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Who is more attached to their car? Comparing automobility engagement and response to shared, automated and electric mobility in Canada and Germany

Viviane H. Gauer [a,*], Jonn Axsen [a], Elisabeth Dütschke [b], Zoe Long [a], Aline Kelber [b]

[a] School of Resource and Environmental Management, Simon Fraser University, TASC 2, Room 7420, 8888 University Drive, Burnaby V5A 1S6, British Columbia, Canada

[b] Fraunhofer Institute for Systems and Innovation Research ISI, Breslauer Strasse 48, Karlsruhe 76139, Germany

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ABSTRACT

The "automobility system" encompasses the prevalence of the privately-owned car in industrialized societies. We apply automobility theory in a novel approach, by investigating consumer engagement with aspects of the automobility system related to car ownership and use in the case studies of Canada and Germany, while also considering openness to new mobility innovations. These countries differ in that Canada has higher levels of car ownership, commutes made by car, and urban sprawl, as well as lower levels of carsharing and electric vehicle adoption relative to Germany. We apply a conceptual framework and 40-item scale of consumer "automobility engagement" to representative survey samples of 3527 Canadian and 2620 German respondents. Exploratory factor analysis identifies five automobility engagement factors: "Driving Enjoyment", "Car Identity", "Car Dependence", "Societal Concern about Car Use", and "Sustainable Travel Norms". Mean scores are significantly higher for Canadian respondents on four factors, but not significantly different for "Driving Enjoyment". In regression analysis, these factors can help to explain consumer interest in carsharing, fully automated vehicles, and electric vehicles in both countries, where "Car Dependence" and "Societal Concern about Car Use" predict interest in fully automated and electric vehicles. Interactions reveal that some patterns differ by country; for example, "Societal Concern about Car Use" predicts carsharing interest among German respondents only. The similarities and differences in country results suggest that the framework can be useful in a variety of contexts.

1. Introduction

Privately-owned vehicles powered by fossil fuels are the leading source of greenhouse gas (GHG) emissions from passenger transportation globally, representing a critical sector that must be decarbonized for Paris Agreement targets to be met [1]. Automobility theory analyzes the dominance of private car use in industrialized societies and sheds light on structural and systemic patterns behind the constitution and reproduction of car dependence [2–6]. Automobility is sometimes portrayed as a system that perpetuates mobility by private vehicles [3]. In this paper, we explore and compare consumer engagement with aspects of the automobility system in Canada and Germany, which we also link to consumer interest in shared, automated, and electric mobility.

The advent of the personal vehicle in the late 19th century enabled human societies to become mobile to an unprecedented extent [7], thereby encouraging social practices to be detached from place. The proliferation of the automobile and urban sprawl contributed to the formation of the so-called "automobility system" – a self-reinforcing system of car-based mobility which includes technologies and actors that enable car ownership and use, such as cars, car drivers, road infrastructure, and the automotive industry [3]. The automobility system prevails in the industrialized world, where the internal combustion engine vehicle looms as the predominant mode of personal mobility [3], with severe consequences for GHG emissions and air pollution, among other impacts [8]. The industrialized world has thus become "locked into" automobility [4], where the reliance on the privately-owned car is systemically reinforced and challenging to transform.

Automobility is seldom explored at the individual level of the consumer. Consumers comprise one among multiple actor categories involved in the automobility system, in addition to policymakers,

* Corresponding author.
E-mail addresses: vhippman@sfu.ca (V.H. Gauer), jaxsen@sfu.ca (J. Axsen), Elisabeth.Duetschke@isi.fraunhofer.de (E. Dütschke), zoe_long@sfu.ca (Z. Long).

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transport providers, and the automotive industry, among others [9–11]. Schwanen [4] argues that macro-level analyses of the systemic nature of automobility are essential – for example, investigations of automobility as a sociotechnical system [9,10,12] – but need to be complemented by micro-level explorations of how individuals subjectively experience, perceive, and use privately-owned cars. Consumers play a role in sustaining automobility through their car purchase and use behaviors, and the privately-owned vehicle forms part of individual consumers' embodied dispositions [13] and lived experiences [14]. Here, we understand consumer perspectives of automobility to comprise micro-level components of the automobility system, while also being influenced by components at the macro level, such as transport policy, land use patterns, and cultural representations of the automobile [4,14]. As such, consumer perspectives of automobility may vary depending on sociocultural contexts and can reflect automobility patterns characteristic of a given nation [15,16]. Further, some authors analyze automobiles (and their use by consumers) as objects that can represent national differences [17] and through which national identities are sometimes constituted [15].

We investigate such “micro” aspects of automobility by applying a conceptual framework of consumer “automobility engagement”, which focuses on consumer engagement with aspects of automobility related to car ownership and use. This conceptual framework does not aim to provide novel theoretical insights to automobility literature; rather, it is the result of a compilation of automobility studies and consumer research. The framework was developed and tested in a previous study, where Gauer et al. [18] derived a survey scale from the framework and applied it to a representative sample of Canadian respondents. In this paper, we intend to empirically explore the automobility engagement scale by applying it to the case studies of Canada and Germany, aiming to better understand how consumer engagement with automobility varies according to national contexts, as well as its role in shaping consumer evaluation of shared, automated, and electric mobility. We focus our analyses at the national level, as most countries across the industrialized world have signed the Paris Agreement and are responsible for submitting nationally determined contributions (NDCs) that communicate plans for lowering national-level GHG emissions [19]. Hence, countries are well positioned to track emissions and implement policies to reduce them in line with NDCs.

We further investigate shared, automated, and electric mobility as so-called “new mobility” innovations [20] that can potentially lower the carbon intensity of the automobility system [21–23]. These innovations are sometimes called the “Three Revolutions” of transportation because of their potential to transform passenger transport toward increased social and environmental benefits, depending on how the innovations are deployed and adopted [22]. Here, we investigate carsharing, fully automated vehicles (FAVs), and plug-in electric vehicles (PEVs) as examples of new mobility innovations.

Shared access to mobility services or “shared mobility” [24] is expected to play an important role in shifting passenger transport patterns toward a net-zero future. The International Energy Agency's (IEA) Net-Zero Emissions scenario calculates that a shift from 20% to 50% of single-occupancy car trips to shared mobility, public transit, and active travel will be required in large cities by 2030 [1]. Further, this scenario assumes a substantial reduction in global car ownership levels by 2050, which can be aided by shared mobility [1]. Carsharing is a form of shared mobility that focuses on short term car rentals, where members can use vehicles that belong to a shared network, usually for a fee. Globally, the carsharing market is growing following its recovery from the COVID-19 pandemic, with estimates of 86 million members and a fleet of 539,000 vehicles in 2021 [25]. Carsharing can function as an alternative to private car ownership by providing members with affordable access to cars without needing to incur ownership costs [26]. Studies estimate that carsharing can decrease car ownership [26–29] and GHG emissions [30,31] in member households. However, some studies indicate that carsharing may also lead to lower transit use [32,33], where carless households are more likely to increase their emissions after joining a carshare service [33].

FAVs are vehicles that reach the highest levels of automation. Vehicle automation is categorized from Level 0 (no automation) to Level 5 (full automation), where FAVs represent automation Levels 4 and 5 [34]. FAVs are able to drive themselves in most or all conditions without requiring a driver to pay attention to the road. This level of automation is being piloted and is not yet available on the market for sale as privately-owned vehicles. FAVs are a potentially transformative technology with uncertain impacts on emissions – FAVs may lead to climate benefits *if* they are deployed as a fleet of shared vehicles, are electrified, or result in increased vehicle efficiency due to automated driving [21–23]. At the same time, several studies forecast that FAVs are likely to increase car use, which may worsen emissions and congestion [35–37]. For example, FAV owners are likely to use their vehicles more because they are not burdened by the stresses of driving and could even send the vehicle unoccupied to find parking or run errands. Taking these uncertainties into account, one study estimates that FAVs could nearly halve or double road transport GHG emissions and energy use, depending on how the technology is deployed [38]. Further, there can be a range of other potential societal implications, where full automation could increase road safety and accessibility for population segments that cannot drive, such as the elderly and people with disabilities. FAVs may also result in negative impacts, such as the risk of cybersecurity breaches [39] and increased urban sprawl [35–37].

PEVs are electric vehicles that can be plugged in to recharge and represent an increasing share of vehicle sales globally, where PEV sales nearly doubled in 2021 relative to 2020, reaching 9% of the global car market [56]. PEVs can drastically reduce GHG emissions from passenger transportation and are recognized as vital for decarbonizing the transport sector [1]. The degree of climate benefits offered by PEVs largely depends on the carbon intensity of a region's electricity mix [40–42]. For example, one full lifecycle analysis shows that battery electric vehicles can currently reduce emissions by 37–45% in China and 66–69% in Europe (relative to conventional vehicles), where further emission reductions are estimated by 2030 due to the decarbonization of electricity mixes [43]. Other issues that must be addressed for the transition to PEVs to be sustainable include the local impacts of raw mineral extraction for battery production [44], challenges in battery reuse and recycling [45], and a trend of increasing sport utility vehicle uptake [46,47], which requires on average 20% more energy than a medium-sized car [46].

Many studies consider how shared, automated, and electric mobility may engender automobility futures, as these innovations could lead to changes in the automobility system if taken up on a large scale [3]. Broadly, carsharing is recognized as a tool to challenge the reliance on private mobility [48–50], whereas privately-owned FAVs and PEVs are seen as technologies that may reproduce or even strengthen the automobility system [51,52], with FAVs potentially increasing its spatial and social inequalities [53]. PEVs are often acknowledged for the transformations that this technology induces in the automotive industry, energy distribution, and GHG emissions [49,51,52], but criticized for not representing a broader definition of sustainability that challenges automobility [48,54]. Krishnan and Butt [55] further discuss myriad “points of continuity” between conventional vehicles and PEVs that the automotive industry exploits to ensure minimal attrition to the automobile experience that consumers are accustomed to. Some studies conclude that, relative to conventional vehicles, consumers may further use FAVs and PEVs to express their status and wealth and to enjoy a private and “cocooned” experience of car use [51,52], which may be increasingly intertwined with entertainment and “mobile digital offices” [52]. There are expectations, however, that shared electric FAVs may help engender futures where car ownership is less perceived as a necessity, reducing the number of vehicles on the road and space allocated for parking [22,49]. This potential largely depends on full automation reducing the costs and increasing the accessibility and attractiveness of

Table 1
Comparing automobility patterns and new mobility innovation availability and adoption in Canada and Germany.

	Canada	Germany
Automobility patterns		
Car density	624 per 1000 inhabitants (2019) [57]	574 per 1000 inhabitants (2019) [58]
% of households owning or leasing one or more vehicles	85% of households (2017) [59]	78% of households (2017) [60]
% of commute to work by private vehicles	79% of commuters (2016) [61]	68% of commuters (2016) [62]
Urban population density rank among OECD members	Lowest among 29 OECD members (2014) [63]	Above the average for OECD members (2014) [63]
New mobility innovations		
Carsharing		
Number of carshare providers	18 (2018) [64]	165 (2018) [65,66]
Registered members	642,472 (2018) [64]	2.1 million (2018) [65,66]
FAVs		
Availability for sale	Not available for sale (2022)	Not available for sale (2022)
PEVs		
Models available for sale	Around 90 (2022) [67]	Around 400 (2022) [68,69]
% of new light-duty vehicle sales	5% (2021) [70]	26% (2021) [71,72]

shared mobility, thus supporting its adoption beyond niche markets [49]. Sprei [49] warns that this future in contingent on changing attitudes toward vehicle ownership and access, and that such transformations are likely more feasible in regions with higher population density and less car dependence.

The use of shared, automated, and electric mobility in conjunction as a shared fleet of electric FAVs is also seen as a solution to reduce fuel use and GHG emissions [21–23], and in idealized scenarios can result in 87% to 94% lower per-mile emissions in 2030, compared to current conventional vehicles [21]. Such climate benefits are largely dependent on consumers shifting their relationships with car ownership and departing from current automobility patterns of private car dependence and fossil fuel use [23,38,39]. Investigating the relationship between consumer engagement with automobility and consumer evaluation of shared, automated, and electric mobility can thus provide indications of how consumers may adopt these innovations within an automobility context.

In this paper, we focus on the case studies of Canada and Germany to explore the following research questions: (1) Does consumer engagement with automobility vary across countries? and (2) Are there different patterns of how automobility engagement relates to consumer interest in shared, automated, and electric mobility? We further state the paper's objectives as follows:

i. Compare consumer engagement with automobility in Canada and Germany by applying and measuring a scale of "automobility engagement" in survey samples from both countries.
ii. Investigate the potential of automobility engagement to explain consumer interest in shared, automated, and electric mobility in Canada and Germany.

In Section 1.1, we present contextual information regarding automobility and new mobility innovations in the case studies of Canada and Germany. In Section 1.2, we detail the conceptual framework and develop hypotheses for country differences in automobility engagement. Section 2 explains the survey design and implementation and describes our methods. Section 3 depicts the results, which we further discuss in Section 4, along with a discussion of study limitations. In Section 5, we present our conclusions and suggestions for future research.

1.1. Background context: Canada and Germany as case studies

We focus on the case studies of Canada and Germany as two examples of industrialized countries with similar levels of economic development that display different automobility and new mobility patterns. Overall, Canada displays relatively higher levels of car ownership and use, fossil fuel-based vehicle adoption, and urban sprawl relative to Germany, as well as a markedly lower rate of shared and electric mobility adoption. Table 1 compares Canada and Germany in automobility patterns and in new mobility innovation availability and adoption. For automobility, we present indicators regarding car ownership and use at the national level, as well as urban population density as an indicator of urban sprawl. For new mobility innovations, we present the state of innovation deployment and, where appropriate, consumer adoption of carsharing, FAVs, and PEVs at the national level.

In addition to these comparisons, we note that Germany has a distinct relationship with the automotive industry. Specifically, Germany stands out as a key player in the global automotive industry and as Europe's number one automotive market, housing companies such as BMW, Daimler, Opel, and Volkswagen [73,74]. Given a long-standing tradition in the automotive industry and its relevance to the German economy [74], automobility may be particularly intertwined with national identities in Germany.

Further, it is relevant to contextualize the adoption of new mobility innovations in Canada and Germany, where the countries differ in policies targeting (1) shared, (2) automated, and (3) electric mobility. Overall, there are more new mobility policies enacted at the federal level in Germany, whereas Canada's approach is more fragmented at the provincial and municipal levels.

First, there are no policies regulating carsharing at the federal level in Canada. However, some municipalities are enacting policies to stimulate carsharing services – for instance, the city of Vancouver has enacted free parking for carshare vehicles for up to two hours [75], and the city of Winnipeg may dedicate permanent on-street spots to carsharing vehicles [76]. Germany, on the other hand, stimulates carsharing adoption by regulating the use of public parking spaces for carsharing providers and enabling municipalities to reduce or waive carsharing parking fees [77].

Second, the testing and deployment of vehicle automation is primarily regulated at the provincial level in Canada, where some provinces have allowed the testing of FAV pilot projects, such as Ontario and Quebec [78,79]. Germany allowed FAV testing in 2015 and has recently become the first national jurisdiction to regulate the operation of Level 4 FAVs in public roads within determined areas, aiming to lead in full automation advancements [80–82].

Third, Canada has a target of 100% sales of light-duty zero-emission vehicles (ZEVs) by 2035. ZEVs in this context include PEVs and hydrogen fuel cell vehicles [83]. PEVs comprised 5% of new light-duty vehicle sales in Canada in 2021 [70]. At the federal level, Canada's policies include financial incentives of up to CAD $5000 for purchase and lease of new ZEVs until 2025 [84] and electric charging investment, such as deploying 33,500 charging stations under the ZEV Infrastructure

Table 2
Automobility engagement framework and scale. The forty scale items are presented in full.

Construct	Description	Scale items
1. Car ownership preferences	Preferences related to private car ownership and sharing of vehicles	1. Owning a car is important to me. 2. If possible, I'd prefer not to own a car. 3. I am (or would be) comfortable lending my car to a friend. 4. I don't (or wouldn't) want to drive a car that someone else was previously driving. 5. It is (or would be) important that I keep my car a particular way (seat, mirrors, cleanliness, etc.).
2. Perceived car dependence	Perceived car needs for regular activities and social interactions	6. I need a car to fulfill my everyday obligations. 7. It is easy to plan my day without a car. 8. It is difficult for me to access my friends and family without a car. 9. In my area, every household needs a car. 10. I need a car for my job. 11. Sometimes I feel too dependent on my car.
3. Residential preferences	Preferences for residential location	12. It is important that I live in a neighbourhood where I can walk to shops and other destinations. 13. It is important for me to live in a place where I can easily access transit. 14. My ideal situation is to live in a private, detached home (not apartment or townhome). 15. It is important for me to own my home. 16. I prefer to live away from urban centers. 17. I don't (or wouldn't) mind having a long commute to work.
4. Driving emotions	Positive and negative emotions of driving a car	18. I enjoy (or would enjoy) driving. 19. Driving is stressful. 20. The idea of driving makes me tired. 21. I feel (or would feel) in control when I am driving. 22. Driving makes me feel (or would make me feel) free. 23. Being inside a car feels like a safe, protected space.
5. Car identity	Expression of self-identity, status, or emotional attachment through cars	24. Owning a car shows (or would show) that I am successful. 25. I want (or would want) my car to represent my personality. 26. You can learn a lot about someone by looking at their car. 27. Buying a car is an important milestone in life. 28. A car is just a way to get around and nothing more. 29. I often feel emotionally connected to cars (or my car).
6. Social norms	Typical travel behavior in social circles	30. Most of my friends own a car. 31. I know a lot of people that use public transit (bus, subway, etc.). 32. Many of my friends are trying to reduce their car use. 33. Many of my friends commonly walk or bike to get around. 34. I often talk about cars with my friends.
7. Perceived societal impacts	Perceptions of societal benefits and impacts of car use	35. Air pollution from cars is a serious problem. 36. Car use is causing climate change. 37. Our transportation system is ineffective for less privileged people (e.g., those with disabilities or lower incomes). 38. Widespread car use is needed to support jobs and the economy. 39. Overall, car use is good for society. 40. Cars, streets and parking take away too much public space.

Program [85]. At the provincial level (and in 2023 at the national level), British Columbia and Quebec have implemented ZEV standards, which require automakers to meet increasing ZEV shares of light-duty vehicle sales [86,87], and are among the provinces that offer ZEV incentives in addition to federal ones [88,89]. Germany's target is to have 15 million PEVs on the road by 2030 [90]. To achieve this target, the German government has been investing in PEV incentives and charging infrastructure. In Germany, PEVs represented 26% of new light-duty vehicle sales in 2021 [71,72]. As of 2022, PEV purchases can receive an incentive of up to EUR €6000 [91]; however, incentive values are planned to lower as PEV market share increases [92]. Further, Germany aims to have 1 million PEV charging stations by 2030 [91]. For this, the German government is investing EUR €500 million to develop public charging infrastructure [93].

1.2. *"Automobility engagement" framework*

The conceptual framework of "automobility engagement" was based on a literature review of automobility studies and consumer perspectives of car ownership and use, as described in more detail in [18]. The framework consolidates themes from a literature review into seven proposed constructs that investigate how consumers perceive and engage with aspects of the automobility system (Table 2). For each proposed construct, we state our hypotheses regarding automobility engagement in Canada and Germany, where we expect that structural differences in automobility between the two countries may induce distinct patterns in consumer engagement with automobility. Due to a lack of literature comparing automobility patterns in these two jurisdictions, we derive our hypotheses primarily from the aggregate automobility patterns described in Section 1.1. We proceed to describe the seven proposed constructs below.

First, "car ownership preferences" explore consumer preferences for private vehicle ownership and openness to shared access to vehicles. Urry [3] analyses the automobile as a symbol of 20th century capitalism and an item of personal consumption viewed as essential to reaching "the good life", where private ownership comprises a central aspect of the automobility system. We hypothesize that Canadians have a higher preference for car ownership, relative to Germans (H1), given higher levels of household car ownership in Canada.

Second, according to automobility theory, car dependence is continuously reproduced by the automobility system, which constrains car users into high mobility and flexibility needs, while facilitating and prioritizing travel by cars [2,3]. Land use patterns, road and public transit infrastructure, and cultural expectations about car use influence a country's level of car dependence, among other factors [94–97]. Here, we investigate a subjective measure of car dependence, thus naming this construct "perceived car dependence". We hypothesize that Canadians perceive themselves as more car dependent than Germans (H2), given higher levels of car density and lower urban population density in Canada.

Third, research indicates that individual decisions regarding residential location and lifestyle (e.g., activities frequently undertaken) can also influence one's level of car dependence, where individuals may have a degree of agency in their own perceived car dependence [98]. For example, research on residential self-selection investigates the link between travel preferences and residential location choices, where some residential locations are chosen partly due to the travel modes that they enable [99,100]. We thus explore “residential preferences” as a construct closely related to perceived car dependence. However, we also acknowledge that residential preferences are often unrealized due to constraints such as affordability, existing land use patterns, and the housing market [101,102]. Given lower urban population density in Canada, we hypothesize that Germans have a higher preference for residential locations with higher population density and urban characteristics (H3), in line with these consumers' lived experiences.

Fourth, “driving emotions” represent emotions stemming from car use, which can comprise intrinsic motivations to drive, or to avoid driving. For example, Sheller [13] coins the term “automobility emotions” to discuss feelings and bodily sensations related to car use, which constitute drivers' embodied dispositions. Several studies indicate that emotions evoked by car driving act as car use motives [103–106], where Stradling et al. [107] further find that survey respondents identify “enjoyment of driving” as a reason for their own anticipated increased driving in the future. We hypothesize that Canadians have more positive emotions toward driving relative to Germans, given higher levels of car use in Canada (H4).

Fifth, “car identity” portrays consumer identification with the vehicle and the social status and symbols linked to it. The potential for private vehicles to signify social status may constitute one of the driving forces that helped generate and that still sustain the automobility system [3,6]. More generally, symbolic values refer to how consumers express their self-identities, social status, or group membership through their privately-owned items, such as automobiles [105,108]. Symbolic motives do not only influence consumer purchase behavior but can also affect the level and attractiveness of car use [105,106]. The symbolic motives attached to car ownership may vary according to national contexts; for example, one cross-country study found that proportionately more Americans than Germans use cars to signify social status [109]. Although these findings are not specific to the Canadian context, we hypothesize that Canadians may be similarly more expressive of self-identity and social status through private vehicles relative to Germans (H5).

Sixth, “social norms” of car use investigate typical travel behavior in consumers' social circles. Automobility is generated and reproduced through social relations [6], but these relations are not thoroughly explored in automobility theory [110]. Here, we investigate social influence by exploring descriptive norms, or what travel behaviors are typical and perceived as normal in consumers' social contexts [111,112]. We hypothesize that sustainable travel behaviors, such as use of public transit and active travel, are perceived to be more common in German social circles, compared to Canadian social circles (H6), given higher car density and levels of commute by car in Canada.

Finally, we investigate “perceived societal impacts” of car use, where societal impacts refer to the direct impacts of a technology to society, such as environmental or economic impacts [113]. Beckmann [2] posits that the public has become increasingly aware of the risks that are inherent to automobility, meaning that public perceptions of the automobile may be increasingly negative. Climate emissions are among the most currently discussed impacts of car use, where studies find that Canada and Germany display similar levels of climate change awareness [114], but Canadians perceive more risk associated with climate change effects, relative to Germans [114,115]. We thus hypothesize that Canadians have more negative perceptions of car use impacts, relative to Germans (H7).

2. Methods

2.1. Survey instrument

We analyze and compare data from two web-based surveys that assess Canadian and German citizens' response to new mobility innovations. The survey was developed and implemented in Canada and partially replicated in Germany. Two German researchers independently translated the survey from English to German and cross-checked it. The median completion time of the Canadian survey was approximately 40 min, while the abbreviated German version was about 22 min.

In this paper, we analyze and compare the automobility engagement scale in the case studies of Canada and Germany. Gauer et al. [18] developed the 40-item automobility engagement scale guided by the conceptual framework of consumer engagement with automobility described in Section 1.2 (Table 2). Scale items are adapted from Nazari et al. [116], Steg [105], and von Behren et al. [117], or otherwise are original to this present work. We applied the scale as a Likert-type scale, where we asked respondents to indicate their agreement with each survey statement and provided response categories ranging from “strongly disagree” (−2) to “strongly agree” (2), including an option for “I don't know/Not applicable”. Due to the context of COVID-19 at the time of survey implementation in Canada and Germany, the surveys instructed respondents to answer automobility engagement scale questions considering their travel patterns and preferences “once social distancing measures are fully removed”.

We further analyze interest in shared, automated, and electric mobility in the two case studies, where we assessed respondent interest using Likert-type response options, with an option for “I don't know”. Research on consumer response to innovations often encounters challenges such as lack of consumer awareness and understanding of innovations, as well as unstable preferences [118]. Given the novelty associated with our studied innovations, we provided context to familiarize respondents with each innovation, as well as to help respondents reflect upon their own experience and level of understanding of innovations, before assessing respondent interest.

More specifically:

1. First, we started the “shared mobility” section of the survey with a description of carsharing and exploration of familiarity with carsharing services. Here, we examined respondent interest in using (or continuing to use) carsharing.
2. Second, we opened the “automated mobility” section with descriptions and exploration of familiarity regarding partial automation technologies, such as self-parking and adaptive cruise control, to increase respondent understanding of vehicle automation. We then described the more novel case of full automation and explored whether respondents had prior experience with the subject. We then examined respondent interest in purchasing or leasing (i) a FAV that can operate in automated mode or be driven manually (i.e., with a steering wheel), and (ii) a FAV that can only operate in automated mode (i.e., without a steering wheel).
3. Finally, in the “electric mobility” section, we provided descriptions for and explored familiarity with battery electric vehicles (BEVs), which run on electricity only, and plug-in hybrid electric vehicles (PHEVs), which can run on electricity but also feature an internal combustion engine. We then examined respondent interest in purchasing or leasing (i) a BEV, (ii) a PHEV, and (iii) an electric vehicle that is fully automated (i.e., electric FAV).

Despite these efforts, we acknowledge that assessing respondent preferences for innovations is a hypothetical exercise [118], and that low respondent understanding or formed opinions regarding shared, automated, and electric mobility may constitute limitations for our study.

Table 3
Demographic characteristics of Canadian sample (weighted) and Canadian Census data.

	Canada sample (total, weighted)	Canada population (2016 Census)
Size (n)	3527	27,711,720 (aged 19+)
Age		
19–24	9%	10%
25–34	17%	17%
35–44	17%	16%
45–54	18%	18%
55–64	18%	18%
65+	21%	21%
Education		
High school education or less	17%	41%
Apprenticeship, trades certificate or diploma	4%	10%
College, CEGEP or other non-university diploma	21%	21%
University below bachelor level	7%	3%
Bachelor's degree	28%	16%
Graduate or professional degree	22%	8%
Income (pre-tax)		
<$40,000	18%	26%
$40,000–$59,999	16%	16%
$60,000–$89,999	23%	20%
$90,000–$124,999	22%	16%
$125,000+	21%	22%
Gender		
Male	48%	49%
Female	51%	51%
Residential area		
Urban and suburban	92%	81%
Rural	8%	19%
Provincial distribution		
British Columbia	14%	13%
Alberta	12%	12%
Prairies (Manitoba and Saskatchewan)	7%	7%
Ontario	38%	38%
Quebec	23%	23%
Maritimes	6%	7%
Territories	0.1%	0.3%

2016 Canadian Census data available from: https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E.

Table 4
Demographic characteristics of German sample (weighted) and German Census data.

	German sample, weighted	German population
Size (n)	2620	69,411,087 (aged 18+)
Age[a]		
18–29	16%	14%
30–39	17%	16%
40–49	20%	16%
50–59	17%	20%
60+	30%	34%
Education[a]		
Not graduated (yet)	1%	4%
Lower secondary school	25%	30%
Secondary school	33%	31%
High school or university degree	42%	35%
Income (pre-tax)[b]		
Less than 900€	9%	9%
900€–1299€	12%	11%
1300€–1499€	7%	6%
1500€–1999€	15%	16%
2000€–2599€	11%	10%
2600€–3199€	12%	13%
3200€–4499€	19%	18%
4500€–5999€	10%	10%
6000€ and more	6%	7%
Gender[a]		
Male	50%	49%
Female	50%	51%
Residential area[c]		
Urban and suburban	84%	84%
Rural	16%	16%

[a] Statistisches Bundesamt (Destatis), 2021.
[b] Norstat, 2020.
[c] Statistisches Bundesamt (Destatis), 2020.

2.2. Data collection

The Canadian survey was implemented in June 2020 with a sample of adult Canadian citizens, and oversamples of three metropolitan areas to allow for regional comparisons (which are not the focus here). The sample was recruited by a market research company. The incentive for survey completion was of CAD $4.50. We received 3762 complete responses, of which 235 were removed for not passing quality checks. The realized sample amounted to 3527 respondents. We apply corrective weights to account for oversampling of some Canadian regions by comparing population proportions from each region to respective survey proportions. The weighted sample is representative of the Canadian population in age, gender, and provincial distribution, and has higher education levels and household income levels relative to the Canadian population (Table 3).

The German survey was implemented from November to December 2020 with a sample of adult German citizens. A market research company was commissioned to recruit participants from its panel. Respondents who completed the survey received an incentive of EUR €1.20. A total of 2753 respondents completed the survey, of which 289 were removed due to low quality responses, reaching a realized sample of 2620 respondents. We apply corrective weights to account for overrepresentation of rural regions by comparing population proportions from each residential area category to respective survey proportions. The weighted sample is representative of the German population in gender and income (Table 4). The weighted sample has slightly lower percentage of adults aged 50 and older as well as higher education levels, relative to the German population.

2.3. Data analysis

We used IBM SPSS statistical software (Versions 25 and 28) for all data analyses. We start by analyzing the automobility engagement scale using exploratory factor analysis (EFA). EFA analyzes the latent variables or factors sharing a common variance that can be derived from a larger set of observable variables (i.e., scale items) [119]. We use EFA to analyze whether scale items can be reduced to a smaller number of factors – in this case, the proposed automobility engagement constructs (Table 2). For this analysis, we combine datasets from the Canadian and German samples into a joint dataset. We used principal axis factoring and direct oblimin (oblique) rotation, and do not apply corrective weights to this analysis. We use oblique rotation because we do not expect the resulting factors to necessarily be mutually exclusive, but to display a degree of correlation [120]. We aimed to select a factor solution that maximizes factor interpretability and loading strength and reduces the number of low-loading and cross-loading items [119,121,122].

Second, we compare automobility engagement in Canada and Germany and thus test our hypotheses (stated in Section 1.2) by (i) conducting independent sample *t*-tests of the resulting automobility engagement factors and (ii) examining descriptive statistics for the automobility engagement scale items. We discuss the results from the country comparison in Section 4. Independent sample *t*-tests analyze whether the difference in the mean scores of two independent groups is statistically significant [123]. Descriptive statistics are the numerical or graphical procedures that describe the characteristics of a sample [124]. Descriptive statistics are conducted separately for each sample, where we compare the results between samples. We also use descriptive statistics to compare interest in shared, automated, and electric mobility in

Table 5
Exploratory factor analysis of automobility engagement scales using joint dataset (shows factor loadings above 0.32, scale items abbreviated, n = 6147).

	Driving enjoyment	Car identity	Car dependence	Societal concern about car use	Sustainable travel norms
I enjoy driving.	0.814				
The idea of driving makes me tired.	−0.696				
Driving makes me feel free.	0.664				
Driving is stressful.	−0.633				
I feel in control when I am driving.	0.556				
Being inside a car feels like a safe, protected space.	0.496				
If possible, I'd prefer not to own a car.	−0.400				
I want my car to represent my personality.		0.835			
Owning a car shows that I am successful.		0.744			
I often feel emotionally connected to cars.		0.639			
A car is just a way to get around and nothing more.		−0.551			
Buying a car is an important milestone in life.		0.550			
You can learn a lot about someone by looking at their car.		0.535			
I often talk about cars with my friends.		0.380			
In my area, every household needs a car.			0.612		
I need a car to fulfill my everyday obligations.			0.605		
It is difficult for me to access my friends and family without a car.			0.533		
Sometimes I feel too dependent on my car.			0.450		
My ideal situation is to live in a private, detached home.			0.415		
I prefer to live away from urban centers.			0.411		
Most of my friends own a car.			0.360		
It is important for me to own my home.			0.329		
Car use is causing climate change.				0.826	
Air pollution from cars is a serious problem.				0.792	
Cars, streets and parking take away too much public space.				0.466	
Overall, car use is good for society.				−0.413	
It is important for me to live in a place where I can easily access transit.					0.611
I know a lot of people that use public transit.					0.608
Many of my friends commonly walk or bike to get around.					0.553
It is important that I live in a neighbourhood where I can walk to destinations.					0.548
It is easy to plan my day without a car.					0.423
Factor number	1	2	3	4	5
Eigenvalue	4.203	3.911	3.442	2.786	3.291
Cronbach's alpha	0.823	0.815	0.753	0.731	0.743

Canada and Germany. We investigate interest in carsharing, FAVs with and without a steering wheel, BEVs, PHEVs, and electric FAVs. We apply the corrective weights described in Section 2.2 to all descriptive statistical analyses.

Finally, we perform multivariable ordinal logistic regressions for the joint dataset combining the datasets of the two samples. We use ordinal logistic regressions to test the potential of automobility engagement factors (i.e., independent variables) to predict interest in shared, automated, and electric mobility (i.e., dependent variables) [125]. We use the proportional odds model, which estimates the probability of being at a particular category of an ordinal dependent variable [126]. We additionally investigate country as an independent variable, treated as a dummy variable. We control for interaction effects between the German subsample and the automobility engagement factors to analyze whether any resulting factors are more strongly associated with interest in innovations in a particular country sample. We further control for sociodemographic characteristics and residential areas.

We treat the control variables as follows:

- Age and household size are treated as continuous variables.
- Education is treated as a dummy variable, where education levels below a Bachelor's degree form the base.
- Income is treated as a dummy variable, where low income forms the base. We use cut-off values for low income as household income below 50% of the annual median in Canada, according to definitions from the Government of Canada [127], and below 60% of the annual median in Germany, as standardly measured in the European Union [128].
- Gender is treated as a dummy variable, where male gender forms the base.
- Residential areas (i.e., urban, suburban, and rural) are treated as dummy variables, where urban residential areas form the base.

3. Results

We start by depicting EFA results of the automobility engagement scale (Section 3.1). We then use independent *t*-test results and descriptive analyses to compare Canadian and German responses to the resulting factors (Section 3.2). We also display and compare Canadian and German interest in shared, automated, and electric mobility (Section 3.3). Lastly, we describe the results of the ordinal logistic regressions (Section 3.4), where we investigate the potential of automobility engagement factors to predict interest in shared, automated, and electric mobility in the joint dataset, while also exploring interaction effects to analyze whether regression results are country-specific.

3.1. Factor analysis of automobility engagement scale

We first investigated "I don't know/Not Applicable" values for automobility engagement scale items. We found that three items showed relatively high proportions of these responses in the Canadian sample (13% to 17%), specifically items 10, 17, and 32 from Table 2. The likely explanation is that these items did not apply to as many survey respondents as the other scale items. For the present analysis, we decided to remove these items from the EFA.

We then proceeded to run EFAs of the automobility engagement scale described in Section 2.1, using a joint dataset combining the datasets from the two samples. Results suggested that the data is suitable for factor analysis, as indicated by Kaiser-Meyer-Olkin measure of sampling adequacy (0.891) and Bartlett's Test of Sphericity ($p = 0.000$) values. We removed items consistently displaying factor loads below 0.32 and communalities below 0.2 [119,121,122]. Analyses indicated that four scale items did not load well onto any factors, which were thus removed from the EFA – items 3, 4, 5 and 37 (Table 2).

After removing these items, we arrived at interpretable solutions. We found that a 5-factor solution was the most interpretable solution for the joint dataset. We further removed items 1 and 38 (Table 2) from the 5-factor solution, which were cross-loading items. Table 5 displays the results, where we present factor eigenvalues (rotated solution), as well as Cronbach's alpha values to assess factor internal consistency (Table 5). We calculated Cronbach's alpha values by creating scales based on the highest factor score for each scale item.

To test the robustness of our results, we further conducted separate EFAs for the German and Canadian samples following the same EFA procedure used in the joint dataset. The same 5 factors presented here were also largely found in these separately conducted EFAs, with minor changes in item distribution. The replicability of these factors when analyzing the samples separately indicates a comparable engagement with automobility across the two countries, as well as the suitability of a 5-factor structure to the data.

We find five factors (capitalized), where:

- Factor 1 represents "Driving Enjoyment", where positively loading items suggest positive emotions of driving a car. Further, items suggesting a negative driving emotion (e.g., "Driving is stressful") load negatively onto the factor.
- Factor 2 represents a "Car Identity", as loading items indicate a connection between car ownership and expression of self-identity and status.
- Factor 3 represents "Car Dependence", being mostly composed of items measuring perceived car needs. This factor also includes items that indicate a car-centered living context, such as residential preferences characteristic of suburban and rural areas.
- Factor 4 indicates a "Societal Concern about Car Use" or concern for car use impacts, such as air pollution, and an overall perception that car use is not "good for society".
- Factor 5 indicates "Sustainable Travel Norms" in social circles, referring to social norms of transit use, active travel, and residential location.

3.2. Comparing automobility engagement in Canada and Germany

We now proceed to compare responses to the automobility engagement scale in the Canadian and German samples. We first compare the Canadian and German samples' mean scores of the automobility engagement factors described in Section 3.1. We saved the factor scores as regression variables to compare the two samples, which standardizes the mean scores of the joint dataset.

We find no statistically significant difference between the Canadian

Table 6
Independent *t*-tests of automobility engagement factors in Canadian and German subsamples of joint dataset (n = 3527; 2620).

Factor n.	Factor	Canadian sample (mean)	German sample (mean)	*t*	Two-sided *p* (*t*-test)
1	Driving enjoyment	0.006	−0.009	0.610	$p = 0.542$
2	Car identity	0.219	−0.295	21.830	$p < 0.001$
3	Car dependence	0.083	−0.111	8.315	$p < 0.001$
4	Societal concern about car use	0.193	−0.260	19.575	$p < 0.001$
5	Sustainable travel norms	0.078	−0.104	7.961	$p < 0.001$

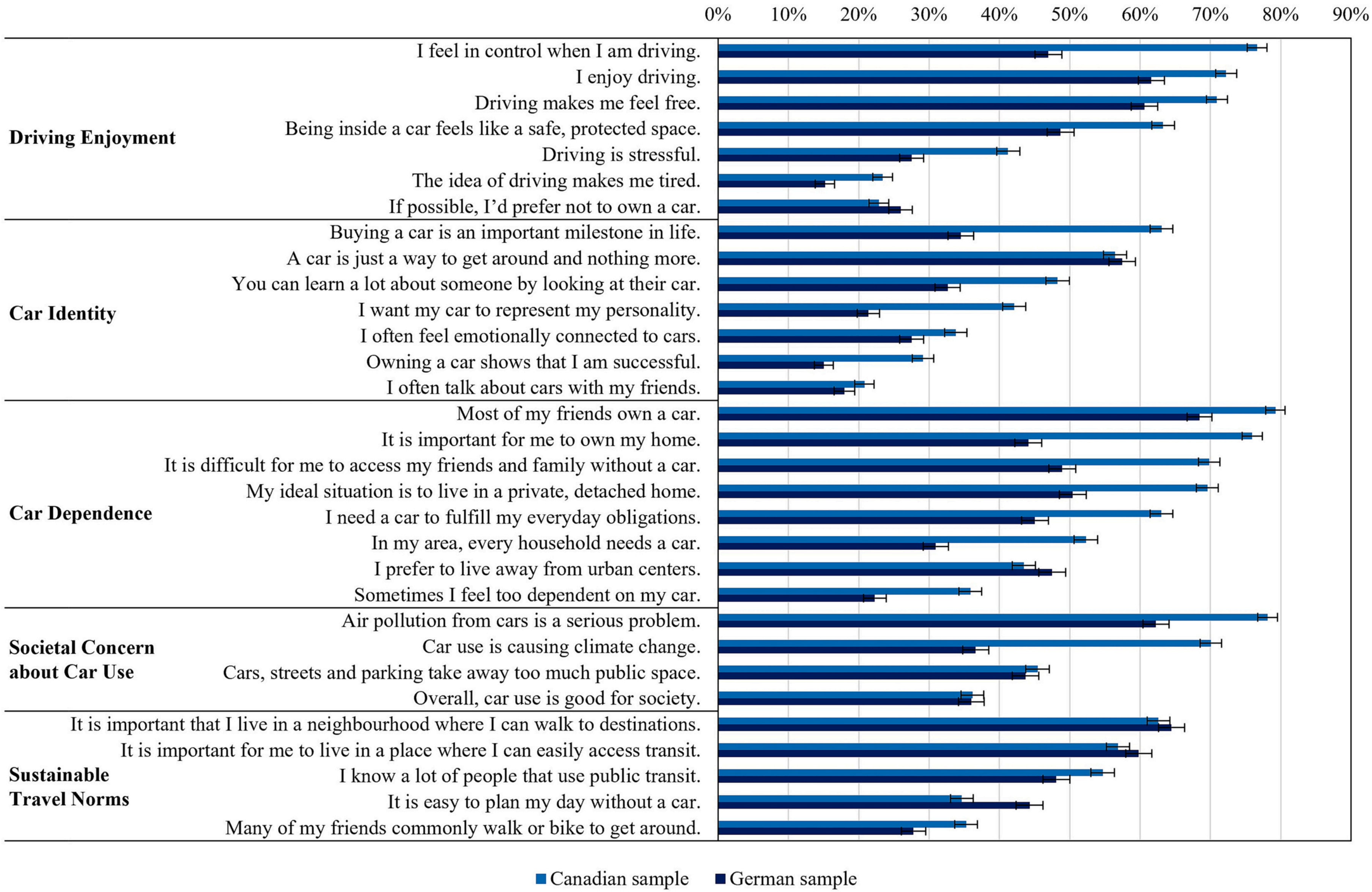

Fig. 1. Percentage of Canadian and German respondents (n = 3527; 2620, weighted) that "somewhat agree" or "strongly agree" with automobility engagement scale items. Scale items are abbreviated and organized according to factor analysis results. Error bars indicate 95% confidence intervals.

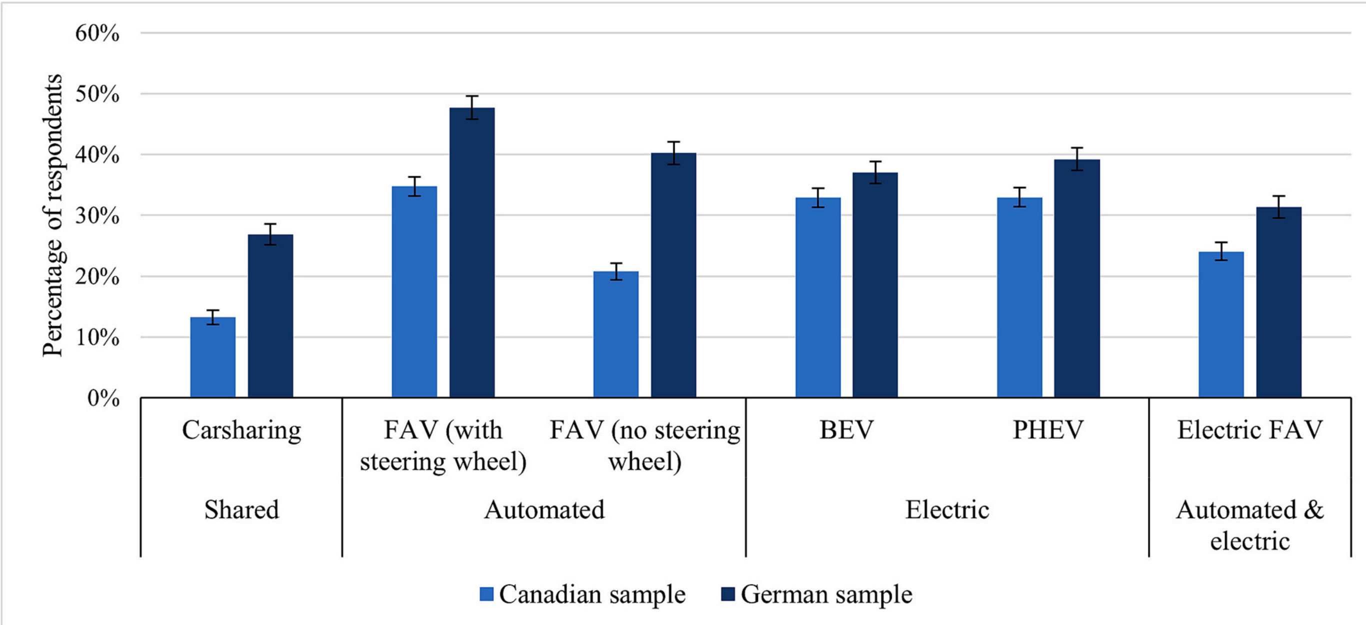

Fig. 2. Percentage of Canadian and German respondents (n = 3527; 2620, weighted) that are "moderately interested" or "very interested" in shared, automated, and electric mobility. Error bars indicate 95% confidence intervals.

and German subsamples' mean scores for Factor 1 (i.e., Driving Enjoyment) (Table 6). For Factors 2 through 5, the Canadian mean scores are higher for all four factors (at a 99% confidence level), relative to the German mean scores.

Second, we compare responses to automobility engagement scale items in Canada and Germany. We display agreement with scale items (i.e., "somewhat agree" and "strongly agree" responses) organized according to automobility engagement factors, on a descending order of agreement for the Canadian sample (Fig. 1). For this analysis, we apply the corrective weights described in Section 2.2. We summarize the results as follows:

- Driving Enjoyment: most respondents in both samples show positive feelings toward driving, as indicated by 72% of Canadians and 62% of Germans agreeing with "I enjoy driving". Diving is significantly more associated with a feeling of being "in control" in Canada (77%) relative to Germany (47%), at a 95% confidence level. At the same time, more Canadians (at a 95% confidence level) indicate to be stressed by driving – 41% of Canadians agree that "Driving is stressful", versus 28% of Germans.
- Car Identity: minorities of respondents (42% of Canadians and 21% of Germans) agree that "I want my car to represent my personality". However, 61% of Canadians (versus 35% of Germans) agree that "Buying a car is an important milestone in life", which suggests that car ownership is more likely to come with symbolic meaning for Canadians.
- Car Dependence: most Canadians indicate that they perceive themselves as being dependent on a car, with 70% agreeing that "It is difficult for me to access my friends and family without a car" and 63% agreeing that "I need a car to fulfil my everyday obligations". In comparison, significantly fewer Germans (at a 95% confidence level) see themselves as car dependent (49% and 45% agreement with scale items, respectively).
- Societal Concern about Car Use: more Canadians perceive car use to lead to negative environmental impacts, relative to Germans, at a 95% confidence level. For example, 78% of Canadians agree that "Air pollution from cars is a serious problem", versus 62% of Germans. The difference in agreement is especially notable regarding climate impacts of car use – 70% of Canadians agree that "Car use is causing climate change", versus 37% of Germans.
- Sustainable Travel Norms: respondents indicate that they do not perceive walking and biking to be common travel modes in their social circles, while transit use is seen as more common. For example, only 35% of Canadians and 28% of Germans agree that "Many of my friends commonly walk or bike to get around". This may suggest that most respondents are situated in car-centered social circles in both countries.

3.3. Consumer response to shared, automated, and electric mobility in Canada and Germany

We now compare responses regarding interest in shared, automated, and electric mobility in Canada and Germany. Fig. 2 displays the percentage of respondents that indicate to be "moderately interested" or "very interested" in each innovation. We apply the corrective weights described in Section 2.2 in this analysis.

The results indicate that Germans are more interested in all studied innovations relative to Canadians, at a 95% confidence level (Fig. 2). A significantly lower proportion of Canadians are interested in carsharing relative to Germans (13% vs. 27%), at a 95% confidence level. The country differences are considerable for interest in FAVs with a steering wheel (35% of Canadians vs. 48% of Germans) and without a steering wheel (21% of Canadians vs. 40% of Germans). Country differences regarding interest in electric mobility are less substantial, but still significant at a 95% confidence level. When comparing electric vehicle drivetrains, interest in BEVs was not significantly different than interest in PHEVs in either sample. Respondents in both samples are relatively less interested in electric FAVs than in standard electric vehicles, at a 95% confidence level.

3.4. Predicting interest in shared, automated, and electric mobility

Finally, we use multivariable ordinal logistic regressions to analyze the potential of the resulting automobility engagement factors to predict interest in shared, automated, and electric mobility. We include automobility engagement factors and country as independent variables and control for sociodemographic characteristics, residential areas, and interaction effects between the German subsample and automobility engagement factors. Pearson Correlation coefficients between independent variables (<0.8) and Variance Inflation Factor values (<5) do not indicate a presence of multicollinearity in the model [129].

Table 7 depicts the model results. Pseudo R Square (Nagelkerke) values for interest in new mobility innovations range from 0.145 to 0.187. We further present unstandardized coefficients (*B*) and odds ratio (OR) for the independent variables (Table 7). The OR indicates the change in odds of the dependent variable outcome increasing above a cut point (i.e., from "not at all interested" to "somewhat interested") per unit increase in the independent variable [130].

Below we list the results that are significant at a 95% confidence level (or higher). We start with the "base" estimates for the five factors, which apply to Canadian respondents, before turning to analyze the interaction effects in the regressions between the German subsample and the automobility engagement factors. We find that:

- Driving Enjoyment predicts interest in all automated and electric mobility innovations. The association with interest in FAVs *with* a steering wheel, BEVs, and PHEVs is positive, and the association with interest in FAVs *without* a steering wheel and electric FAVs is negative.
- Car Identity positively predicts interest in FAVs and electric FAVs.
- Car Dependence and Societal Concern about Car Use positively predict interest in FAVs, BEVs, PHEVs, and electric FAVs (i.e., all automated and electric mobility innovations).
- Sustainable Travel Norms positively predict interest in carsharing, FAVs without a steering wheel, and electric FAVs.

Most of the patterns above also apply to the German respondents. However, the interaction effects indicate some differences. We find that there is a significant positive interaction effect between Driving Enjoyment and the German subsample for interest in FAVs without a steering wheel, indicating that Driving Enjoyment is essentially *not* associated with interest in FAVs without a steering wheel among German respondents. There are significant interaction effects between Car Identity and the German subsample for interest in carsharing, BEVs, PHEVs, and electric FAVs, indicating that Car Identity plays more of a role in predicting interest in new mobility innovations among German respondents. Further, in the German subsample, Societal Concern about Car Use is a predictor of carsharing, as well as a stronger predictor of interest in electric FAVs (relative to the Canadian subsample). Finally, Sustainable Travel Norms positively predict interest in FAVs with a steering wheel among German respondents and are less strongly associated with carsharing interest.

As expected from the results shown in Fig. 2, where Germans were more interested in all innovations at a 95% confidence level relative to Canadians, regression results find that Germany as a country of residence is a significant positive predictor of interest in all studied innovations. We investigate sociodemographic characteristics without controlling for interaction effects for model simplicity. We find that education positively predicts interest in all innovations, while age and female gender negatively predict interest in all innovations. Income and household size are significant (positive) predictors of interest in FAVs, BEVs, PHEVs, and electric FAVs, but not in carsharing. Rural residential areas are significantly negatively associated with interest in carsharing, FAVs without a steering wheel, and PHEVs.

Table 7
Predicting interest in shared, automated, and electric mobility by using multivariable ordinal logistic regressions (n = 6147). We present unstandardized coefficients (*B*) and odds ratio (OR) for the independent variables (**$p < 0.01$, *$p < 0.05$).

	Carsharing interest		FAV interest (with steering wheel)		FAV interest (no steering wheel)		BEV interest		PHEV interest		Electric FAV interest	
	B	OR	*B*	OR	*B*	OR	*B*	OR	*B*	OR	*B*	OR
Sociodemographics												
Education *(Dummy = Bachelor's diploma or above)*	0.412**	1.510	0.358**	1.430	0.198**	1.219	0.328**	1.388	0.346**	1.414	0.253**	1.287
Income *(Dummy = Above low income)*	0.112	1.118	0.412**	1.509	0.297**	1.345	0.292**	1.339	0.291**	1.338	0.277**	1.319
Age *(Continuous)*	−0.025**	0.975	−0.025**	0.976	−0.022**	0.979	−0.026**	0.975	−0.019**	0.981	−0.025**	0.976
Household size *(Continuous)*	0.016	1.016	0.100**	1.105	0.090**	1.094	0.120**	1.127	0.125**	1.133	0.128**	1.137
Gender *(Dummy = Female)*	−0.300**	0.741	−0.432**	0.649	−0.471**	0.625	−0.577**	0.562	−0.359**	0.698	−0.509**	0.601
Residential area *(Dummy, base = Urban)*												
Suburban	−0.280**	0.756	0.097	1.102	−0.004	0.996	0.041	1.042	0.031	1.032	0.001	1.001
Rural	−0.322**	0.725	−0.092	0.912	−0.212*	0.809	−0.135	0.874	−0.213*	0.808	−0.135	0.873
Country												
Germany *(Dummy, base = Canada)*	0.706**	2.025	0.661**	1.936	1.067**	2.907	0.238**	1.268	0.307**	1.360	0.451**	1.570
Automobility engagement												
Driving enjoyment	0.010	1.011	0.086*	1.089	−0.179**	0.836	0.091*	1.095	0.124**	1.132	−0.100*	0.905
Car identity	−0.034	0.967	0.262**	1.299	0.230**	1.259	0.047	1.048	0.028	1.029	0.200**	1.221
Car dependence	−0.032	0.968	0.177**	1.193	0.213**	1.237	0.267**	1.306	0.252**	1.287	0.236**	1.267
Societal concern about car use	0.064	1.066	0.289**	1.334	0.180**	1.197	0.491**	1.634	0.364**	1.439	0.328**	1.389
Sustainable travel norms	0.662**	1.939	0.063	1.065	0.162**	1.176	0.059	1.061	0.070	1.073	0.109*	1.115
Interaction effects *(Interaction with German subsample)*												
Driving enjoyment	0.068	1.070	0.102	1.108	0.173**	1.189	0.006	1.006	0.094	1.098	0.076	1.079
Car identity	0.277**	1.319	0.059	1.061	0.123	1.131	0.253**	1.287	0.259**	1.295	0.152*	1.164
Car dependence	0.135	1.144	0.123	1.130	0.109	1.115	0.019	1.020	0.099	1.104	0.041	1.042
Societal concern about car use	0.240**	1.271	−0.072	0.930	0.028	1.028	0.120	1.127	0.011	1.011	0.154*	1.166
Sustainable travel norms	−0.265**	0.767	0.182**	1.199	0.054	1.055	0.054	1.055	0.082	1.086	0.087	1.091
Model summary												
Nagelkerke R^2	0.179		0.166		0.159		0.187		0.145		0.168	
Pearson	$p = 1.000$		$p = 0.657$		$p = 0.449$		$p = 0.286$		$p = 0.540$		$p = 0.234$	
Deviance	p = 1.000		$p = 1.000$		$p = 1.000$		$p = 1.000$		$p = 1.000$		$p = 1.000$	

4. Discussion

The automobility system refers to the dominance of the privately-owned car in passenger transport [2–5], where the prevalence of this transport mode across the industrialized world has significant impacts on global climate emissions [1,8]. Automobility has been instituted as a system across the industrialized world – yet, there may be national variances in how this self-sustaining system of car use is structured, regulated, and ultimately experienced by its constituents [15,16]. In this paper, we investigate consumer engagement with aspects of automobility related to car ownership and use, or "automobility engagement", in Canada and Germany, while exploring consumer interest in shared, automated, and electric mobility as innovations that may help decarbonize the automobility system [21–23]. We discuss results pertaining to our first and second research questions in Sections 4.1 and 4.2 respectively and consider our study limitations in Section 4.3.

4.1. Country variations in automobility engagement

Responding to our first research question, we find that consumer engagement with automobility varies between the two case study countries, and that these differences may be difficult to predict from aggregate automobility patterns. For example, it is logical that Canadian consumers experience relatively high levels of Car Dependence, living in a country characterized by urban sprawl and prevalence of car ownership and use (see Table 1). At the same time, Canadians are more likely to perceive higher levels of Sustainable Travel Norms in their social circles, which we did not predict from aggregate automobility patterns. Future research could investigate the determinants behind country differences in consumer perspectives of automobility. We further discuss the results pertaining to our exploratory factor analysis and country comparisons below.

Factor analysis of the automobility engagement scale finds five resulting factors (Section 3.1). Of these, "Driving Enjoyment", "Car Identity", and "Societal Concern about Car Use" are largely consistent with three of our literature-informed constructs of automobility engagement (Table 2). The remaining two factors may prompt revisions in the conceptual framework. "Car Dependence" mostly replicates the proposed "perceived car dependence" construct, but also includes items that indicate a car-dependent residential context (e.g., item "I prefer to live away from urban centers" from Table 2). We thus conclude that this factor relates to a respondent's level of Car Dependence, and not only to their perceptions of it [95,97,98]. Further, "Sustainable Travel Norms" represents "social norms" of travel, as expected. However, two items previously thought to measure "residential preferences" also loaded onto this factor (items 12 and 13 from Table 2; e.g., "It is important for me to live in a place where I can easily access transit"). We conclude that these two items may assess subjective norms [111,131], or socially desirable residence behaviors that enable transit use and active travel.

We now compare automobility engagement in Canada and Germany and respond to our proposed hypotheses from Section 2.2. For this, we analyze independent sample *t*-tests of factor scores and examine responses to automobility engagement scale items in the two samples (compared using 95% confidence intervals). First, the factor analysis did not identify the proposed construct of "car ownership preferences"; consequently, we were not able to respond to our first hypothesis (H1).

Second, the results indicate that Canadians perceive themselves as having a higher Car Dependence relative to German respondents, at statistically significant levels – supporting H2. This finding aligns with data indicating higher urban sprawl in Canada relative to Germany, and a trend of increasing suburbanization in Canada [63,132].

Third, we did not identify the proposed "residential preferences" construct through factor analysis. Thus, the data is not conclusive regarding H3.

Fourth, we find no statistically significant difference between the countries in Driving Enjoyment mean scores, in opposition to H4. However, looking further into the data, we find that higher proportions of Canadians (at a 95% confidence interval) agree with scale items reflecting both positive *and* negative emotions of driving. The results are thus mixed but may indicate that Canadians associate more positive emotions with the act of driving but are also more stressed by driving, relative to Germans.

Fifth, H5 is supported, where the results indicate that Canadians display higher Car Identity mean scores at statistically significant levels, or see the private car more as a channel for themselves and others to express self-identity, social status, and other symbols, relative to Germans. In a similar vein, Sommer [109] finds that proportionately more Americans than Germans use cars to signify social status.

Sixth, the comparison of Sustainable Travel Norms in Canada and Germany does not support H6. We find small but statistically significant differences in results indicating that sustainable travel behaviors are perceived more as the "social norm" in Canada, relative to Germany.

Lastly, Canadians display higher Societal Concern about Car Use relative to Germans, supporting H7. The descriptive results are especially indicative of a higher proportion of Canadians perceiving the climate impacts of car use, relative to Germans. This may be related to different perceptions of climate risk between the countries [114,115].

4.2. The role of automobility engagement in shared, automated, and electric mobility interest

In response to our second research question, we conclude that the patterns of how automobility engagement interacts with consumer interest in shared, automated, and electric mobility are mostly consistent across the two countries. The regression results indicate that in both countries potential consumers of FAVs and PEVs may be car dependent, but also interested in these innovations' abilities to lower car use impacts on the environment, which aligns with previous findings [18]. Conversely, the results do not indicate an association between Car Dependence and consumer interest in carsharing, which hints at expectations that this form of shared mobility may help decrease automobility patterns of dependence on car ownership, or at least is associated with decrease in such dependence [26–29]. Further, consumer interest in FAVs seems particularly tied to the symbolic value of car ownership, where consumers with higher levels of Car Identity are more likely to be interested in FAVs in both countries. Overall, these results empirically support previous studies that posit shared mobility as a potential alternative to automobility, whereas privately-owned FAVs and PEVs are seen as likely to maintain or reinforce aspects of automobility [48–52]. Lastly, it is notable that Sustainable Travel Norms in one's social circle are associated with consumer interest in carsharing, FAVs, and electric FAVs, which suggests a link between social norms of travel and openness to new mobility innovations.

We also find some distinct patterns between the countries. One notable difference found in the regressions is that a lack of Driving Enjoyment may constitute a motivation for interest in driverless vehicles in Canada, but not in Germany. This could be associated with our earlier finding that Canadians display a higher proportion of agreement with negative driving emotions, such as feeling that "Driving is stressful" (Fig. 1). Another relevant difference is that Societal Concern about Car Use only predicts carsharing interest in Germany, suggesting that carsharing may be perceived as a solution to lower car use impacts in Germany more so than in Canada. The data thus paints a picture where Canadians are especially concerned about the environmental impacts of cars; however, the potential consumer market for innovations in Canada is more compelled by the environmental benefits of privately-owned FAVs and PEVs than those of carsharing.

Regarding energy and climate implications, the future of passenger transport could become more sustainable through widespread adoption of shared, automated, and electric mobility, where these innovations can deeply reduce fuel use and GHG emissions if deployed in conjunction while optimizing vehicle efficiencies [21–23]. Our findings suggest that, from a consumer perspective, there is potential for the adoption of carsharing, FAVs, and PEVs to expand in Canada and Germany (Fig. 2). However, policies may be needed to maximize the energy and climate benefits of these innovations. First, we do not find carshare interests at the levels portrayed as necessary for shared mobility to support a transition to net-zero passenger transportation [1]. Second, the results suggest that interest in FAVs may decrease when an electric drivetrain is specified, where this difference in consumer interest is most evident in Germany (Fig. 2). The results thus echo the risk of further developments in automation not being accompanied by sharing and electrification, which could increase transport emissions [22,23,38]. Third, regression results indicate that consumer adoption of FAVs and PEVs may reproduce patterns of private car dependence, which are energy intensive [1,95]. Future research could investigate to what extent policies are needed to steer these innovations toward desired outcomes, where policy examples could include promoting shared mobility uptake, curbing private car use, and prioritizing the regulation of shared and electric FAVs over private and internal combustion engine modes [49].

4.3. Study limitations

Limitations to this study include the context of the global COVID-19 pandemic at the time of survey implementation, potential differences in survey samples, the use of market research companies for participant recruitment, and the limited scope of the framework and methods. First, we acknowledge that the global COVID-19 pandemic could have affected results. For example, the perception that shared travel increases the risk of exposure to COVID-19 could have influenced responses to survey items that compose the factor "Sustainable Travel Norms", which includes items assessing social norms of transit use and access.

Second, our comparison across samples could be influenced by sample differences. For example, the German survey only replicated certain sections of the Canadian survey and was reduced in length – as a result, there might have been less respondent burden in the German sample [133]. We further note that we used two different market research companies which employed different recruitment strategies. One difference is that German respondents received a lower financial incentive relative to Canadian respondents, which was related to the German survey's reduced length as well as differences in company procedures.

Third, studies using respondent panels from market research companies should anticipate potential issues that may arise in survey responses, as respondents may be burdened due to multiple study requests or motivated by financial gains only, resulting in inattentive responses [134]. We have addressed this potential limitation by checking our survey responses for data quality and removing low quality responses, as detailed in Section 2.2.

Finally, the conceptual framework is limited and only addresses certain aspects of consumer engagement with automobility, where there may be other country differences in how consumers perceive and engage with automobility engagement that lie beyond the scope of this framework. Further, the automobility engagement scale has not been validated, which may explain the differences between the proposed conceptual framework and the resulting automobility engagement factors.

5. Conclusions

We conclude that investigating consumer engagement with aspects of automobility can identify differences in how the system of automobility is experienced across national contexts. Increased knowledge of how consumers perceive and engage with automobility can provide contextual information for developing effective policies to lower car use impacts. For example, our study suggests that higher proportions of consumers in Canada perceive themselves to be dependent on cars for various aspects of their daily lives, relative to Germans. Such findings indicate that more research is needed to understand how to reduce car dependence, notably in Canada, while considering that such efforts could stumble upon other identified factors of consumer automobility engagement, such as Driving Enjoyment or symbolic attachments to the private car in the form of a Car Identity.

We further conclude that automobility engagement can help to explain consumer motives for interest in shared, automated, and electric mobility, and that similar patterns may occur across countries. Understanding how consumer motives for new mobility innovations relate to their engagement with automobility can contribute to clarifying the impacts that these innovations may exert on the automobility system. Future research could further explore consumer engagement with automobility through qualitative studies to better understand the subjective meanings associated with the identified country differences.

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CRediT authorship contribution statement

Viviane H. Gauer: Conceptualization, Data curation, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Jonn Axsen:** Conceptualization, Supervision, Funding acquisition, Methodology, Formal analysis, Writing – review & editing. **Elisabeth Dütschke:** Conceptualization, Supervision, Data curation, Funding acquisition, Methodology, Formal analysis, Writing – review & editing. **Zoe Long:** Data curation, Funding acquisition, Project administration, Writing – review & editing. **Aline Kelber:** Data curation, Formal analysis, Writing – review & editing.

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.

Data availability

Data will be made available on request.

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