Where should speed-pedelecs ride? Perspectives from riders versus other road users

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SHORT SUMMARY

This study investigates the integration of speed-pedelecs (S-pedelecs) into the existing mobility system, focusing on the perspectives of various road users across Austria, Germany, and Switzerland.

S-pedelecs, capable of pedal-assisted speeds up to 45 km/h, present an alternative to motorized transport but challenge existing infrastructure due to their unique speed and performance characteristics. Using a survey approach that included an image-based stated preference and acceptance survey, the study reveals strong acceptance for sharing cycling facilities among S-pedelec riders and other road users, regardless of country or road type. S-pedelec riders prefer using cycling facilities, with mixed traffic being more acceptable under conditions like lower speed limits (30 km/h) and low vehicular traffic.

Results from this study fill a gap in the existing research and can inform policy makers and planners on the next generation of mobility infrastructure that is accepted, safe and inclusive for S-pedelec riders as well as for other road users.

Keywords: cycling, e-bike, s-pedelec, acceptance, stated-preference

1. INTRODUCTION

Amid the two-wheeler market's clear trend towards electrification speed-pedelecs (S-pedelecs) are witnessing high growth rates (DESTATIS, 2021; Velosuisse, 2024). Due to their pedal-assistance up to 45 km/h, S-pedelecs present a competitive option for longer trips that are currently undertaken using motorized transport (Ballo et al., 2023). Nevertheless, the integration of S-pedelecs into existing infrastructure in a safe and accepted manner poses a challenge and different countries have taken a different approach to integrating S-pedelecs in the mobility system (Hendriks et al., 2023).

On the one hand, the relatively high differential speed of S-pedelecs versus other forms of active mobility can result in conflicts on cycling facilities and shared sidewalks. On the other hand, it is possible to allow S-pedelecs to share the roadway with vehicular traffic. Yet, sharing the roadway can result in dangerous interactions between S-pedelecs and vehicular traffic. As such S-pedelecs, occupy a unique position between conventional bicycles and motorcycles in terms of their speed characteristics and performance and their integration into the existing road infrastructure remains to be investigated. The objective of the present research is to analyze the acceptance and design of different policy measures to integrate S-pedelecs into a sustainable and safe transportation system.

Previous literature has investigated preferences for bicycle infrastructure (Heinen et al., 2010). Bicycle infrastructure encompasses various forms, including dedicated bicycle paths, shared sidewalks (sharing with pedestrians), designated bicycle lanes, and standard roads (sharing with motorized vehicles).

Road designs that are accepted by all road users are likely to gain approval even before implementation and may lead to higher compliance after their introduction. Therefore, understanding their acceptance is crucial. The acceptance of cycling infrastructure and regulations from the perspective of different road users has been examined in a limited number of studies (Sanders, 2016). Among actual and potential users as well as among drivers there is a general preference for dedicated bicycle paths over bicycle lanes or shared roads lacking dedicated cycling infrastructure (Ballo et al., 2023; Heinen et al., 2010; Pucher & Buehler, 2008; Sanders, 2016). In the United States, it was found that both cyclists and motorists prefer a higher degree of separation, as measured by the comfort and safety of these groups (Sanders, 2016). Similarly, research in Germany revealed that cyclists and motorists have different perspectives on safety: while motorists prefer any form of separation, cyclists favor sharing the road with narrow bike lanes (von Stülpnagel & Rintelen, 2024). Route choice modeling for cyclists has been carried out using revealed preference data (e.g. Meister et al., 2023) and in image-based stated preference surveys (e.g. Meyer de Freitas & Axhausen, 2023)

Yet, existing literature has not yet explored and compared users' preferences regarding various policy approaches for integrating S-pedelecs into the current transportation system. Likewise, prior studies have largely overlooked the perspectives of other road users in addition to current and potential S-pedelecs users. Therefore, the present research aims to contribute to existing research by adopting a participatory approach that includes the perspectives of all road users, answering the following research questions.

RQ1: Which policies to integrate S-pedelecs into existing infrastructure are accepted from the perspective of various road users across different countries?

RQ2: What are the preferences of S-pedelec riders and cyclists for different types of cycling infrastructure and different regulations?

2. METHODOLOGY

To answer the research questions a survey approach was applied. In addition to the introduction and the collection of socio demographics the survey consisted of two parts: (1) a stated preference (SP) survey and (2) an acceptance survey.

Sample

The sample for the online survey was recruited through the panel of the company Dynata in Germany, Austria, and Switzerland. Various quotas by were set to ensure a balanced sample of cyclists, e-bike users and other road users by gender and occupations and country. This resulted in a total sample of n = 1402, with participants from Germany (n = 455), Austria (n= 470) and Switzerland (n = 477).
All participants completed the acceptance survey. Additionally, cyclists, E-Bike riders and S-pedelec riders took part in an image-based stated preference (SP) experiment (n = 859). In two

separate experiments focusing on urban and suburban/rural areas, participants were presented with choices between two routes featuring different street designs, travel times, and regulations. The average duration for participants solely taking part in the acceptance survey was 24 minutes, with a median of 10.8 minutes. For participants taking part in the acceptance and SP survey, the average survey duration was 29 minutes, with a median duration of 15.8 minutes.

The overall sample shows a largely balanced distribution in terms of gender and age, with a slightly underrepresented proportion of participants aged 60 and older in the SP group.

Acceptance survey

In the acceptance survey, participants were asked to rate the acceptance of a series of policy measures from their own perspective. The policies evaluated were based on an extensive inventory of S-pedelec related policies in Europe (Hendriks et al., 2023) and selected on the basis of qualitative focus groups (Stemmler et al., 2024). In this paper we evaluate four measures related to infrastructure regulation, which are listed in Table 1.

The infrastructure measures integrating S-pedelecs into the existing transport infrastructure were further differentiated according to type of road: urban, rural, independent of road type. The acceptance conditions for speed regulation measures were only assessed within urban areas.

Table 1 Evaluated infrastructure policies for S-pedelec integration

Infrastructure Policy	Mandatory use of the roadway for S-pedelecs
	Mandatory use of cycling infrastructure for S-pedelecs (bike lanes, bike paths, etc.)
	Mandatory use of shared pedestrian and bike paths for S-pedelecs
	Freedom of choice for S-Pedelecs

Acceptance data was conceptualized to cover three dimensions (Schuitema & Bergstad, 2018): acceptance, fairness, and—where appropriate—safety and usage intention, and were assessed using a five-point unipolar Likert scale (1 = very unacceptable – 5 = very acceptable, 1 = very unfair – 5 = very fair, 1 = very unsafe – 5 = very safe, 1 = very unlikely – 5 = very likely).
To analyze the survey results, we used the Aligned Rank Transform (ART) method to account for the repeated-measures design of the survey, ensuring that individual variability is appropriately handled. ART is a non-parametric statistical technique that facilitates the analysis of interaction effects and main effects in factorial designs while maintaining the interpretability of ranks (Wobbrock et al., 2011).
The analyses reported in this study focus on infrastructure measures evaluated on the dimension of acceptance differentiated by the perspective of S-pedelec riders, e-bike riders, cyclists, pedestrians and car drivers.

Stated Preference

To address the underlying research questions regarding the impact of street design, cycling infrastructure, and applicable regulations on traffic behavior, four different stated-choice experiments were included in the stated-preference survey:

- 'Urban' for cyclists
- 'Urban' for S-pedelec riders
- 'Rural' for cyclists

- 'Rural' for S-pedelec riders

The software Ngene (ChoiceMetrics Pty Ltd, 2014) was used to design the four stated-choice experiments. Ngene facilitates the development of efficient experimental designs through an optimization algorithm (Rose & Bliemer, 2009).

For these experiments, 3D models of streetscapes were created using the software City Engine and rendered in the game engine Unreal. This approach allowed for realistic and visually engaging representations of the scenarios used in the survey. Figure 1 shows impressions of the different cycling facilities shown on urban roads. In addition to the type of cycling facility, in the images we varied width of the facility (two levels), color of the facility (two levels), presence of parked cars, position of parking, number of lanes for vehicular traffic, volume of vehicular traffic and the volume of cyclists. Text attributes included the speed limit of vehicular traffic, a speed limit for bicyclists and whether S-pedelecs were allowed on the facility. For S-pedelec riders, we varied the position of the camera in the image – they could choose if they would prefer to cycle on the road or on the facility.

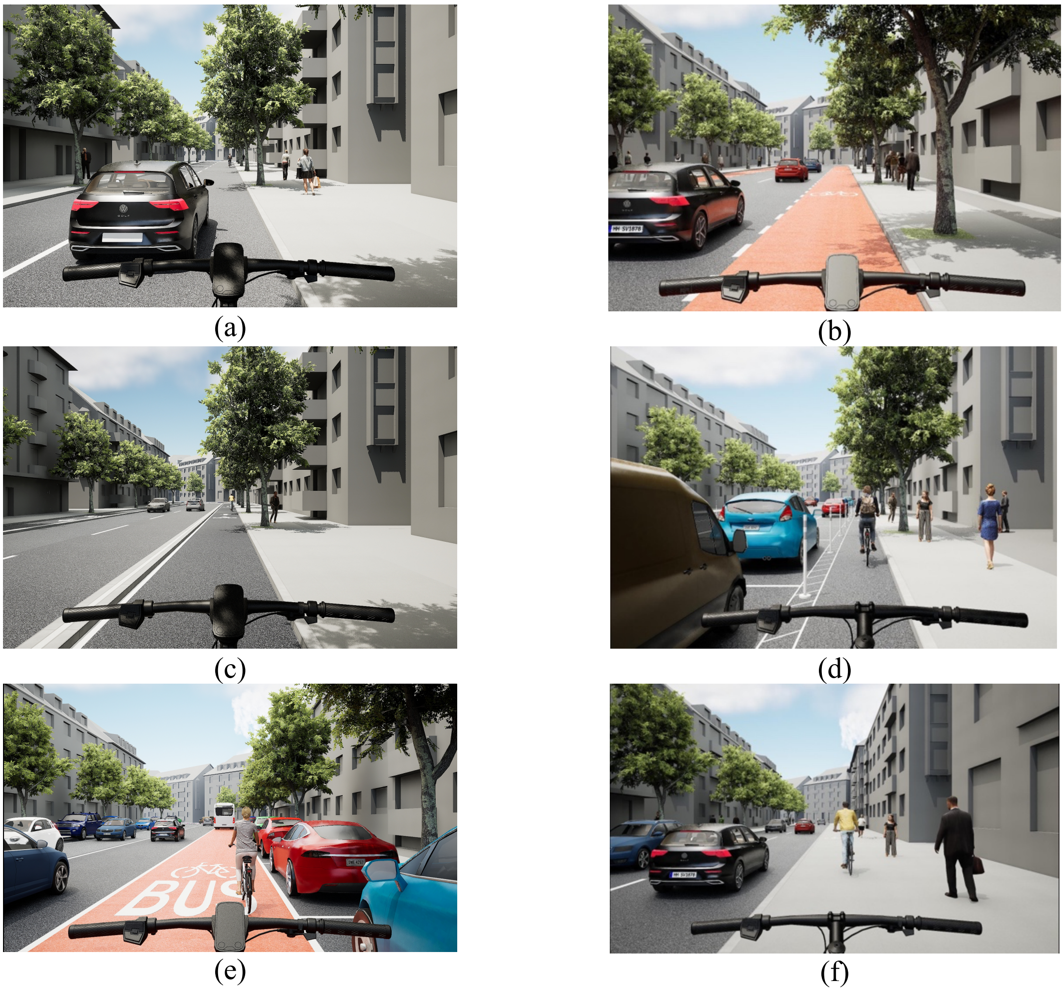

Figure 1 Cycling facilities (including shared pedestrian and cycling paths) in urban areas in the stated-preference survey included the following options: (a) No cycling facility, (b) Painted bike lane, (c) Separate bike path, (d) Protected bike lane with posts, (e) Bicycle lane shared with public transport, (f) Shared pedestrian and cycling path

Figure 2 shows to two decision scenarios in urban areas. The image on the left-hand side shows a choice situation for cyclists. In addition to the image, cyclists were shown travel time, speed limit on the road, whether a speed limit for S-pedelec riders was in place and whether S-pedelecs were allowed on the cycling infrastructure. The image shows a choice situation for S-pedelec riders. S-pedelec riders were either depicted in mixed traffic conditions or on cycling infrastructure, to resemble policies in place in Germany and Austria, where S-pedelec riders are not allowed to make use of cycling infrastructure. S-pedelec riders were informed about the prevailing speed limit on the road and whether they were imposed a speed limit. Both cyclists and S-pedelec riders saw seven choice scenarios for urban settings and six scenarios for rural settings.

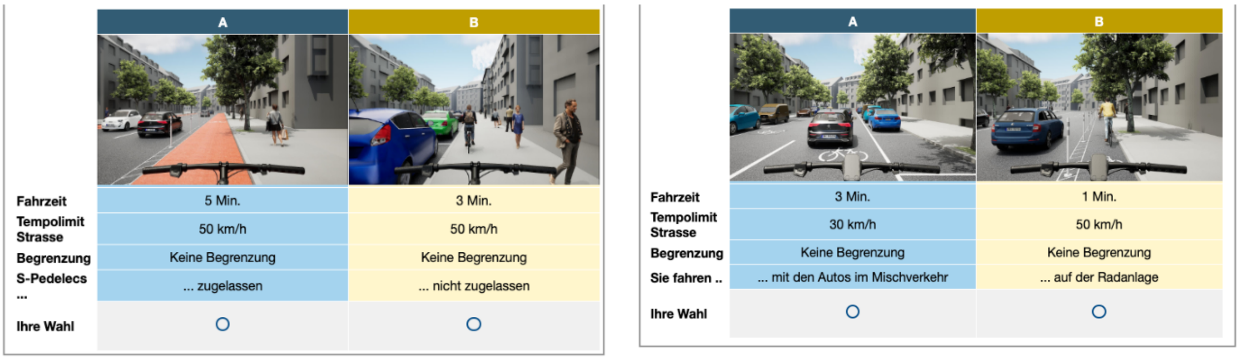

Figure 2 An example of two decision scenarios in urban areas for cyclists (left) and S-pedelec riders (right)

3. RESULTS AND DISCUSSION

Acceptance of policy measures

The analysis presented in this paper focuses on the different infrastructural policy measures and perspective, and localization. The interaction effect of measure and perspective was examined by estimating the following model

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Response ~ Measure × Perspective + (1|Participant)
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Due to the repeated measures design of the survey, the primary conditions (measure, perspective, and localization) were treated as fixed effects, while repeated measurements on participants across all conditions were accounted for as random effects (1|Participant).

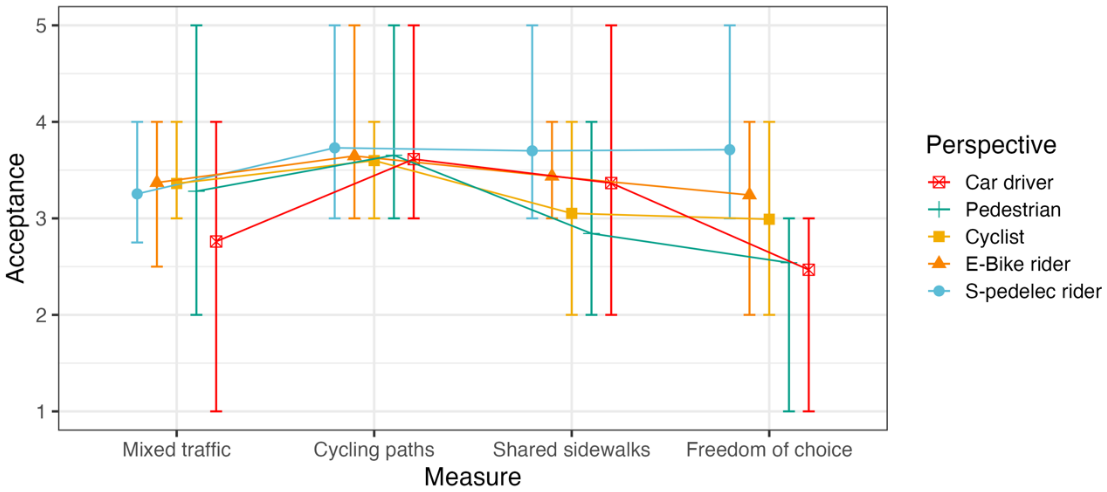

Figure 3 Acceptance of infrastructural measures. (means and interquartile ranges, Scale: 1 = very unacceptable; 5 = very acceptable; N = 1400)

Figure 3 shows the acceptance of the infrastructural measures. We found that S-pedelec riders primarily preferred using cycling facilities (average rating: 3.68), followed closely by the freedom of choice (3.66) and shared sidewalks (3.65). In contrast, they showed a lower preference for mixed traffic environments (3.18). Post-hoc tests revealed significant differences in preferences: mixed traffic was rated significantly lower than freedom of choice (difference: -555.75, $t = -4.47$, $p < 0.05$), shared sidewalks (difference: -534.30, $t = -4.29$, $p < 0.05$), and cycling facilities (difference: -572.27, $t = -4.60$, $p < 0.001$).

E-bike riders were willing to accept S-pedelecs on *cycling facilities* (average rating: 3.62), followed by shared sidewalks (3.39) and mixed traffic (3.33). Cyclists showed similar acceptance of mixed traffic environments (3.34). Post-hoc tests indicated a significant difference between shared sidewalks and cycling facilities (difference: -616.35, $t = -5.58$, $p < 0.001$).

We found that cyclists rated the acceptance of S-pedelecs in *mixed traffic* the highest (average rating: 3.34), followed by E-Bike riders (3.32), pedestrians (3.31), S-pedelec riders (3.18), and public transport users (3.14). Post-hoc tests revealed a significant difference between car drivers and E-Bike riders (difference: -626.55, $t = -4.84$, $p < 0.001$), as well as a significant difference between car drivers and pedestrians.

Pedestrians rated the acceptance of S-pedelecs on *shared sidewalks* lower (2.83) than S-pedelec riders (3.65). Post-hoc tests indicated a significant difference between these groups (difference: -869.68, $t = -6.20$, $p < 0.001$).

Car drivers rated the acceptance of the measure *freedom of choice* lower (2.41) than S-pedelec riders (3.66). Post-hoc tests showed a significant difference between these groups (difference: -1315.26, $t = -10.19$, $p < 0.001$). Cyclists and E-Bike riders also rated this measure lower than S-pedelec riders. Cyclists rated the measure at 2.94 compared to 3.66 for S-pedelec riders, with a significant difference observed (difference: -771.87, $t = -6.37$, $p < 0.001$). Similarly, E-Bike riders rated it at 3.19 compared to 3.66 for S-pedelec riders, with post-hoc tests indicating a significant difference (difference: -499.19, $t = -6.37$, $p < 0.05$).

Overall, sharing cycling paths is the most accepted infrastructure measure by all road users. Analyses revealed no (or only isolated) differences with respect to country and road type.

Stated Preference

First, decision-making behavior was analyzed. S-pedelec riders chose to use cycling facilities in 67% of cases, compared to 33% opting to ride on the road. Cyclists chose to take a longer route in 53% of cases, while S-pedelec riders opted for a longer route in 47% of cases, indicating that participants made trade-offs. Subsequently choice models were estimated. Choice models were estimated using Apollo (Hess & Palma, 2021). These models initially included travel time and subsequently included main effects for cycling facilities. Subsequently, interaction variables included for specific design features of cycling facilities. At different stages, it was attempted to determine different preferences by type of cyclist and country in the model estimation process. Table 2 presents the MNL model results for urban roads.

Table 2 MNL model results

Variable	Beta	Std. Error	T-Test
Travel time	-0.052	0.014	-3.775
- Travel time offset for S-pedelec riders	-	-	-
- Travel time offset for E-Bike riders	-	-	-
Mixed traffic	0.488	0.084	5.794
- Correction for S-pedelec riders	-	-	-
- Speed limit 50 kmh (Ref: 30km/h)	-0.988	0.196	-5.038
- On-street parking (Ref: No parking)	-0.593	0.136	-4.358
- Car traffic near (Ref: far)	-0.605	0.175	-3.457
- Bike lane visible (Only S-pedelec riders)	0.643	0.293	2.195
Bike lane	0.418	0.112	3.734
- Correction for S-pedelec riders			
- Speed limit 50 kmh (Ref: 30km/h)	-0.433	0.21	-2.058
- Colour: red (Ref: grey)	0.768	0.382	2.011
- On-street parking (Ref: No parking)	-	-	-
- Wide (Ref: Narrow)	1.292	0.498	2.592
Protected bike lanes	1.1	0.107	10.262
- Correction for S-pedelec riders	-0.512	0.118	-4.339
- On-street parking (Ref: No parking)	-	-	-
- Wide (Ref: Narrow)	0.226	0.107	2.118
- On-street parking (Ref: No parking)	-	-	-
Seperated bike lane	1.125	0.101	11.152
- Correction for S-pedelec riders	-0.253	0.128	-1.98
- On-street parking (Ref: No parking)	-	-	-
- Wide (Ref: Narrow)	0.376	0.117	3.214
Lane shared with public transport	0.312	0.087	3.605
- Correction for S-pedelec riders	-	-	-
Shared bicycle and pedestrian lane	-	-	-
Constant for the right alternative	-0.004	0.031	-0.126

Model performance	
Individuals	854
Choice situations	5953
LL(start)	-4126.31
LL(final)	-3722.26
Adj.Rho-squared	0.0934

The expected negative parameter for travel time indicates that longer travel times reduce the likelihood of a route being chosen. For S-pedelec and E-Bike riders, the interaction terms were not significant, meaning they perceive travel time similarly to regular cyclists.

Riding in mixed traffic is generally perceived more positively than riding on shared pedestrian and cycling paths and a bike lane, in line with previous results by von Stülpnagel & Rintelen (2024). However, negative parameters for certain road features — parking areas (-0.593), speed limits of 50 km/h (-0.988), and high traffic volumes for S-pedelec riders — indicate that these features reduce the preference for cycling in mixed traffic, making other cycling facilities more attractive. If bike lanes or lanes shared with public transport were visible to S-pedelec riders, these were viewed these positively, indicating that S-pedelec riders consider making use of these facilities. Other road characteristics, such as the number of lanes or one-way streets, were not significant.

Bike lanes were preferred for protective bike lanes over shared pedestrian and cycling paths. However, bike lanes along roads with a 50 km/h speed limit are perceived less favorably. Wider protective lanes and red bike lanes are preferred, as shown by positive parameter values.

The positive parameters for protected bike lanes and separated bike lanes indicate that these types of infrastructure are the most preferred. Riders especially favor wider lanes or paths, though the preference for width is less pronounced than for protective bike lanes. S-pedelec riders prefer elevated paths to those separated by posts. Nearby parking spaces do not significantly influence preferences.

Lanes shared with public transport were preferred, albeit less than dedicated cycling infrastructure.

Moving towards the willingness-to-pay for cycling infrastructure, it was found that both cyclists and S-pedelec riders would prefer a route with a shared pedestrian and cycling path if it were 9 minutes shorter than a road with a 30 km/h speed limit. On the other hand, a road with a 50 km/h speed limit and near traffic would need to be 5.5 minutes faster for S-pedelec riders to consider it. For protected bike lanes with bollards and separated cycle tracks with elevation, S-pedelec riders and cyclists exhibit differing preferences. S-pedelec riders are only willing to take a 1-minute detour for a separated bike lane with bollards compared to a road with a 30 km/h speed limit, while cyclists are willing to take an 11-minute detour. If the road has a speed limit of 50 km/h, S-pedelec riders are willing to take a 10-minute detour to avoid it.

4. CONCLUSIONS

This paper presented the results of a survey conducted in Austria, Germany and Switzerland – countries with different policies in place for S-pedelecs. Contributing to existing research by

Sanders (2016) on preference of cyclists and car drivers, we find that other road users consider it acceptable that S-pedelec riders use cycling infrastructure, regardless of country and road type. Therefore, our participatory approach uncovers a common ground for the acceptance of this emerging form of mobility reconciling the question on where S-pedelecs should ride.

Similarly, choice models reveal a strong preference of S-pedelec riders to use cycling facilities, where the type of facility plays a smaller role when compared to the preference of regular cyclists. Riding in mixed traffic enjoys a higher preference when a lower speed limit is imposed (30km/h), no parked cars are present and/or less traffic is present.

Nevertheless, choice models point to high detour factors for the usage of cycling facilities, in line with several other image-based SP surveys (e.g. Hardinghaus & Papantoniou, 2020). Further investigation of the depiction of text-based attributes in image-based surveys is necessary. Moreover, to realistically depict cycling in surveys, intersections, and perhaps a variety of cycling infrastructures along a route is necessary.

Overall, our results point in two diverging directions: cyclists and S-pedelec riders are generally willing to use mixed traffic environments when speed limits are low, preferring this option over narrow bike lanes adjacent to roads with high-speed limits. However, if implementing speed reductions is not politically viable, sufficiently wide, separated cycling facilities become essential—potentially accompanied by speed limits for S-pedelecs on these facilities. Several countries, such as the Netherlands and Belgium, already enforce such policies within urban areas (Mobycon, 2023). Further research into mode choice behavior under different policy scenarios is necessary to understand their relationship.

Results from this study fill a gap in the existing research and inform policy makers and planners that sharing cycling facilities for S-pedelecs together with speed limits may offer a broadly accepted avenue to integrate this emerging transportation mode into a sustainable future mobility system.

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