section of the research focuses on person characteristics that might aid in CAV acceptance; for example, from a technological perspective, higher tech savviness, trust in technology, and direct experience with a CAV have been found to be relevant to higher acceptance (Dennis, Paz, & Yigitcanlar, 2020; Lavieri et al., 2017; Penmetsa, Adanu, Wood, Wang, & Jones, 2019; Wang, Jiang, Noland, & Mondschein, 2020; Zhang et al., 2020), as well as motivational factors such as hedonic motivation or sensation seeking (Gkartzonikas & Gkritza, 2019; Haboucha et al., 2017; Nordhoff, Madigan, et al., 2020; Payre, Cestac, & Delhomme, 2014; Wang et al., 2020).

As a limitation, the above approaches rely heavily on investigating aspects that make CAVs more attractive to potential future users, focusing on immediate consequences of using CAVs. However, more than future users, it will be policy makers, manufacturers and service providers that shape CAV introduction and therefore determine how socially inclusive, environmentally beneficial, and safe the introduction of CAVs will be. To meet broader needs, it is paramount that they understand how citizens expect CAVs to impact the world around them, especially in the case of large-scale adoption. Policy design and regulation should strive to allay citizens' fears and fulfill their hopes in how wide-spread CAV adoption might affect society.

Some studies deal with citizens' expected larger-scale consequences, such as for sustainability, infrastructure efficiency or economic comfort, though they are infrequent compared with studies on personal risks and benefits (for literature reviewers where this is showcased, please see Golbabaei et al., 2020; Jing et al., 2020; Nordhoff, Kyriakidis, et al., 2019). Research has specifically investigated the expected impact of CAVs on the environment (Fagnant & Kockelman, 2014; Jing et al., 2020; Wu, Liao, Wang, & Chen, 2019), on economic prosperity (Golbabaei et al., 2020; König & Neumayr, 2017), and on larger-scale infrastructure and safety improvements (Payre et al., 2014; Schoettle & Sivak, 2014). Overall increases in social inclusiveness, and social recognition have also been reported as relevant by participants (Jing et al., 2020; König & Neumayr, 2017). However, further study seems necessary to identify which large-scale consequences are most important for citizens, their relative importance compared to personal consequences, and which predict acceptance and behavioral intention better. All consequences might plausibly affect CAV acceptance, but to date it is unclear how they are interrelated and how much each of these expectations contributes to CAV acceptance when jointly investigated.

Theoretically, the prediction of behavioral intention is often built on the theory of planned behavior (TPB) (Ajzen, 1991) and the theory of reasoned action (TRA) (Fishbein, 1979), which deal with attitudes and social norms, but are domain free. The theories build the basis for more specialized theories such as the TAM and the UTAUT2, which fill the models with content and add such factors as ease of use and usability. While this ensures that they capture domains closely related to technology acceptance, they often preclude consequences that are indirectly related to technology use, such as ecology, job security and social inclusion. The core feature of the TPB, i.e. that it views attitudes as expected behavioral consequences, is often overlooked. The TPB provides straightforward implications about how to study acceptance: by semantic differentials enabling positive versus negative consequences within the same item (Ajzen, 2002; Vogel & Wänke, 2016). Despite such clear measurement implications, studies often use an eclectic measurement approach instead of assessing expected consequences and, even if they do investigate consequences, rarely offer differentiated valence options. The present research seeks to address both these weaknesses, studying both personal and large scale expected consequences with a stringent measurement approach.

Further, we differentiate between general evaluations and affect-based evaluations, as emotional pathways to CAV acceptance have previously proved important (P. Liu, Xu, et al., 2019). For example, anxiety-related feelings (Hohenberger, Spörrle, & Welpe, 2017), fear, and amusement (Zoellick et al., 2019) have been linked to CAV usage intentions. Yet, usually acceptance is studied as a homogenous, largely cognitive construct, for example when assessed as overall attitudes from positive to negative (H. Liu, Yang, et al., 2019), or from opposing to favoring CAVs (Hulse et al., 2018). Other studies have assessed the comfort with CAVs (Hudson et al., 2019) or concern with CAVs (Charness, Yoon, Souders, Stothart, & Yehnert, 2018), containing affective components, but did not differentiate them from a general, more cognitive assessment, as we attempt in the following research.

To identify factors of expected consequences as well as their relative impact on CAV acceptance, a cross-national survey was conducted collecting representatively drawn samples from panels in Germany, France, Italy and the UK. So far, most studies on CAV acceptance have been conducted with participants from one country only, or a random sample from multiple English-speaking countries, such as 38 out of 43 surveys reported by Gkartzonikas and Gkritza (2019), 14 out of 16 surveys reviewed by Becker and Axhausen (2017), and all studies focusing on behavioral intentions reviewed by Keszey (2020). Many other prominent reviews do not report country of residence at all (Faisal, Yigitcanlar, Kamruzzaman, & Currie, 2019; Golbabaei et al., 2020; Milakis, Van Arem, & Van Wee, 2017; Nordhoff, Kyriakidis, et al., 2019). Previous studies that have reported country-level differences in acceptance have used them to predict the effects of GDP and developmental indexes (Kyriakidis et al., 2015; Nordhoff, de Winter, Kyriakidis, et al., 2018). In the following, we will therefore analyze in an explorative manner differences in expected consequences and acceptance across four European countries; such differences, when controlling for age, gender and income, could provide insight into indications for CAV acceptance other than socio-demographics.

We assessed a multitude of expected consequences based on literature and expert opinion, together with CAV evaluations and usage intentions as indicators of CAV acceptance. We employed Structural Equation Modelling (SEM) to analyse the data. This approach has been successfully used in previous research assessing the predictive power of different CAV aspects: most commonly TAM factors, including subsets of other predictors such as trust, feelings of safety and self-efficacy, or ownership as predictors (Choi & Ji, 2015; Lee, Lee, Park, Lee, & Ha, 2019; Xu et al., 2018); and UTAUT2 factors, including hedonic motivation, performance and effort expectancy and social influence (Nordhoff, Louw, et al., 2020; Nordhoff, Madigan, et al., 2020). Other SEM approaches have predicted CAV acceptance from demographic factors and mobility patterns (Hassan, Ferguson, Razavi, & Vrkljan, 2019; Montoro et al., 2019), as well as technological competency (Choi & Ji, 2015; Manfreda, Ljubi, & Groznik, 2019; Nazari, Noruzoliaee, Mohammadian, & Kouros, 2018). A combination of safety, sustainability and cost was used in one model, (P. Liu, Yang, et al., 2019), though merged into a common factor, therefore not allowing for conclusions about the relative contribution of different aspects. Lastly, while many of the above investigate attitudes and evaluations of CAVs, or intention to use/adopt, none model a relationship between the two variables, with evaluations predicting behavioral intentions.

1.1. Present research and hypotheses

The present research aims at integrating the diverse findings on CAV acceptance obtained from previous research. Complementing previous research that assesses immediate consequences and general CAV evaluations, we included large-scale consequences as well as affect-based evaluations within the same questionnaire. For a sensitive measure of expected positivity versus negativity, the questionnaire is developed against the original conception of the TPB. By means of factor analysis, we will examine the interrelation of expected consequences, and by means of SEM, we will study each factor's relative impact on usage intentions.

We predict to find distinguishable factors of CAV consequences. We expect ambivalence across factors (i.e., a participant holding positive and negative expectations depending on the factor). We further expect polarization between participants (i.e. for the same factor, some participants hold positive, but others hold negative expectations). We expect that residing in different countries will yield differences in expectations. Lastly, we hypothesize that consequence factors would predict both general and affective evaluations with varying strength, and that both general and affective evaluations would predict behavioral intentions. Based on findings on demographics from previous literature (Becker & Axhausen, 2017; Charness et al., 2018; Golbabaei et al., 2020), age and gender are included, expecting that younger and male participants would have higher intentions to use CAVs.

2. Methods

2.1. Survey

An extensive survey was generated with CAV-related items[1] based on prior literature. The study design is presented in Fig. 1. After introduction and consent procedures, but before participants were asked to answer the items, they were shown an icon graphic of an

[1] Please see Appendix A for full list of items for all scales.

autonomous car (a sedan with a wireless signal emitting from it), and a short vignette depicted the functioning of a self-driving car (Level 5)[2]. Then participants were asked about their general and affective evaluations regarding CAVs, presented with the items on personal and large-scale consequences, their intention to use CAVs, and expected CAV ease of use, all adapted from items previously used in the CAV literature. Lastly, current mobility behaviors, participants' experience with CAVs, and socio-demographics were collected.

For the consequence items, we took into consideration the wide range of previously predicted personal and large-scale consequences from CAV propagation (Anderson et al., 2016; Kassens-Noor et al., 2020; Narayanan, Chaniotakis, & Antoniou, 2020; Nordhoff et al., 2016) and based on insights from qualitative interviews carried out independently with various stakeholders (Kacperski et al., 2020). For each consequence, we measured its evaluation, and its importance for the participant (Krosnick & Abelson, 1992; Vogel & Wänke, 2016). For example, with reference to the large-scale environmental consequences, we asked to rate on 7-point semantic differentials the statement, "If large sections of the population used connected and autonomous vehicles, the environment would be doing [better to worse]." For importance we asked to rate the statement "The fact that the environment is doing well is [unimportant to important] to me." For personal consequences, an example would be "If I used an autonomous car, my personal data would be [less secure to more secure], followed by "A high level of security for my personal data is… [unimportant to important] to me." Only scale end points were labelled as indicated in square brackets above. The text and labels of all items can be found in Appendix A.

Only six individuals reported experience with autonomous cars, and thus the variable was excluded from further analyses. Table 1 gives an overview over scale reliability (Cronbach alphas all acceptable), and an example item for each scale.

Items and the vignette, developed in English, were translated into three further languages by a professional translation service in line with ISO17100, as participants were recruited from four countries (Germany, Italy, France, and UK). A translation back into the original English was then conducted by researchers fluent in both the target language and English. Minor discrepancies were discussed and corrected by the professional translation service. Additionally, two versions of the survey were generated. To control for potential biases of agreeing to right hand options, participants randomly received the more positive option on the most right or on the most left pole of the scale.

The survey was carried out in line with ethics requirements of the German Ethics Board (DGPS) as well as European data protection guidelines (DGPR).

2.2. Participants and data

536 participants were recruited from a professional panel provider. All participants were remunerated for their time based on the panel's standard practices. Participants spent a median of 20 min on the survey ($SD = 6.87$). We excluded participants due to a failed instructional attention check (Oppenheimer, Meyvis, & Davidenko, 2009) and retained 529 participants (249 women) across the four selected countries (France = 132, Germany = 120, Italy = 149, UK = 120, Other = 8). Ages ranged from 18 to 71 ($M = 43.14$, $SD = 14.03$), with over 68% of participants having obtained high school degree or equivalent). The panel provided a representatively drawn sample based on country-level demographics in terms of age and gender (crossed).

Regarding mobility behavior, 40 participants did not have a driver's license (7.5%), and 91 did not own a car (17.2%). Only 6 participants indicated having used an autonomous car before, with 32 having used an autonomous train or shuttle; 43 respondents indicated having used some form of autonomous function, with the majority using cruise control.

Data was handled with R statistics (R Development Core Team, 2008). For the items measuring consequences, we created a measure weighting the expected consequences with the perceived importance. Valence ratings were recoded into the range −3 to 3 and multiplied with the importance ratings from 1 to 7 (Ajzen & Fishbein, 2008; Krosnick & Abelson, 1992). Before conducting the analyses, all variables were mean-centered. EFA, CFA and SEM were performed on these weighted items. Descriptive statistics are reported of raw valence and importance scores.

2.3. Analytical approach

Fig. 2 shows the process undertaken to analyze data in this study. The first step was an examination of survey responses and data quality checks, including processing exclusions.

Factor analyses were conducted on the set of items on expected consequences upon widespread CAV introduction[3]. To extract the number and nature of latent factors, an exploratory factor analysis with Promax rotation was conducted, as orthogonality could not be assumed (Hendrickson & White, 1964). This was done on a random 50% subset of the data. For the EFA, the iterative approach by Hair, Black, Anderson, and Babin (2018) was followed. Dependent variables were not included in the EFA; the evaluation scales, and the behavioral intention scale were analyzed separately for factor structure, supporting a two-factor solution for evaluation, and one-factor solution for behavioral intention (see Appendix F). For the consequence items, while loadings above 0.30 are usually accepted as statistically significant, our aim was to reduce the number of items extensively both for best interpretability and to generate a short

[2] "In the following we will ask you some questions about autonomous and connected vehicles (Connected Autonomous Vehicle, CAV for short). The distinctive feature of a CAV is that it is not controlled by a human driver. Instead, it is completely controlled by a computer system. The vehicle takes over all driving tasks and automatically controls all actions, including steering, acceleration and braking."

[3] The item "impact of CAVs on state control" (Appendix A Part 2, Item 77/78) had to be excluded from analysis due to a data collection error.

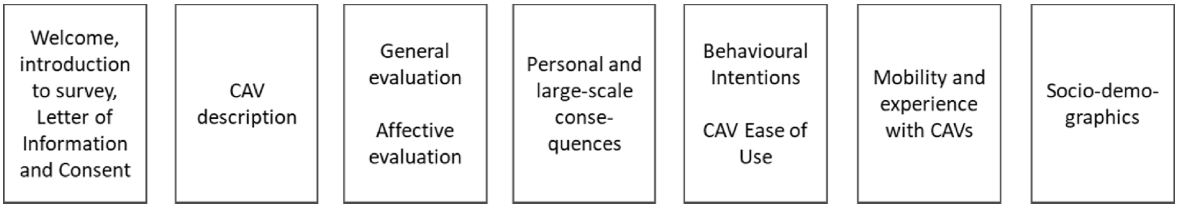

Fig. 1. Survey flow. Items of individual scales were sometimes presented across multiple pages for better readability.

Table 1
Measurement properties for key constructs.

Construct	Example item	α
General evaluation	In principle, I find connected and autonomous cars… [*very bad to very good*]. (7-point rating)	0.94
Affective evaluation	The idea of large sections of the population using connected and autonomous cars feels good. [*disagree completely to agree completely*] (7-point rating)	0.91
Behavioral Intention to Use	If connected and autonomous cars were available, I would use them. [*disagree completely to agree completely*] (5-point rating)	0.92
Ease of Use	I think I could do well with connected and autonomous cars. [*disagree completely to agree completely*] (5-point rating)	0.80
Knowledge	I think I am very well informed about the latest trends in autonomous mobility. [*disagree completely to agree completely*] (5-point rating)	0.77
Experience	I have used autonomous technologies before, namely a completely autonomous car.	–

Note. Further items in Appendix A. Alpha (α) refers to Cronbach's alpha value.

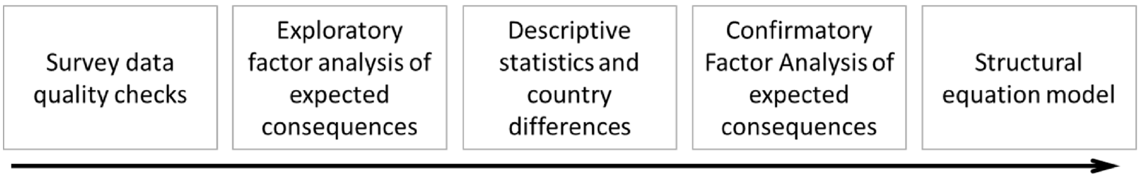

Fig. 2. Procedure description to final structure.

survey version based on this analysis. Thus, we decided on a stricter cutoff for factor loadings at 0.70. To assure that factor loadings were as unique as possible, no secondary factor loadings above 0.15 were accepted.

Following the EFA, descriptive statistics such as means and standard deviations, as well as group differences for country were calculated. Linear regressions and Tukey multiple comparisons were conducted, controlling for age, gender and income. We report F-statistics and partial eta squared for effect sizes.

On the second half of the data, a confirmatory factor analysis was conducted to confirm the structure and ensure adequate values on the fit indices (Fokkema & Greiff, 2017). The final SEM path analysis, including the modelling of the factors, was conducted with the entire dataset for maximum power.[4] Significances and β regression coefficients as an estimate of the effect size are reported.[5]

3. Results

3.1. Exploratory factor analysis

The Kaiser-Mayer-Olkin (KMO) test and Bartlett's test showed that the examined data was acceptable for factor analysis in terms of sampling adequacy (0.96) and held sufficient significant correlation in the data ($\chi 2\ (1326) = 12669.06$, $p < 0.001$). The screeplot (see Fig. 3) points to a satisfactory four factor solution.

Out of the original 53 item pairs, 15 were retained, and the final item solution can be seen in Table 2. The four latent factors accounted for 73.77% of the total variance, with the first factor (safety) accounting for 20.00%, the second factor (sustainability) accounting for 18.30%, the third factor (efficiency) accounting for 21.46%, the fourth factor (privacy) accounting for 14.01%.

Acceptable discriminant validity was found for this solution, with heterotrait-monotrait (HTMT) criteria for each pair of constructs on the basis of item correlation values between 0.59 (for Safety/Efficiency) and 0.46 (for Sustainability/Privacy), clearly smaller than one (Henseler, Ringle, & Sarstedt, 2015). Average variances extracted (AVE, shown on the diagonal in Table 3) were >0.5, and greater

[4] Please see Appendix B for a detailed description of the procedure used.

[5] Unstandardized *b* values as well as standard errors and *z*-values, and results of all group difference statistics and Tukey mean comparisons can be found in Appendix C, the model-implied covariance matrix in Appendix D, and residuals of the fitted model in Appendix E.

than the associated inter-construct correlations, shown off the diagonal in Table 3 (as suggested by Hair et al., 2018).

3.2. Descriptive statistics

Descriptive statistics of raw scores for consequence and importance items are reported in Table 4. On average, participants' ratings for intention to use, and both general and affective evaluation of CAVs, consistently stayed below the scale midpoint. More positive was the expectation regarding CAV ease of use. Additionally, participants on average felt that CAVs would positively affect road safety and environmental sustainability, while they felt neutral regarding efficiency, and negative regarding privacy matters. Ratings were generally high for all assessed importance factors, particularly for safety and sustainability, while respondents did not feel quite as strongly about the importance of efficiency.

Country-specific means and standard deviations for intentions to use, evaluations, ease of use, and the consequence and importance factors are reported in Table 5. It can be observed that Italian residents consistently had more positive expectations for CAVs than their German, French and UK counterparts.

In terms of behavioral intention, we found a significant difference for residence country, $F(3, 458) = 4.86$, $p = 0.002$, $\eta p = 0.03$; a Tukey comparison revealed that compared to residents from Italy, both French ($p = 0.003$) and German ($p = 0.012$) participants had lower intentions to use CAVs. The same pattern could be observed for general evaluation, $F(3, 458) = 4.19$, $p = 0.006$, $\eta p = 0.03$; here, French ($p = 0.006$) and German ($p = 0.044$) participants also reported a lower evaluation. In terms of the affective evaluation, which differed for residence countries, $F(3, 458) = 6.96$, $p < 0.001$, $\eta p = 0.04$, French, German and UK residents indicated significantly lower evaluations than Italian participants (p's < 0.02). Ease of use showed a similar pattern, $F(3, 458) = 6.39$, $p < 0.001$, $\eta p = 0.04$, with again Italian participants expecting a more positive outcome (all p's < 0.006).

Additionally, we observed significant differences predicted by participants' residence country on the factors safety, $F(3, 458) = 5.95$, $p < 0.001$, and privacy, $F(3, 458) = 19.27$, $p < 0.001$. Tukey comparisons here indicated that regarding safety, participants from Italy had higher positive expectations than participants from the other three countries (p's < 0.006); no significant differences were found between the other three (p's > 0.980). Regarding privacy, no significant differences were found between participants from France and Germany ($p = 0.999$) and between participants from Italy and the UK (p's $= 0.428$), while residing in France and Germany concurred with higher negative expectations regarding privacy consequences as compared to in Italy and the UK ($p < 0.001$). No significant country-level differences were found for any of the importance ratings (p's > 0.108).

At the same time, we found between-participant polarization about the expected consequences, as can be seen in the bar plot in Fig. 4, which shows the number in % of respondents that believed improvement (top bars) or deterioration (bottom bar) would be the consequence of CAV introduction regarding the specified areas of impact (safety, sustainability, efficiency, privacy). Specifically, there was considerable divergence about safety, with over 49% of respondents across all countries expecting CAVs to improve it (rating values > 0.5), and 28% or more participants expecting CAVs to deteriorate it (rating values $<$ -0.5). The exception was Italy, where only 19% of the respondents expected worsening. Regarding efficiency, over 25% of respondents across the four countries expected improvement and 30% or more expected a deterioration. There was a clearer trend for privacy among respondents from France and Germany, almost two thirds expecting a worsening; for participants from the UK and Italy, this was still over half the respondents. Very few respondents expected privacy to improve. Regarding ecological sustainability, 48% or more of the participants across all countries expected CAVs to bring an improvement, while only maximally 22% expected a worsening.

3.3. Structural equation model

A confirmatory factor analysis was applied to the second half of the dataset and confirmed the findings of the exploratory factor analysis above. Latent variables were confirmed as reported in Table 3, with fit measures adequate to good as reported in Table 6 (Hooper, Coughlan, & Mullen, 2007; Kline, 2005).

Acceptable discriminant validity was found for the CFA, with heterotrait-monotrait (HTMT) criteria for each pair of constructs on the basis of item correlation values between 0.62 (for Safety/Efficiency) and 0.29 (for Sustainability/Privacy), clearly smaller than one (Henseler et al., 2015).

We defined the path model in *lavaan* based on the theoretical foundations of the TPB, where evaluations are a result of expected consequences (Ajzen, 1991); therefore, we modelled effects onto evaluations, which we expected in turn to affect behavioral intentions[6]. We obtained similar fit statistics, indicating a good fit of the model (see Table 6 and Appendix C for further detail). Fig. 5 shows the obtained parameter values with significances illustrating the relationships from the model output. The R^2 value in the structural model for behavioral intention was 0.874, with $R^2 = 0.871$ and $R^2 = 0.424$ for affective and general evaluations respectively; R^2 values of all other predictors were > 0.287, greater than the cutoff value of 0.10 (Falk & Miller, 1992). Almost all values were >0.50 (see Appendix C). Thus, acceptable explanatory power for all endogenous variables in our model was reached.

Participants' intentions to use CAVs were most strongly predicted by their affective evaluations of CAVs, $\beta = 0.88$, $p < 0.001$, and, to a lesser degree, by their general evaluations, $\beta = 0.09$, $p = 0.001$. Age and gender did not affect intention to use, p's >0.19. Affective evaluations were most strongly predicted by expected impact of CAVs on safety, $\beta = 0.33$, $p < 0.001$, and the expected ease of use, $\beta = 0.53$, $p < 0.001$. Consequences for privacy, $\beta = 0.10$, $p = 0.001$, efficiency, $\beta = 0.07$, $p = 0.033$, and sustainability, $\beta = 0.06$, $p = 0.05$,

[6] We additionally tested a second model including additional direct paths from the factors Sustainability, Privacy, Safety, and Efficiency to Intentions to Use; we did not find significant direct effects, with all p's > 0.085.

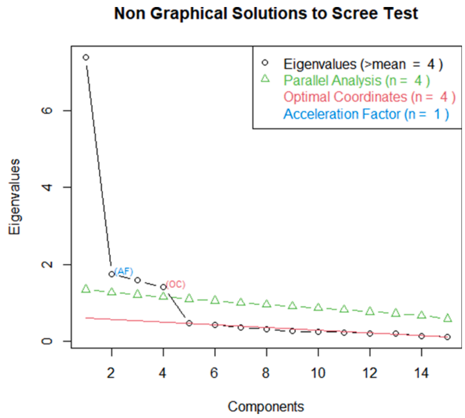

Fig. 3. Scree Plot with number of components suggested by Eigenvalues, Parallel Analysis and Optimal Coordinates all point to a four-factor solution.

Table 2
Latent factors with content of items, their loadings, complexity and uniqueness values.

Latent factor	Item	Loading	Complexity	Uniqueness
Safety	Number of accidents	0.91	1.03	0.19
	Danger of travel	0.90	1.05	0.15
	Accident risk	0.87	1.05	0.23
	Road safety	0.85	1.05	0.21
Sustainability	Emissions	0.92	1.02	0.18
	Pollution	0.84	1.01	0.30
	Environmental degradation	0.83	1.08	0.17
	Environmental cost	0.80	1.00	0.35
Efficiency	Speed of travel	0.85	1.01	0.29
	Speed of vehicles	0.84	1.06	0.33
	Travel time	0.78	1.06	0.26
	Duration of trip	0.76	1.06	0.36
Privacy	Data abuse	0.86	1.03	0.26
	Data safety	0.84	1.02	0.21
	Surveillance	0.74	1.06	0.44

Table 3
Factor correlations and AVEs.

Construct	Safety	Sustainability	Efficiency	Privacy	α
Safety	*0.79*	0.51	0.56	−0.52	0.94
Sustainability		*0.74*	0.42	−0.48	0.92
Efficiency			*0.68*	−0.50	0.89
Privacy				*0.69*	0.87

Note: Diagonals are average variance extracted (AVEs). The off-diagonal elements are the correlations between the constructs. Alpha (α) is the Cronbach's alpha for each factor.

also predicted affective evaluations. General evaluations were predicted by expected consequences for safety, $\beta = 0.40$, $p < 0.001$, efficiency, $\beta = 0.15$, $p = 0.003$ and ease of use, $\beta = 0.18$, $p = 0.011$. No association was found with expected consequences for sustainability and privacy, p's >0.11, nor was there an association with knowledge about CAVs (p's >0.10).

4. Discussion

As autonomous vehicles are reaching road readiness, understanding what drives public acceptance is key in developing a functional and inclusive standard for their better integration into everyday life. The present paper elaborates on drivers of public acceptance in terms of expected consequences of widespread autonomous car adoption that can inform the design of autonomous transport solutions that maximize acceptance. A survey administered to a representatively drawn panel sample of respondents in four large European countries measured a multitude of expected consequences and their subjective importance. Based on factor analysis, four major expected impact areas emerged: safety, environmental sustainability, efficiency , and privacy.

Results indicate that participants were reticent about their intention to use CAVs. The present study allows for insights as to the

Table 4
Raw score means and standard deviations for intention to use, evaluations, ease of use, consequence and importance factors.

Scales (midpoint)		α	Mean	SD	Median	SE
Intention to Use (3)		0.92	2.96	1.33	2.80	0.12
Evaluation (4)	General	0.96	3.86	1.87	4.00	0.17
Evaluation (4)	Affective	0.92	3.88	1.77	4.00	0.16
Ease of Use (3)		0.76	3.20	1.29	3.50	0.12
Consequence (0)	Safety	0.93	0.47	1.66	0.50	0.07
Consequence (0)	Sustainability	0.93	0.62	1.47	0.50	0.06
Consequence (0)	Efficiency	0.87	−0.06	1.35	0.00	0.06
Consequence (0)	Privacy	0.84	−1.07	1.45	−1.00	0.06
Importance (4)	Safety	0.88	6.29	1.00	6.75	0.04
Importance (4)	Sustainability	0.91	6.10	1.08	6.25	0.05
Importance (4)	Efficiency	0.78	4.81	1.28	4.75	0.06
Importance (4)	Privacy	0.77	5.80	1.21	6.00	0.05

Note. Alpha (α) is the Cronbach's alpha for each factor. SD is the standard deviation. SE is the standard error. Intention and Ease of use ratings ranged from 1 to 5. Consequence valence ratings ranged from −3 to 3; Evaluation and Importance ratings ranged from 1 to 7. Scale midpoints are indicated in brackets behind scale name.

Table 5
Raw score means and standard deviations for consequence and importance factors per country.

Scales (midpoint)		Germany	France	Italy	UK
Intention to Use (3)	*	2.96 (1.32)	2.90 (1.24)	3.29 (1.17)	3.14 (1.30)
Evaluation (4)	General*	3.86 (1.87)	3.78 (1.65)	4.29 (1.62)	4.01 (1.84)
Evaluation (4)	Affective*	3.88 (1.77)	3.82 (1.78)	4.45 (1.51)	4.01 (1.74)
Ease of Use (3)	*	3.19 (1.29)	3.14 (1.32)	3.62 (1.22)	3.18 (1.18)
Consequence (0)	Safety*	0.36 (1.66)	0.30 (1.73)	0.80 (1.56)	0.29 (1.64)
Consequence (0)	Sustainability	0.62 (1.41)	0.45 (1.50)	0.76 (1.41)	0.61 (1.60)
Consequence (0)	Efficiency	−0.06 (1.46)	−0.20 (1.20)	−0.08 (1.36)	0.09 (1.34)
Consequence (0)	Privacy*	−1.53 (1.37)	−1.58 (1.25)	−0.58 (1.41)	−0.77 (1.44)
Importance (4)	Safety	6.23 (0.93)	6.31 (1.04)	6.38 (0.88)	6.18 (1.15)
Importance (4)	Sustainability	6.00 (1.03)	6.17 (1.04)	6.27 (0.97)	5.92 (1.22)
Importance (4)	Efficiency	4.84 (1.32)	4.88 (1.33)	4.88 (1.19)	4.60 (1.28)
Importance (4)	Privacy	6.02 (1.24)	5.80 (1.27)	5.70 (1.56)	5.73 (1.24)

Note. Means (standard deviations) of consequence and importance factors. Intention and Ease of use ratings ranged from 1 to 5. Consequence valence ratings ranged from −3 to 3; Evaluation and Importance ratings ranged from 1 to 7. Scale midpoints are indicated in brackets behind scale name. Further values (Cronbach alphas, standard errors), as well as results from statistical comparisons between countries on each factor are reported in Appendix C. * indicates significant difference ($p < 0.05$) between countries.

origin of these intentions. Descriptive analyses of the expected consequences confirmed previous findings about individuals' general ambivalence regarding CAVs (Becker & Axhausen, 2017; Xu et al., 2018). On average, respondents felt that CAVs would positively affect road safety and environmental sustainability, while they felt neutral regarding efficiency, and negative regarding privacy matters. A certain level of polarization was found with regards to safety and efficiency; for each, roughly a third of respondents felt that wide-spread CAV introduction would improve these areas of life, while another third of respondents felt that CAVs would worsen the situation. A far less polarized picture existed for privacy, where worsening was expected by a large majority of participants, and ecological sustainability, where improvement was expected by a large majority.

Country-level analyses yielded insights into differences in expectations regarding safety and privacy: participants from Italy expected higher increases in safety than participants from Germany, France and the UK; and participants from France and Germany had increased negative expectations regarding privacy matters when compared to participants from the UK and Italy. Overall, Italian respondents had consistently more positive expectations from CAV introduction. As we controlled for age, gender and income, and the selected countries do not majorly differ regarding their positioning on the development index, these differences could be indicative of differences that do not stem from sociodemographic factors or GDP as previously assessed (Kyriakidis et al., 2015; Nordhoff, de Winter, Kyriakidis, et al., 2018); future studies into CAV acceptance might do well to include measures to assess cultural or language-based indicators.

Importance ratings for all consequence factors were high, particularly for safety and sustainability. Participants felt that efficiency was the least important of the four factors. No country-level differences were observed for importance.

A structural equation model was employed to explore the predictive relationships between the expected consequences, CAV evaluations and usage intentions. Based on standard models and recent evidence (TPB, TAM, see for example Choi & Ji, 2015; Kaye, Lewis, Buckley, & Rakotonirainy, 2020; Zoellick et al., 2019), we included general and affective evaluations as intermediary variables and ease of use as additional predictor for the evaluations. As expected, usage intentions were predicted by both general and affective evaluations. Yet, the lesser studied affective path proved considerably stronger in predicting usage intentions.

Deepening the understanding of what policy makers, manufacturers and mobility service providers could do to improve CAV

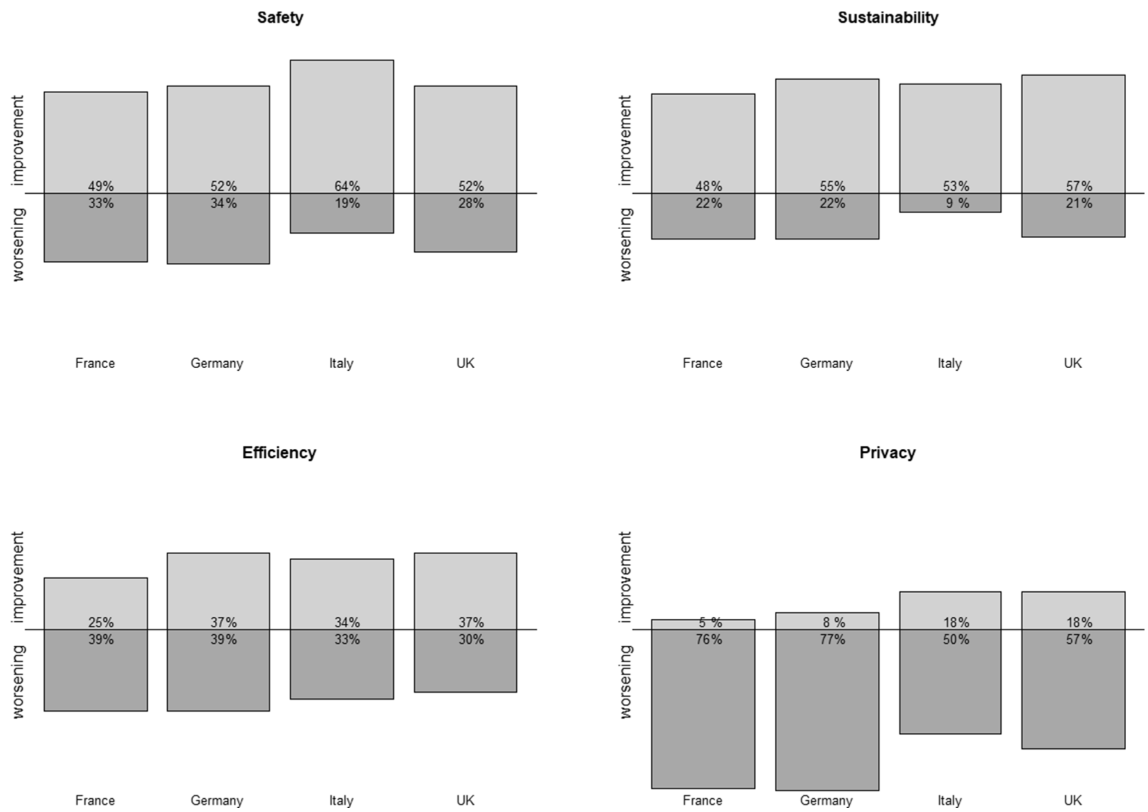

Fig. 4. Percentage of respondents across four countries (France, Germany, Italy, UK), expecting improvement (rating values > 0.5) or worsening (rating values < -0.5) from CAV introduction on the four factors Safety, Sustainability, Efficiency, Privacy.

Table 6
Fit indices for CFA and lavaan model (SEM).

Measure	CFA	SEM	Cutoff
CFI	0.967	0.934	> 0.9
TLI	0.958	0.926	> 0.9
RMSEA	0.068	0.060	< 0.08
SRMR	0.049	0.047	< 0.08
Relative χ^2 (χ^2/df)	2.2:1 *185/84*	2.9:1 *1540/530*	< 3:1

acceptance, multiple areas of expected consequences were predictive of general and affective evaluations. Most prominently, expected consequences for safety were strongly related to both general and affective evaluations. Affective evaluations were additionally related to expected consequences for privacy, ecological sustainability and every-day efficiency. Concerns regarding safety, privacy and sustainability have been previously recognized in the context of CAV trust research (Choi & Ji, 2015; Kaur & Rampersad, 2018; Zhang et al., 2019). The present research empirically supports the notion that safety is the most important issue for CAV acceptance (Acheampong, Cugurullo, Dusparic, & Guériau, 2019; Nastjuk, Herrenkind, Marrone, Brendel, & Kolbe, 2020; Van Brummelen, O`Brien, Gruyer, & Najjaran, 2018; Wu et al., 2019). Any autonomous vehicle solution should be designed to maximize road safety, not only for vehicle passengers but also for co-road users and even at the cost of other variables such as efficiency and leisure options. Yet, especially for the important affective path to usage intentions, acceptable solutions also need to guarantee privacy and environmental protection, as well as improvements to every-day efficiency. Further research is needed as to which autonomous transport solutions, from privately owned cars introduced as top-of-line products, to shuttles as part of public transport, will strike the best trade-offs for citizens.

The present research also calls for an emphasis on affective responses to CAVs. One might speculate that affective CAV evaluations are of prime importance at the present stage where citizens lack reliable knowledge about CAVs. With increasing knowledge, the relevance of cognitive aspects might increase. Until then, and in order to increase predictive validity, more than just direct and mostly cognitive measures of CAV evaluations should be included, such as for example the implicit association test (IAT, Greenwald, McGhee, & Schwartz, 1998).

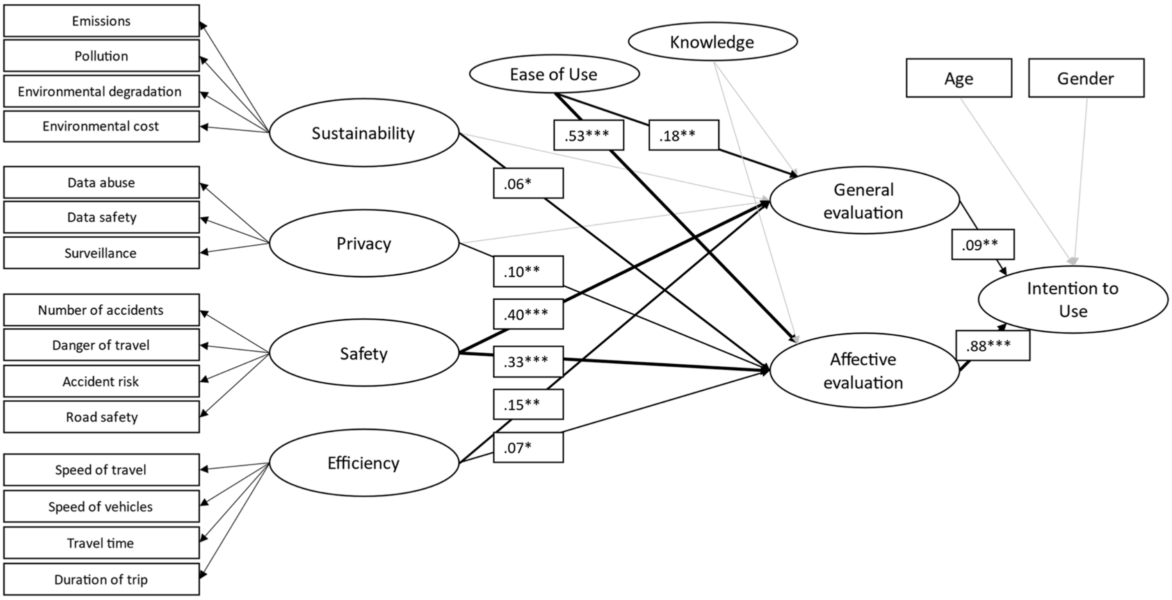

Fig. 5. Path model with standardized regression parameters and significance levels. Paths without regression weight = n.s. Note: line width indicates strength of relationship, with p-values indicated as follows: * < 0.05; ** < 0.01; *** < 0.001.

Concurrently studying a wide array of precursors of CAV acceptance, including psychological and socio-demographic ones, offers advantages. Some precursors, like the expected consequences and ease of use in the current demonstration, might turn out to better predict acceptance than others, such as age, gender and knowledge. This offers clear guidance as where to put the focus when designing CAV solutions. Also, while socio-demographics merely offer guidance to segmented marketing, psychological precursors hold the promise to implement CAV solutions that resonate with society at large.

4.1. Limitations

While the current study presents a first attempt to sample CAV evaluations Europe-wide, with country-level stratification regarding age and gender, the number of participants needs to be increased in future research to study between=country differences with structural equation models. These differences will provide further insights into the levers needed to improve CAV introduction, and to make it accessible, safe, and inclusive for a variety of subpopulations and their cultural demands. Giving voice to subpopulations such as persons with visual impairments, pedestrians, and other road co-users, as well as other vulnerable populations or minorities is strongly encouraged. While some studies exist specifically researching the experience of for example blind people, they are rare and tend to be more qualitative in nature (Bennett et al., 2020; Brinkley, Posadas, Sherman, Daily, & Gilbert, 2019).

Finally, the study of affective and cognitive pathways and evaluations deserves further attention; while we shone a spotlight on the necessity to include affective evaluations when researching CAV acceptance, an important facet of further study should be the contrasting of affective and specific cognitive evaluations, both to investigate their impact on willingness of CAV adoption, but also to provide ideas for further interventions and incentive strategies.

4.2. Conclusions

In summary, our research confirms previously reported perceptions of ambiguity towards CAV adoption. We add to the evidence regarding anticipated benefits and risks by going beyond the study of individual interactions with CAVs, providing a more nuanced picture of which areas of life and society are expected by citizens to be most strongly affected by CAV introduction: road safety, sustainability, privacy and everyday efficiency. We model the relationships between expected consequences and CAV evaluation, as well as how this affects individuals' intentions to use, and find that affective evaluations in particular are a major indicator towards CAV acceptance.

CRediT authorship contribution statement

Celina Kacperski: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Project administration. **Florian Kutzner:** Conceptualization, Methodology, Writing - review & editing, Supervision. **Tobias Vogel:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2021.06.004.

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