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E-bike adoption: cycling trajectories, uses, and experiences. The case of Lausanne, Switzerland

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The case of Lausanne, Switzerland

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Summary

Over the past ten years, sales of electrically-assisted bicycles (e-bikes) have exploded in Switzerland and elsewhere in the world, and they now account for a significant proportion of all bicycles sold. E-bikes are equipped with an assistance that engages when pedalling, increasing the power of the rider. By reducing the effort required, they have the potential to extend cycling to a wider audience despite limited physical ability or age. They also increase the spatial reach of cycling in hilly areas and over long distances, and increase the uses of the bicycle, such as for transporting goods or children. The rise of the e-bike is part of a wider renaissance of cycling in cities over the last twenty years. In the context of a transition to sustainable mobility, the e-bike is emerging as an ideal mode of transport for cities, due to its small environmental and spatial footprint and its ability to replace car journeys. In the face of increasingly sedentary societies, the e-bike represents an active mobility that allows for daily physical activity with significant health benefits.

This thesis focuses on the adoption of the electrically-assisted bicycle (e-bike). It seeks to understand this phenomenon from the point of view of its users, asking what drives them to adopt an e-bike and how they appropriate and use it in everyday life. The data used in this thesis were collected in the context of a research project on e-bikes in Lausanne, with the partnership of the Services Industriels de la Ville de Lausanne (SiL). The quantitative part includes a questionnaire survey filled in by more than 1400 e-bike users who benefited from a subsidy for their purchase granted by the SiL. The qualitative part includes semi-directive biographical interviews with 24 e-bike users.

From a theoretical point of view, this thesis places the study of the e-bike in the context of an emerging field of research on the practice of cycling, in which approaches from the social sciences are playing an increasing role. The adoption of the e-bike is analysed through a theoretical framework that combines two major approaches. On the one hand, a biographical approach that sees e-bike adoption over time as a continuation of an existing cycling practice in the life course. On the other hand, a systemic approach to cycling, vélomobility, which defines the practice of e-biking as the relationship between an individual’s potential for mobility and the territory’s potential to accommodate cycling.

The central part of the thesis consists of five articles published or submitted to scientific journals, each of which sheds a different light on the phenomenon of e-bike adoption. The first three articles deal with the adoption of the e-bikes in a biographical approach. The first article uses interviews to analyse the 'cycling trajectories' of e-bike users, i.e. their relationship to cycling before the adoption of an e-bike. Two types of trajectories are identified: resilient trajectories, where the e-bike represents a way of continuing an existing cycling practice, and restorative trajectories, where it allows cycling to be resumed after an interruption or to be taken up regularly. The second article expands on this finding by combining the interviews and questionnaire survey results to analyse the characteristics of individuals in each of these two trajectories. The third article continues this biographical approach by considering the role of certain key events in the life course (residential moves, childbirth) as triggers for the adoption of e-bikes.

The fourth article focuses on the use of the e-bike as a meeting point between an individual potential for mobility and a territorial hosting potential for cycling. It considers the factors which explain the frequency of use of the e-bike. These factors are located at the level of uses (e-biking for utilitarian trips, the past use of alternative modes to the car), of the territory (proximity to the workplace), and of the individual (the absence of competing modes of transport, a recent purchase of the e-bike, skills for cycling in different situations, strong motivations for purchase, and a low sensitivity to barriers).

The fifth article deals with the frictions that result from the meeting of individual and territorial potentials, through the theme of the safety of e-bike users in Lausanne. Based on their comfort for riding in different situations, satisfaction with cycling infrastructure, and sensitivity to barriers, five groups of e-bike users are identified: *confident all-rounders, recreational on-roaders, utilitarian traffic avoiders, and unconfident path-users*. Despite the potential of the e-bike, there are still significant differences in perceived safety according to gender, age, and frequency of use, while only a portion of current cyclists are comfortable in the current conditions. Cycling safety therefore remains a barrier to the development of e-bikes.

The conclusion offers a reflection on the research contributions of this thesis, which develops both a biographical and systemic approach that could be pursued in different spatial contexts of study, and to study changes in the use of e-bikes beyond adoption. Several recommendations are made to accompany the development of e-bikes. Acting on the individual potential for mobility involves strengthening access to e-bikes through subsidies targeting key events associated with mobility practices (moving house, childbirth, retirement), strengthening cycling skills through courses and group rides, or promoting a positive and "normal" image of e-biking. Acting on the territory's hosting potential requires the improvement of safety conditions through cycle infrastructure separated from motorized traffic, and restrictions on motorized traffic in the city centre.

Résumé

Depuis une dizaine d'années, les ventes de vélos à assistance électrique (VAE) explosent en Suisse et ailleurs dans le monde, représentant aujourd'hui une part importante des vélos vendus. Les VAE sont dotés d'une assistance qui s'engage lors du pédalage en démultipliant la force de l'usager. En réduisant l'effort nécessaire, ils ont le potentiel d'étendre la pratique du vélo à un plus large public malgré des capacités physiques limitées ou l'âge. Ils permettent également d'accroître la portée spatiale du vélo dans des territoires vallonnés et sur de longues distances et de multiplier les usages du vélo, comme pour le transport de courses ou d'enfants. L'essor du VAE s'inscrit plus largement dans une renaissance de la pratique du vélo dans les villes depuis une vingtaine d'années. Dans le contexte d'une transition vers une mobilité durable, le VAE se profile comme un mode de transport urbain idéal, de par sa faible empreinte environnementale et spatiale et sa capacité de remplacement des trajets en voiture. Face au défi posé par des sociétés de plus en plus sédentaires, le VAE représente une mobilité active qui permet une activité physique quotidienne bénéfique pour la santé.

Cette thèse se concentre sur l'adoption du vélo à assistance électrique (VAE). Elle cherche à comprendre ce phénomène du point de vue de ses usagers, en se demandant ce qui les pousse à adopter un VAE et comment ils se l'approprient et l'utilisent dans la vie courante. Les données utilisées dans cette thèse ont été collectées dans le contexte d'un projet de recherche sur le VAE à Lausanne, avec le partenariat des Services Industriels de la Ville de Lausanne (SiL). La partie quantitative inclut une enquête par questionnaire remplie par plus de 1400 usagers de VAE ayant bénéficié d'une subvention pour leur achat octroyée par les SiL. La partie qualitative comprend des entretiens biographiques semi-directifs avec 24 usagers de VAE.

D'un point de vue théorique, cette thèse place l'étude du vélo à assistance électrique dans le contexte d'un champ de recherche émergeant sur la pratique du vélo, où les approches issues des sciences sociales jouent un rôle grandissant. L'adoption du VAE y est analysée à travers un cadre théorique qui combine deux approches majeures. D'une part, une approche biographique qui voit l'adoption du VAE à travers le temps, comme la continuité d'une pratique du vélo existante dans le parcours de vie. D'autre part, une approche systémique du vélo, la vélomobilité, qui définit la pratique du VAE comme la relation entre un potentiel individuel de mobilité et un potentiel d'accueil du territoire pour le vélo.

La partie centrale de la thèse se compose de cinq articles publiés ou soumis dans des revues scientifiques qui apportent chacun un éclairage différent sur le phénomène de l'adoption du VAE. Les trois premiers articles portent sur l'adoption du VAE dans une approche biographique. Le premier article se base sur les entretiens pour analyser les « trajectoires cyclistes » des usagers de VAE, c'est-à-dire leur rapport à la pratique du vélo avant l'adoption du VAE. Deux types de trajectoires sont identifiées : les trajectoires résilientes, où le VAE représente une manière de continuer une pratique du vélo existante, et les trajectoires restauratrices, où il permet de reprendre le vélo après une interruption de la pratique ou de s'y mettre régulièrement. Le second article approfondit ce résultat en combinant les entretiens et les résultats de l'enquête par questionnaire pour analyser les caractéristiques propres aux personnes dans chacune de ces deux trajectoires. Le troisième article poursuit cette approche biographique en considérant le rôle de certains événements-clés dans le parcours de vie (déménagements, naissances d'enfants) comme déclencheurs de l'adoption du VAE.

Le quatrième article se concentre sur l'usage du VAE comme la rencontre entre un potentiel individuel de mobilité et un potentiel d'accueil du territoire. Il s'intéresse aux facteurs qui permettent d'expliquer la fréquence d'utilisation du VAE. Ces facteurs se situent à la fois au niveau des usages (l'utilisation du

VAE pour les trajets utilitaires, l'usage passé de modes alternatifs à la voiture), du territoire (la proximité au lieu de travail), et de l'individu (l'absence de modes de transport concurrents, un achat récent du VAE, la capacité à faire du vélo dans différentes situations, de fortes motivations d'achat, et une faible sensibilité aux obstacles).

Le cinquième article porte sur les frictions qui résultent de la rencontre entre potentiels individuels et territoriaux, à travers la thématique de la sécurité des usagers de VAE à Lausanne. Sur la base de l'aisance à rouler dans différentes situations, de la satisfaction avec les aménagements cyclables, et de la sensibilité aux obstacles, cinq groupes d'usagers du VAE sont identifiés : les *confiants en toute situation*, les *récréatifs sur route*, les *utilitaires évitant le trafic*, les *usagers de pistes peu confiants*. Malgré le potentiel du VAE, il subsiste d'importantes différences dans la sécurité perçue en fonction du genre, de l'âge, et de la fréquence d'utilisation, tandis que seule une partie des usagers est à l'aise dans les conditions actuelles. La sécurité cyclable reste donc une barrière au développement du VAE.

La conclusion offre une réflexion sur les contributions de cette thèse pour la recherche, qui développe une approche à la fois biographique et systémique qui pourrait être poursuivie dans différents contextes spatiaux d'étude, et pour étudier les changements dans l'utilisation du VAE au-delà de l'adoption. Plusieurs recommandations sont formulées pour accompagner le développement du VAE. Agir sur le potentiel individuel de mobilité passe par le renforcement de l'accès aux VAE à travers des subventions ciblant les événements-clés associés aux pratiques de mobilité (déménagements, naissances d'enfants, retraite), le renforcement des compétences cyclistes grâce à des cours et des sorties de groupe, ou la promotion d'une image positive et « normale » du VAE. Agir sur le potentiel d'accueil du territoire demande l'amélioration des conditions de sécurité à travers des aménagements cyclables séparés du trafic motorisé, et des restrictions sur le trafic motorisé au centre-ville.

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1. Presentation of the thesis

1.1 Introduction

In the last decade, several countries of the Global North have experienced a boom in sales of e-bikes, bicycles which offer an electrical assistance to the rider when pedalling. E-bikes have been progressively catching up to conventional bicycles. Four in ten bicycles sold in Switzerland are currently e-bikes (Velosuisse, 2022), and half of all bicycles sold in the Netherlands and Belgium (Bike Europe, 2017, 2019). In the near future, e-bikes could account for a majority of bicycle sales. E-bikes come in two main categories. The most frequent are "pedelecs" which offer a pedalling assistance until 25 km/h and have similar form and performance to traditional bicycles. There are also faster "speed-pedelecs" which provide a pedalling assistance until 45 km/h and can enable trips on much longer distances. E-bikes also take on different shapes, such as cargo bicycles which enable the transport of large goods or volumes, or foldable e-bikes which can be carried on trains without additional space[1].

By reducing the effort needed to cycle, e-bikes have fundamentally changed people's understanding of what cycling is (Behrendt, 2018). They have made cycling accessible to a wider audience including older people, those less physically able, or simply those who wished to return to cycling or continue to do so. E-bikes have also made it easier to accomplish cycling trips which were considered too difficult, such as carrying heavy goods such as groceries, bringing children to school, or commuting on long distances or in hilly environments. The adoption of the e-bike, as a new form of cycling, is also related to a larger-scale phenomenon which is the renaissance of cycling in cities around the world (Pucher & Buehler, 2017, Héran, 2014). Within this renaissance, e-bikes have a role to play to widen the appeal of cycling beyond traditional barriers related to distance, topography, or physical effort.

In the context of a transition towards sustainable mobility, cycling has the potential to reduce greenhouse gas emissions as well as other negative externalities including congestion, noise and air pollution, and road crashes, by replacing individual motorized transport trips. Thanks to their electric assistance, e-bikes play an "intermediator role" (Wolf & Seebauer, 2014) and represent a "transitional step" (Popovich et al., 2014) between conventional bikes and cars. They could thus replace more motorized trips than traditional, purely mechanical or "unassisted" bicycles. Because e-bikes attract people who drive cars and live in rural areas, their adoption represents a significant environmental gain (Sun et al. 2020). Moreover, e-bikes have a low energy consumption because of their hybrid propulsion which is not fully electric but a "combination of leg and battery power" (Behrendt, 2018, p. 64). Only half of the energy required to move an e-bike is provided by the electric assistance (depending on the assistance level), with muscular power providing the other half. Given their low weight compared to other vehicles (about 25 kg), e-bikes are very frugal, requiring only an estimated 1 kWh of electricity to travel 100 km, depending on the slope and speed, or between 10 and 33 times less than a car for the same distance (Weiss et al., 2020). E-bikes' total environmental impact, including the "grey energy" required for the production of lithium-ion batteries, is the second-lowest among transport modes after mechanical bicycles (and in Switzerland, commuter trains) (International Transport Forum, 2020; OFEV, 2018). Within electric mobility, e-bikes represent a more economical and sustainable mode of transport than electric cars, and have been adopted at a much greater rate in several countries (Bloomberg, 2022; New York Times, 2021).

[1] These models were relatively rare in 2018, when the data for this thesis was collected.

E-bikes also have important potential health benefits. Physical activity levels have been declining in western societies, with increased sedentary behaviour having been declared a "health emergency" by the World Health Organization (WHO, 2020). E-biking represents a form of active mobility like walking or cycling which can be practised during daily trips, making it more accessible than competitive sports. Despite their assistance, e-bikes have been shown to offer sufficient physical activity to meet recommended daily health guidelines (Gojanovic et al., 2011; Bourne et al., 2018; Castro et al., 2019). Crucially, they cater to older adults who suffer the most from a lack of physical activity and health issues (Van Cauwenberg et al., 2019). Other health benefits to be gained from e-biking include mental health, quality of life, and maintaining an independent mobility (Götschi et al., 2016; T. Jones, Chatterjee, et al., 2016; Spencer et al., 2019). By accelerating the uptake of cycling and a shift from driving, e-bikes can greatly contribute to health benefits at the level of the whole population (Sundfør et al., 2020), by reducing the burden of traffic crashes, lowering illnesses related to air pollution, and reducing mortality through increased physical activity (De Hartog et al., 2010).

Due to e-bikes' success and potential, they have received growing scientific interest in the last years, as they have become "mainstream" (Bourne et al., 2020; Fishman & Cherry, 2016). Most research on e-bikes has come from transport research, with the goal of understanding the profile of e-bike users, how they are used, and their substitution effects for replacing trips by other modes (Bigazzi & Wong, 2020; de Haas et al., 2021; Kroesen, 2017; Hiselius & Svensson, 2017; Söderberg f.k.a. Andersson et al., 2021; Melia & Bartle, 2021). Some studies have specifically focused on differences between conventional bicycles and e-bikes, as well as the effects of e-bike trials and switching to e-bikes on cycling patterns (Fyhri & Fearnley, 2015; Fyhri et al., 2017; Fyhri & Beate Sundfør, 2020). In the field of health literature, much of the focus has revolved around the physical activity benefits provided by e-bikes (Bourne et al., 2018). Older adults have also been a notable focus of literature, with interest in the physical activity benefits but also increased mobility, mental well-being and leisure possibilities brought by e-bikes (Johnson & Rose, 2015; T. Jones, Chatterjee, et al., 2016; Spencer et al., 2019; Van Cauwenberg, De Bourdeaudhuij, et al., 2018; Van Cauwenberg et al., 2019).

However, much research on e-bikes has remained rather descriptive and lacking a cohesive theoretical foundation, which would take into account the specificities of e-bikes over other transport modes. This need to consider cycling within a holistic perspective has also been emphasized by conventional cycling research (Handy et al. 2014, Rérat, 2019). To address this, we will propose a theoretical framework which incorporates the influence of social science approaches to mobility in two ways: (1) to analyse e-bike adoption dynamically over the life course rather than at a fixed point in time, and (2) to consider e-bike use within a system which considers the mutual relationship between the individual and a given territorial context, as well as the frictions resulting from it.

1.2 Research questions

This thesis focuses on the phenomenon of e-bike adoption within urban utility cycling, in other words, as a form of transport rather than purely for leisure. We start by asking the following questions:

Why are e-bikes adopted? How are they being used? And what are e-bike users' experiences in a given context?

To answer them, we consider e-bike use within a holistic framework, the system of vélomobility, as the result from the meeting between individuals with a potential for mobility, and an environment which has a hosting potential for cycling or bikeability, which can either encourage or deter cycling. Within this framework, this thesis consists of five articles which each cast a different light to the adoption of the e-bike. These five articles can be viewed chronologically as representing three phases: the adoption of the e-bike (1), the use of the e-bike (2), and the experiences and frictions related to e-bike use (3).

The first three articles of the thesis take a biographical approach to e-bike adoption. They aim to understand why e-bikes are adopted, by whom, and when. The adoption of the e-bike is thus viewed within individuals' cycling practice over the life course, including their interruptions, variations, and new beginnings. It is argued that e-bikes are not an entirely new practice but rather fit within a person's existing cycling trajectory which is the result of their past experiences of cycling. The first article and second article examine and classify the different types of cycling trajectories which e-bike users have, and how these reflect an individual's relationship to cycling over their lives. Meanwhile, the third article focuses on how changes in cycling happen throughout life, using the concept of key events (e.g. the birth of a child or a residential move) as a potential trigger for the adoption of an e-bike. Through these articles, we aim to answer the following questions and sub-questions:

Q1: Why do people choose to use an e-bike and under which circumstances do they adopt it over their life course?

a. *What are the different cycling trajectories of e-bike users?*
b. *What is the role of the e-bike within the individual's cycling trajectory?*
c. *What are the links between e-bike adoption and biographical events which change the daily mobility of e-bike users?*

The fourth article considers the effects of the adoption of the e-bike. Applying the framework of the system of vélomobility, it addresses how e-bikes are being used by different individuals within a specific environment. The article focuses on understanding which factors affect the frequency of e-bike use, both at the individual level (in terms of access to vehicles, cycling skills, and motivations and barriers), at the environmental level (in terms of built environment and bikeability), and in terms of uses (trip purposes, previous travel modes). The following questions are thus addressed:

Q2: How are e-bikes used and what is the influence of individual characteristics (mobility potential) and environmental characteristics (territorial potential)?

a. *How does the frequency of e-bike use vary among users according to their personal characteristics and their residential location?*
b. *Which individual and environmental factors determine the frequency of e-bike use?*

The fifth article aims to address how e-bike users experience e-cycling on the day-to-day, by analysing the frictions or deterrents which they face within a spatial context which is sometimes unwelcoming for e-bike use. We focus on e-bike users' perceived safety as one of the barriers to the development of e-bikes. To better understand individual differences, we propose a segmentation of e-bike users according to their perceived safety. We aim to answer the following questions:

Q3: How do e-bike users perceive cycling safety according to their personal characteristics, skills and experiences?

a. *What are the differences in the perception of safety among e-bike users?*
b. *Which individual factors (age, gender, frequency, experience) influence the safety perception of e-bike users?*

1.3 Structure of the thesis

This is a thesis composed of several scientific publications, rather than a single text or monography. The structure of this thesis therefore aims to link these different articles through a common thread by offering a cohesive theoretical framework.

The thesis is composed of nine main chapters. The first three (including the present chapter) serve as an introduction and framing of the subsequent articles. Chapter 2 presents the theoretical framework of the thesis and the background to the five articles. Chapter 3 introduces the context of the study, methodology, data collection and analysis, as well as a presentation of the sample and description of the data.

The heart of the thesis (Chapters 4 to 8) is composed of peer-reviewed scientific articles and book chapters, which were all written by the author (as a first author) during the contract of the thesis. The first three have been published, while the last two are currently under review.

- Chapter 4: "From Conventional to Electrically-assisted cycling: A biographical approach to the adoption of the e-bike"
- Chapter 5: "The Cycling Trajectories of E-Bike Users: A Biographical Approach"
- Chapter 6 : "Key Events, Motivations, and Past Experiences in the Adoption of the E-Bike"
- Chapter 7: "A systemic approach to understanding the frequency of e-bike use in a low-cycling city"
- Chapter 8 : "Comparing e-bike users' perceptions of safety: The case of Lausanne, Switzerland"

Lastly, in Chapter 9, we return to the main findings of the thesis, discuss its contribution to the existing literature, its limitations and outlook for future research. Finally, we conclude by offering a few policy recommendations.

2. Theoretical framework

This chapter aims to provide the theoretical background to this thesis. It gives an overview of research on cycling and e-bikes and presents the theoretical concepts used in the articles.

The first two sections give the general context of the thesis and situate this research within existing fields of study. Section 2.1 presents the context of the emergence of e-bikes, the subject of this study. We define their characteristics and specificities compared to conventional bicycles, their emergence and development, and the current state of e-bike research, its main themes and research gaps. In section 2.2, we give a general overview of the theoretical approaches to cycling. We first introduce cycling research as a meeting point between transport research and the social sciences. We then review the main approaches to cycling research.

The next three sections serve to develop our own theoretical approach which combines a biographical approach over time, with a systemic approach of cycling. Section 2.3 views e-bike adoption through a biographical approach as the continuity of a cycling trajectory. Within this approach, we focus on the role of key events for triggering changes in cycling, and on individual cycling trajectories. This approach is related to the first three articles (Chapters 4, 5, 6).

Section 2.4 places e-bike adoption within a system of cycling or vélomobility, as the meeting between individuals with a propensity for cycling, and an environmental context which offers certain conditions for cycling. We use this systemic approach to review the determinants of cycling, at the environmental and individual level. This approach is related to the fourth article (Chapter 7).

Section 2.5 considers e-bike adoption from the viewpoint of cycling safety. Perceived safety is viewed as resulting from the friction between the contextual environment for cycling, and the individual's mobility potential. It also represents a (negative) consequence of e-bike adoption. We define safety as including both an objective and a perceived dimension, before focusing on the perceived safety of e-bike use. This approach is related to the fifth article (Chapter 8).

2.1 Context: the emergence of e-bikes

2.1.1 Seven characteristics of cycling and e-bikes

Cycling differs fundamentally from motorized modes of transport such as the car or public transport. To properly understand e-bikes, it is also important to take into account their specificities compared to conventional cycling. According to the Dutch manual for cycle planning, there are seven specific characteristics to consider when designing cycling infrastructure (CROW, 2016).

First, bicycles are ***muscle-powered*** and require physical effort to move, especially when cycling in hilly environments, carrying goods or children, on longer distances, or when restarting after a stop, which requires as much energy as additional distance (Héran, 2015). Although e-bikes reduce the effort required to cycle, they still require the user to pedal continuously (Gojanovic et al., 2011; Bourne et al., 2018).

Second, cycling takes place on two wheels[2] and requires constant ***coordination between body and machine*** to maintain an equilibrium. This means that sufficient width needs to be allocated for swaying movements. Although e-bikes' assistance may facilitate maintaining balance, their increased speed

[2] There are also tricycles with three wheels for carrying freight (i.e. cargo bikes) or for additional stability

requires additional space for passing and turning, as well as for accommodating cargo bicycles or tricycles.

Third, cyclists differ from motor vehicles due to their ***low weight and a lack of external protection*** in case of an impact, and thus are considered as vulnerable road users with whom collisions should be avoided at all costs (WHO, 2009). E-bikes unfortunately offer no additional protection and are also increasingly becoming victims of traffic crashes due to other road users misestimating their speed (Petzoldt, Schleinitz, Heilmann, et al., 2017).

Fourth, because most bicycles have little shock absorption, cyclists are very ***sensitive to the quality of road surfaces***, with uneven surfaces requiring more effort to maintain regular speeds. Though e-bikes' assistance gives them a slight speed advantage over rough terrain, they remain sensitive to uneven road surfaces (bumps, cracks, loose gravel) which can cause crashes.

Fifth, cyclists are ***exposed to the elements*** such as cold and rain, unlike closed vehicles. Although they do not protect them from the rain, e-bikes may help cyclists to cycle against the wind thanks to their assistance.

Sixth, cycling is a ***social practice*** which is often (in high-cycling countries) practised as a group or with two people side-by-side. Here, e-biking may play an important role by allowing people of different ages and abilities to cycle together and by "equalizing" cycling levels (Popovich et al., 2014)

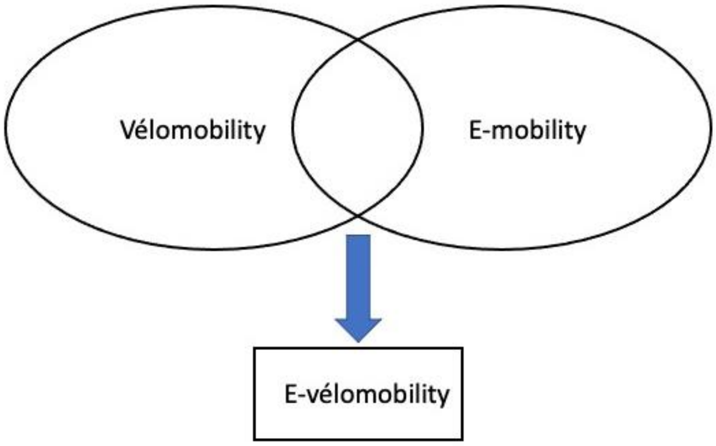
Seventh, cycling is practised by ***humans*** who have very different abilities and regularly commit errors, just like other road users. Thus, cycling infrastructure should minimize the negative consequences of such errors, which are bound to happen. E-bike users have the same needs for safe, physically separated infrastructure which tolerates their mistakes, and those of other road users (Rérat, 2021c).

2.1.2 Defining e-bikes

To better understand the potential of e-bikes, it is necessary to properly define what they are, and also, what they are not. Traditional, unassisted bicycles are considered a fundamentally "low-tech" mode of transport whose components and basic diamond shape has not changed much for a century, despite advances in gearing and materials. Cox & Van De Walle, (2007) argue that one of the barriers to the development of the bicycle has been the dominant "evolinear model of technology", which sees the bicycle as a slow vehicle having been replaced by faster, more advanced modes of transport such as the car. However, the e-bike challenges this view by offering a major technological development of the bicycle through the addition of a pedal assistance driven by an electric motor. Crucially, this development does not aim to make it faster, but rather, to make it more accessible to a wider audience. Within the practice of cycling, e-bikes can therefore be seen as representing a technological change, with the potential to attract new users and incite a transition, for example from driving to cycling (Spotswood et al., 2015).

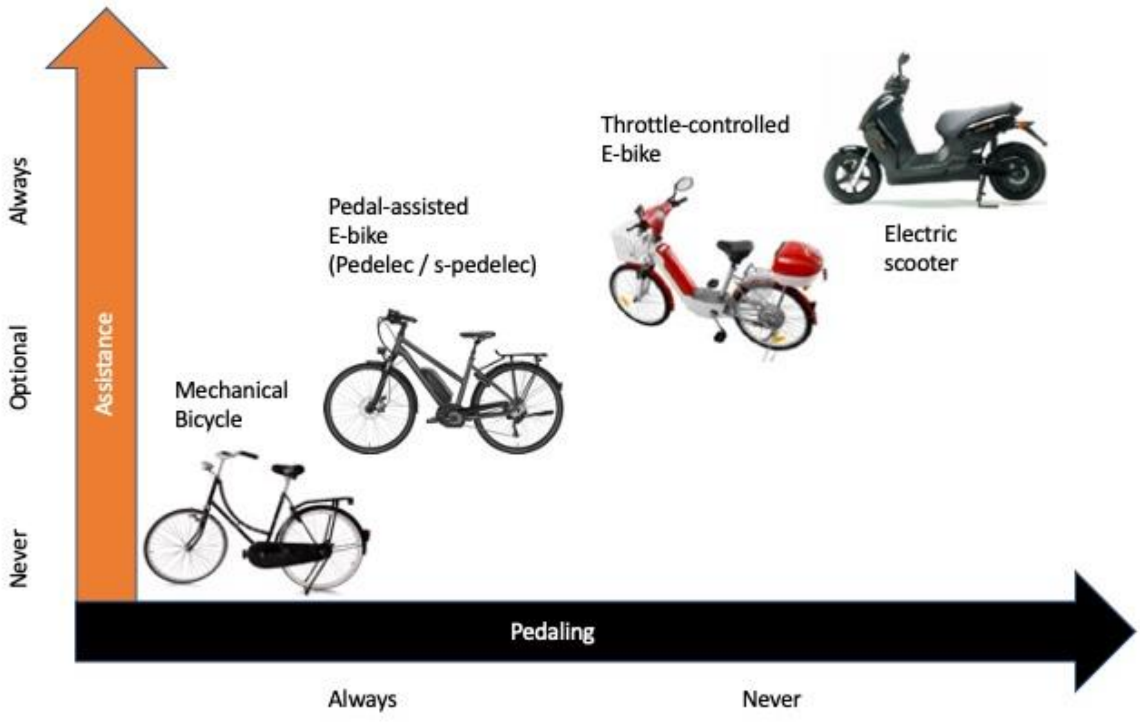
E-biking can be seen as a hybrid practice situated between strictly muscular-powered cycling (vélomobility) and electric mobility (electric cars or two-wheelers), as shown in Figure 1. Behrendt (2017) introduces the term e-vélomobility to refer to "practices, systems and technologies of electrically-assisted cycling where vélomobility pedal-power combines with e-mobility's battery/motor assistance to propel the rider" (Behrendt, 2018, p. 12). Compared to vélomobility, e-vélomobility offers a different embodied experience due to its electrical assistance which could enable "more people to cycle more" (Behrendt, 2018), by addressing a larger audience and enabling a more intensive use than a conventional bicycle.

Figure 1: E-vélomobility. Adapted from Behrendt, 2018.



As represented in Figure 2, e-bikes are located at the lower end of a spectrum going from muscular cycling, which offers no assistance, to fully electrical two-wheelers which require no pedalling at all (Behrendt, 2018). Technically speaking, e-bikes are bicycles with an electrical assistance (provided by a battery and motor), which requires pedalling at all times, and which serves to multiply the strength of the rider. This is an essential criterion for defining e-bikes, as there are also vehicles labelled as "electric bicycles" that do not require pedalling and can be operated by a throttle (Behrendt, 2018; Rose, 2012). Vehicles of this sort, which are essentially electric scooters, are popular in China (Weinert et al., 2007; Bloomberg, 2021) where they appeared at the end of the 1990s as a "policy accident" resulting from a ban on gasoline-powered scooters (Yang, 2010). In this thesis, we will not consider this kind of vehicle which falls outside the legal definition of pedal-assisted e-bikes in Switzerland and is quite rare.

Figure 2: Pedal-assisted e-bikes and other electrical bicycles. Adapted from Behrendt, 2018



In Switzerland and the European Union, there are two main legal categories of e-bikes*.* ***"Pedelecs"*** are the most common type, with a pedal assistance which stops at a speed of 25 km/h[3] (20 mph or 32 km/h in the United States and Canada). Meanwhile ***"speed-pedelecs"*** (or "s-pedelecs") are e-bikes with a pedal assistance up to 45 km/h[4]. Legally, in Switzerland, pedelecs are considered as "light mopeds", a category related to traditional bicycles, with the exception that a driving licence is required from the age of 14 to 16. Speed-pedelecs are in the same vehicle category as mopeds and thus require a registration plate, a driving licence (category M) and mandatory use of a helmet (OFROU & DETEC, 2019). Recently, specific laws for e-bikes have been introduced in Switzerland, such as the obligation to ride with headlights turned on at all times (from the 1st of April 2022) (OFROU, 2022).

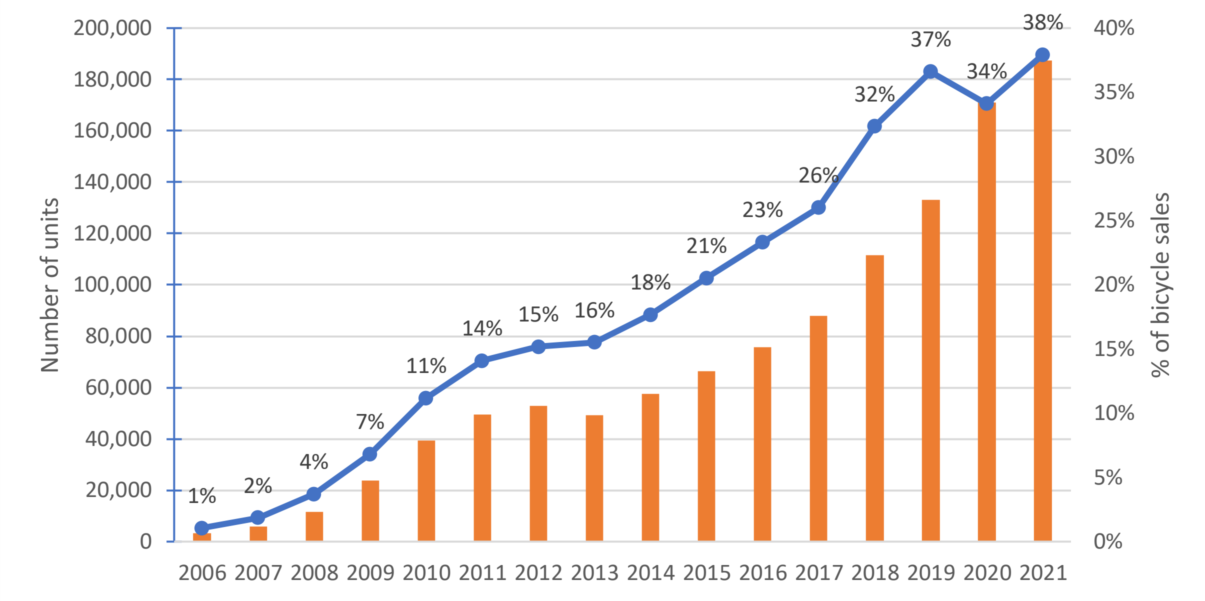
In most European countries, speed-pedelecs are forbidden from using cycle lanes and paths, a legal status which has hampered their development (Rotthier et al., 2016, 2017; Hendriks & Sharmeen, 2019; Hendriks, 2017). Switzerland is currently one of the only countries with Belgium where speed-pedelecs are allowed on cycle paths, and because of this, the country where the highest proportion of speed-pedelecs is found. In 2020, they represented 11.3% of e-bike sales (Velosuisse, 2021) compared to 5.5% in Belgium (Traxio, 2021), 0.9% in the Netherlands (RAI & BOVAG, 2021), and 0.5% in Germany (ZIV, 2021).

The variety of shapes of e-bikes has evolved much since the first models which were targeted towards older adults. Increasingly, e-bikes are marketed towards younger users, in what has been called a "rejuvenation" (Peine et al., 2017). The provision of electrical assistance has also enabled developments in the shape of the bicycle, such as cargo bicycles which enable the transport of goods or of children (Hess & Schubert, 2019). E-bikes are not only made for utility, but also for recreation. The popularity of the sports segment among e-bikes has grown in recent years, with mountain e-bikes and road bikes[5] representing a new category which can expand sports cycling regardless of age, physical ability, and topography. As a result, e-bikes also represent an opportunity for expanding bicycle tourism (Schlemmer et al., 2020).

Since the 2010s, e-bikes have grown into a major market in Europe and across the world. Between 2014 and 2019, the number of e-bikes sold annually in Europe grew from 1.1 to 3.4 million (+150%) (CONEBI, 2020). This makes e-bikes by far the best-selling electric vehicle before electric cars and two-wheelers. The highest market penetration rates are in the Netherlands (24 e-bikes sold annually per 1000 inhabitants), followed by Belgium (22), Germany, Switzerland, and Austria (16). These countries also have the highest proportions of e-bikes among new bicycle sales (the Netherlands, 42%; Switzerland, 37%; Belgium, 33%; Austria, 33%; Germany, 32%). In Switzerland itself (Figure 3), the number of e-bikes sold in 2021 reached an all-time high of 187'302 units, or 38% of bicycle sales (Velosuisse, 2022). It is entirely possible that e-bikes may overtake conventional bicycle sales in the near future, as they potentially attract a much larger percentage of the population because of their advantages (reduced effort, ability to cycle in hilly areas, longer range, carrying capacity).

[3] In Switzerland, pedelecs have a maximum power output of 500 W, compared to 250 W in the European Union.
[4]In Switzerland, speed-pedelecs have a maximum power output of 1000 W, compared to 4000W in the European Union, (category L1e-B). A third category (L1e-A) includes pedelecs with a higher power output from 250 to 1000 W (like cargo bikes), and throttle-controlled e-bikes.
[5] These types of e-bikes were not considered specifically in this thesis as they were quite rare at the time of the study (2018).

Figure 3: E-bike sales per year in Switzerland, in total units and as a % of total bicycle sales. Data: Velosuisse, 2022.



2.1.3 State of e-bike research

E-bike research is still young, as the very first studies date from 15 years back (Cherry & Cervero, 2007; Weinert et al., 2006), but has been growing as a result of the success of e-bikes. In recent years, a few literature reviews have been produced to summarize the main findings and the remaining research gaps (Fishman & Cherry, 2016; Bourne et al., 2018, 2020). Below, we review the main findings on e-bikes. E-bikes have several potential benefits for cycling, including the ability to extend the spatial range of cycling across longer distances and hilly terrain and to increase the number of possible trips and carrying capacity (2.1.3.1). They can facilitate cycling for a wider proportion of people (2.1.3.2) and provide important health benefits (2.1.3.3). E-bike users share similar motivations for adopting e-bikes than conventional cyclists but are also affected by specific barriers (2.1.3.4). Within the context of a transition towards sustainable mobility, e-bikes have the potential to substitute a range of trips by other transport modes, including the car, as well as public transport (2.1.3.5). However, these potentials may be negatively affected by a lack of safety, which may reduce e-bikes' actual use (2.1.3.6).

2.1.3.1 Spatial range and trip purposes

In comparison to conventional bicycles, the electrical assistance of e-bikes makes it easier to maintain a constant speed (of 25 km/h for pedelecs, or 45 km/h for s-pedelecs) and thus cover longer distances (Cairns et al., 2017; T. Jones, Harms, et al., 2016). In a recent review, average daily distances by e-bike were found to vary between 3 and 11.5 km depending on the study context and type of user (Bourne et al., 2020), but are generally much higher than for conventional bicycles. Switching from a bicycle to an e-bike has been found to increase the distance and frequency of cycling (Fyhri et al., 2017; Fyhri & Beate Sundfør, 2020). Moreover, e-bikes "flatten" the barrier of topography by helping people to cycle in hilly cities and contexts (Behrendt et al., 2021; Lopez et al., 2017; MacArthur et al., 2014).

E-bikes also facilitate cycling when carrying heavy loads such as groceries or transporting children to school. Cargo bikes in particular have the ability to carry loads up to 100 kg (Hess & Schubert, 2019). This opens up a larger number of trips to cycling that are often made by motorized modes of transport.

Due to their practicality, e-bikes have been shown to be used for more utilitarian trips (e.g. commuting, shopping) than conventional bicycles (Bourne et al., 2020).

2.1.3.2 User profile

Thanks to their electrical assistance, e-bikes have made cycling accessible to a wider demographic base. Nonetheless, the profile of e-bike users varies very strongly between different geographical contexts.

E-bike users mainly stand out from conventional cyclists by their higher age. Mature age categories between 50 and 65 are overrepresented in most contexts (Johnson & Rose, 2013; MacArthur et al., 2014; Simsekoglu & Klöckner, 2018; de Kruijf et al., 2019). However, in some contexts, e-bike users are even older and mainly of retirement age, such as in rural areas where recreational use dominates (Wolf & Seebauer, 2014), or in the Netherlands, where all age categories already cycle (de Haas et al., 2021). A specificity of e-bikes is that their early adopters were older people, contrary to the stereotype this group being reluctant to innovation, before they became popular among younger adults (Peine et al., 2017). Teenagers and students (<25) remain an underrepresented category among e-bike users, due to the barrier of high price, licence requirements and restrictions[6], a negative image of e-biking associated with elderly users (Popovich et al., 2014), and arguably, lesser need for an electrical assistance. However, the share of younger user groups (e.g. students) has recently been increasing (de Haas et al., 2021).

Gender make-up among e-bike users follows that of conventional cyclists, with high-cycling countries in northern Europe having an equal gender split or even a majority of women (Haustein & Møller, 2016a), while men tend to be a majority in low-cycling countries in North America or Australia (Johnson & Rose, 2013; MacArthur et al., 2014). In terms of household composition, and as a result of the over-representation of mature age categories, e-bike users tend to live in families or couples without children, and to have higher income and education levels than average (Johnson & Rose, 2013; MacArthur et al., 2014; Wolf & Seebauer, 2014). On a spatial level, they tend to be located in suburban or rural areas rather than in city centres (de Kruijf et al., 2018; Rérat, 2021c).

2.1.3.3 Health and physical activity

Despite their electrical assistance, e-bikes require pedalling and are therefore an active mode of travel like walking and conventional cycling. They have been shown to provide a sufficient amount of physical activity to reach health guidelines (Bourne et al., 2018; Gojanovic et al., 2011). Crucially, they provide physical activity to segments of the population who suffer most from a lack of exercise due to sedentary lifestyles, such as older people or women (Wild et al., 2021). E-bikes are considered an important way of promoting "active ageing" among older adults (Johnson & Rose, 2015; Van Cauwenberg et al., 2019). They help to improve cognitive functions such as balance, and by providing an engagement with the outdoor environment, contribute to mental health and to maintaining an independent mobility outside of the car (T. Jones, Harms, et al., 2016; Leyland et al., 2019; Spencer et al., 2019). Beyond older adults, the net health benefits of e-cycling extend across all population groups, even when taking into account negative effects such as crashes or exposure to air pollution (Götschi et al., 2016).

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[6] In Switzerland, e-bikes with an until 25 km/h (pedelecs) can be driven from the age of 14 with a moped license, or from the age of 16 without a license or higher (driver's license). Faster e-bikes with an assistance until 45 km/h (s-pedelecs) can also be driven from the age of 14 but require a license regardless of age.

2.1.3.4 Motivations and barriers

Several of the motivations for using an e-bike are similar to those for using a conventional bicycle, including exercise, independence compared to cars or public transport, and pleasure (Bourne et al., 2020; Haustein & Møller, 2016a). The ability to do a limited amount of exercise, either for recreation or while travelling, remains an important driver for e-bikes, despite the electrical assistance provided (Bourne et al., 2018). Thanks to the reduced effort they require, e-bikes may also motivate people to cycle despite a lower physical condition or in spite of old age (Johnson & Rose, 2015; Van Cauwenberg, De Bourdeaudhuij, et al., 2018; Van Cauwenberg et al., 2019). E-bikes may be chosen as a way for two people of different cycling abilities to cycle together, "equalizing" their differences (Popovich et al., 2014). Thanks to their assistance, e-bikes may enable people to discover a wider range of trips and destinations, reducing the impact of hilly topography or long trip distances. For people commuting to work, the ability to cycle without the discomfort of sweating may be an argument (Dill & Rose, 2012; Haustein & Møller, 2016a; MacArthur et al., 2014; Popovich et al., 2014). By maintaining a constant speed, e-bikes may also attract commuters by reducing travel times compared to conventional bicycles but also to cars or public transport. For young parents, the ability to carry children (with a trailer or child seat) or do groceries by e-bike rather than by car, may also be a motivation (T. Jones, Harms, et al., 2016). When cycling in traffic, e-bikes make people feel more confident by accelerating more rapidly and blending more easily with the flow of traffic than conventional bikes (T. Jones, Harms, et al., 2016; MacArthur et al., 2014; Popovich et al., 2014). They can also help to maintain balance at low speeds, for example when making hand signals before a turn (Edge et al., 2018; Popovich et al., 2014; Rose, 2012).

However, e-bike users also face barriers which refrain them from cycling more. Some of these barriers also apply to conventional bicycles, such as sensibility to bad weather (Bourne et al., 2020). Specifically, lacking safety due to motor traffic remains a significant barrier for e-bike users (see section 2.5) and is related to a lack of dedicated cycling infrastructure. While e-bikes offer some advantages for cycling in traffic over conventional bicycles, cycling in traffic remains a limiting factor for a large number of people. Moreover, due to their older age, e-bike users may be more sensitive to safety than many conventional cyclists (Rérat, 2021c).

Among e-bikes' specific barriers are their higher price, which increases concerns about the risk of theft and storage (Melia & Bartle, 2021). Fewer storage possibilities in urban housing may be one of the reasons for higher e-bike ownership in rural and suburban areas (Ravalet et al., 2018). Another barrier is their heavier weight (over 20 kg, or twice as much as a conventional bicycle) which can make it difficult to carry them up stairs or onto a train, or to keep balance at a stop - resulting in crashes from falling over (Haustein & Møller, 2016b; Hertach et al., 2018). Lastly, range anxiety, or the fear or running out of battery, remains a barrier for some users, although most models now have an autonomy of more than 100 kilometres. Although technically e-bikes may be used with an empty battery, their high weight makes them very difficult to use (Bourne et al., 2020).

2.1.3.5 Substitution of trips by other travel modes

Due to their increased range and ease of use compared to conventional bicycles, e-bikes can substitute trips made by motorized modes (although many car trips are short). They may also facilitate the transition from driving to cycling by playing an 'intermediator role' (Wolf & Seebauer, 2014) or being a 'transitional step' to cycling for people wanting to get back to it (Popovich et al., 2014). The modal shift effect of switching to an e-bike depends on the local context, and which form of transport is the most common there (Sun et al., 2020). Whereas in North America or Australia, e-bikes mainly reduce trips taken by car (Johnson & Rose, 2013; MacArthur et al., 2014), they substitute a combination of modes in European countries, including conventional cycling, public transport, and car trips (Haustein & Møller, 2016a; Hiselius & Svensson, 2017; Kroesen, 2017). However, e-bikes do not completely replace conventional bicycles, which many people continue to use even after adopting an e-bike (Haustein & Møller, 2016a). Moreover, biographical approaches (see section 2.3) suggest that it is important to consider e-bike use over time (throughout the life course), rather than substitution effects at a given moment. From this long-term perspective, switching to an e-bike from a conventional bicycle may help some people to continue cycling despite old age, physical difficulties, or a change in residential or workplace locations, which would have led them to interrupt cycling (Marincek & Rérat, 2020, see chapter 5).

2.1.3.6 Crashes and road safety

Within traffic research, e-bike safety has become a concern because of a rise in e-bike crashes in the last years. However, this rise should be put into perspective with the increasing diffusion of e-bikes among the population (Haustein & Moller, 2016). Some studies have suggested that e-bike riders are more prone to single-vehicle crashes including falls or slippages, due to the heavier weight of e-bikes and their greater speed (Hertach et al. 2018). However, crashes may also be due to motorists, who have been shown to underestimate e-bikers' speeds at intersections (Petzoldt, Schleinitz, Heilmann, et al., 2017) and create dangerous situations. A further reason for rising e-bike crashes is higher age, which makes e-bikers more vulnerable in case of a fall or a collision, and more likely to report their crash to police than younger cyclists, who typically walk away unscathed. Given these elements, it remains up to debate whether e-bikes are intrinsically more prone to crashing than conventional bicycles (Haustein & Møller, 2016b).

2.1.3.7 Research gaps

Current e-bike research has come a long way since the first studies more than ten years ago. Initially, due to the lack of reliable data on e-bikes and their users, studies were often based on small sample sizes, mostly descriptive in their focus, and reported inconclusive results. With the ongoing diffusion of e-bikes in the last years, the practice of e-cycling and the profile of e-bike users have evolved to the point that comparisons to older studies are becoming difficult.

E-bikes and conventional bicycles share some common traits but also key differences, such as the profile of their users (which are older), or their patterns of use (which are more intensive). Thus, merely transposing findings from conventional cycling literature is not sufficient, and e-bike specific research is needed. However, research has also tended to treat e-biking as an entirely separate practice from conventional cycling, although the same people practise both over their life course. Given the fact that all e-bike users are also cyclists in their own right, it is essential to understand the links between e-cycling and conventional cycling. This can be done through a biographical approach which views mobility over time rather than at a given point (see section 2.3).

E-bike research remains a new field of study and much published research is descriptive, rather than based on a specific theoretical framework. It is heavily inspired by cycling research, which itself comes from a variety of academic fields - transportation, health, and social sciences (i.e. geography, sociology, anthropology). To better understand this context, the next chapter aims to provide an overview of the three main strands of cycling research, their respective theoretical approaches and advantages and disadvantages (section 2.2). This will then enable us to propose our own theoretical approach for analysing the adoption of the e-bike throughout the life course (section 2.3) and its use within a specific context (section 2.4).

2.2 An overview of cycling research

2.2.1 Introduction

Cycling research is located at the point of contact between transport research, health research, and the social sciences. Whilst historically studies on cycling represented a minor domain of study within transport research, often bundled up with walking, cycling research has grown into a field of study of its own. In recent years, interest for cycling research has grown very strongly, with the number of academic publications increasing threefold between 1991-1995 and 2011-2016 (Pucher & Buehler, 2017). In addition to the broader developments in transport research and mobility, current cycling research comes from a diversity of academic fields including transportation, sociology and other social sciences, urban planning, but also medicine and public health research (Pucher & Buehler, 2017).

Cycling research has always had a practical purpose, as it is closely related to the development of public policies for promoting cycling. According to Handy et al. (2014), cycling research poses three questions of interest for policymakers. Firstly, understanding the *uses* of cycling, or *"How much cycling is there? Who is cycling, where, when, and for what purposes?"* (Handy et al., 2014, p. 5). Secondly, understanding the key *factors* influencing cycling, in other words *"what strategies offer the most promise for increasing cycling?"* (Ibid.). Thirdly, understanding the *effects* of cycling, in other terms *"what are the benefits to cities if they succeed in increasing cycling?"* (Ibid.).

In this brief overview, we distinguish three main strands of cycling research: (1) Historical and geographical comparisons which analyse differences in cycling levels at an aggregate, macro level, for example between cities or countries, or across time; (2) Behavioural approaches from the transport and health domains which aim to model the influence of psychological constructs (attitudes, preferences, perceptions, social environments) and environmental characteristics, on the individual's decision to cycle; (3) Social science approaches which aim to go beyond the sole function of transport by understanding the bodily experiences, inequalities and struggles of cyclists, the power relations at stake between the practice of cycling and the dominant practice of automobility. We will now present each of these approaches.

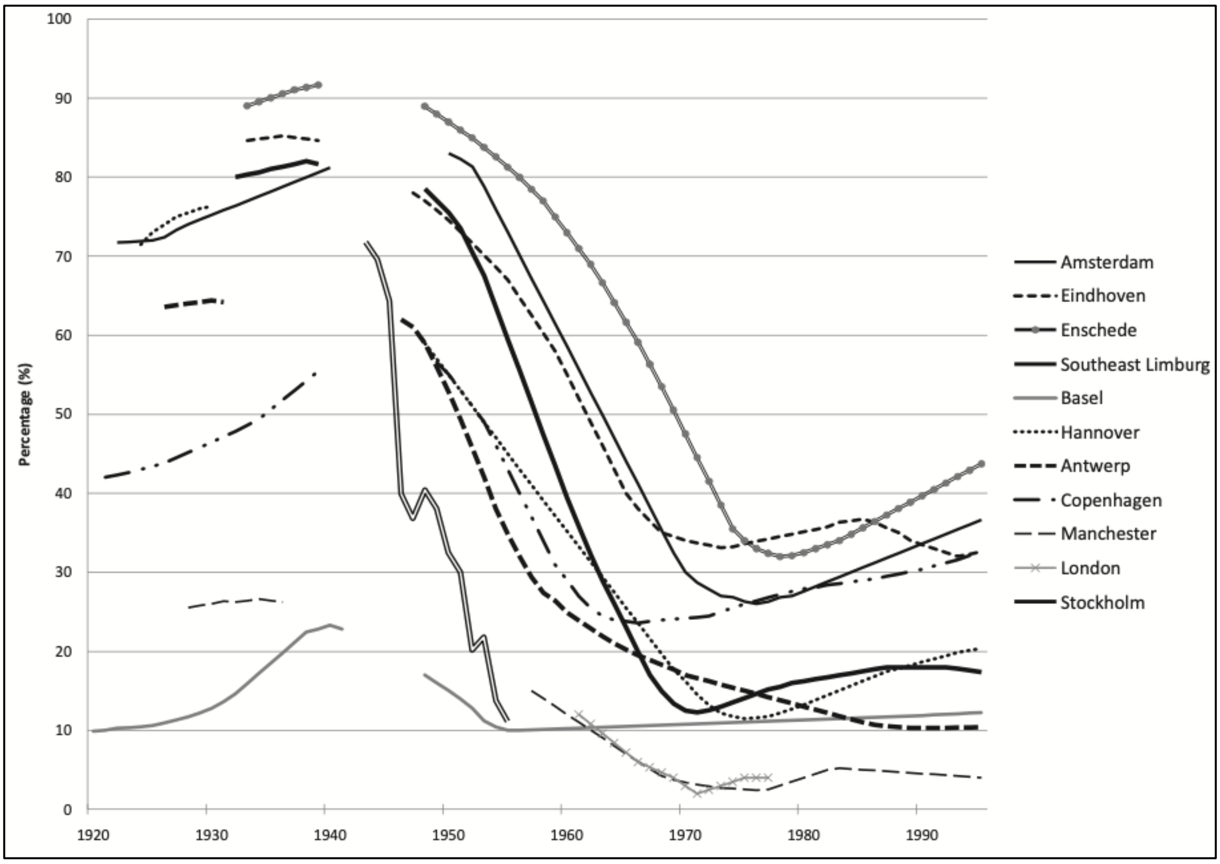
2.2.2 Historical and geographical comparisons

A first series of comparative approaches view cycling at the aggregate level, aiming to compare and understand differences in cycling levels between geographical contexts (e.g. cities, countries), historical periods, and population groups. This strand of research relates to the key question of "how much cycling is there?" (Handy et al., 2014).

Historical comparisons can serve to better understand the changing status of cycling over time, and the effect of societal changes on cycling through evolving economic, cultural, and planning contexts. The French researcher Frédéric Héran takes an "omnimodal" approach to cycling, viewing the development of cycling throughout history as linked to the development of other transport modes such as the motor car, tram and bus, which appeared since the end of the 19th century (Héran, 2015). The ancestor of the bicycle, the "Laufmaschine" or running machine, was famously invented by the Baron Karl Von Drais in 1817, supposedly as a mechanical replacement for another mode of transport – the horse - after a year of famine. Thereafter, cycling in its various guises remained an aristocratic leisure activity akin to horse racing, until the end of the 19th century and mass production of the so-called "safety bicycle" (Bijker, 1997)[7]. During this period, cycling also played a role in women's rights movements, as a symbol of their emancipation (Héran, 2015). Cycling was adopted as an urban mode of transport for workers in industrialized cities, and reached its apex in the 1930s, when the share of bicycle trips in many European cities was much higher than current levels, for example over 25% in Manchester (Oldenziel & Albert de la Bruheze, 2011) (Figure 4).

The advent of mass motorization in the post-war period (earlier in the United States) saw a period of sharp decline in cycling, as transport planning aimed to accommodate cities to rising motor traffic, leading to the marginalization of cyclists (Koglin & Rye, 2014). A first return of cycling was observed in northern Europe (Denmark and the Netherlands) during the 1970s, when the oil crisis increased the price of petrol and safety concerns with motor traffic led to the development of dedicated cycling infrastructure, while in the rest of Europe, cycling continued to fall in the 1980s and 1990s (Héran, 2015). More recently, since the start of the 2000s, the current "cycling renaissance" in many cities across the world can be seen as a direct consequence of a combination of public policy measures to impose limitations on motor traffic (through, for example traffic-calming, taxes on car purchase and fuels, parking limitations), combined with the development of cycling infrastructure, which once again made the bicycle an attractive mode of transport (e.g., Buehler & Pucher, 2012; Pucher & Buehler, 2008).

Figure 4: Evolution of the modal share of cycling in eleven European cities (1920-2000). Source: Oldenziel and de la Bruhèze, 2011



[7] In contrast to bicycles of the time which had large front wheels, the safety bicycle was a bicycle which had small wheels of equal size and was designed to be ridden more easily and safely by older people or women. Interestingly, this is a similarity it shares with early designs of e-bikes, which were also addressed to older people.

Geographical comparisons can identify which policies could increase the share of cycling trips, for example by comparing a low-cycling context such as the United States, to a high-cycling context such as the Netherlands, Denmark or Germany (Pucher & Buehler, 2008b). There remain significant gaps in cycling levels between so-called high-cycling countries and low-cycling countries. Whereas an estimated 27% of trips are taken by bicycle in the Netherlands, 18% in Denmark, 10% in Germany, or 7% in Switzerland[8], less than 2% are undertaken in the United States or Great Britain (Buehler & Pucher, 2021b; Goel et al., 2022).

There are also significant differences among cities. Small or medium-sized cities such as Groningen in the Netherlands (40%) or Münster in Germany (38%) retain the highest cycling rates overall (Buehler & Pucher, 2012b; Handy et al., 2012). Among larger cities in high-cycling countries, cycling levels have risen from an already high level in recent years, as in Amsterdam (Netherlands) (30%) or Copenhagen (Denmark) (35%). Meanwhile, in large cities in historically low-cycling countries, cycling trips tripled in Paris (4%), London (3%) or Vienna, with even stronger increases in Seville (Spain), Bogota (Colombia), and Portland (Oregon, United States) (Buehler & Pucher, 2021c).

However, there is still a lack of knowledge on cycling levels outside of western Europe, North America, and Australia. For example, Japan is often not mentioned among high-cycling countries despite a share of 11.5% of trips by bicycle nationwide, and 28.4% in Osaka or 18.7% in Tokyo, which rivals many northern European cities. Meanwhile, many cities of the global south such as Bogota (Colombia), Rosario (Argentina) or Delhi (India) have modal shares above or around 5% (Goel et al., 2022).

The level of participation of women and young and old age groups also shows important differences between geographical contexts. Several studies point towards an association between age and gender equity and cycling levels (Buehler & Pucher, 2012b; Goel et al., 2022; Götschi et al., 2015). In the Netherlands, 40% of children and teenagers (under the age of 17) cycle, as well as 23% of older adults (over the age of 65), which is much higher than in low-cycling countries (Buehler & Pucher, 2012b). The gender gap in cycling is highly unequal in most countries, while the percentage of cycling trips made by women exceeds 50% in only a few countries (the Netherlands: 54.4%, Japan, 56.4%, Finland, 50.4%) (Goel et al., 2022). Both the representation of older adults and women among cyclists has a strong statistical association with the overall share of cycling in a given country or city (Goel et al., 2022). These differences can even be observed at the city level, between "high-cycling, women overrepresented, age-equal" cities, on the one hand, and "low-cycling, gender-unequal, age-unequal" cities on the other hand (Goel et al., 2022, pp. 74–75).

General overviews of trends in cycling are essential to keep track of the long-term evolution of cycling levels. Such international comparisons are also useful to track the development of cycling between cities. This reflects the growing place of cycling within city marketing strategies and global rankings such as the "Copenhagenize index" (Copenhagenize, 2019). A well-known categorization proposed by the European PRESTO cycling policy guide defined cycling cities as either "starter" (<5% modal share), "climber" (between 5% and 20%) and "champion" (>20%) cycling cities. The term "starter cycling cities" has begun to be used in research to describe cities where cycling remains at a low modal share, for example in southern European countries (Silva, Teixeira, & Proença, 2019; Silva, Teixeira, Proença, et al., 2019).

[8] Within Switzerland, 8.6% of trips are made by bicycle in the German-speaking part compared to only 2.9% in the French and Italian-speaking parts (Rérat, 2021a).

In addition to long-term evolutions in cycling levels, some studies have analysed short-term changes in cycling, for example due to specific events, over a few months. With increasing data available from automated bicycle counts, such short-term comparisons can now be done on a national or international level. Recent research has shown the impacts of the COVID-19 pandemic on cycling (Buehler & Pucher, 2021a). The share of cycling trips as a percentage of total trips has risen strongly as a result of restrictions on travel and teleworking which reduced the number of overall trips. This has resulted in a boom in cycling, especially in larger cities, and for recreational trips (Möllers et al., 2021). Furthermore, cities where there has been a temporary reallocation of road space for cycling witnessed strong increases in cycling counts (Kraus & Koch, 2021). In Switzerland, a series of studies in which the author has participated have used automated bicycle counts to give valuable insights on the increase in cycling volumes in urban areas in the last few years (Baehler et al., 2018, 2019, 2020; Marincek & Rérat, 2021).

2.2.3 Behavioural approaches in transport and health research

Much cycling research is inspired by developments in transport research. Transport research traditionally views the use of a specific mode of transport (such as cycling) as the result of a decision process, by using the concept of modal choice. Modal choice represents a "black box", with research attempting to understand the contents of this decision process. According to De Witte et al., (2013) modal choice approaches fall into three main families: Firstly, "rationalist" approaches derived from economics see individuals as choosing a transport mode with the goal of maximizing the utility of the trip (i.e. reducing travel time and costs), and view modal choice as a perfectly rational decision explained by a series of "objective" determinants such as price, speed, convenience. Secondly, "socio-geographical" approaches derived from geography consider modal choice as a "derived demand" related to the location and timing of activities distributed across space and time. Thirdly, "sociopsychological" approaches derived from social psychology view modal choice as a form of behaviour influenced by personal attitudes towards transport modes as well as the influence of social values and norms. In cycling research, modal choice approaches include those focusing on attitudes (2.2.3.1), and social-ecological models (2.2.3.2) which consider the influence of the environment.

2.2.3.1 Attitudes, behaviour, and choice (ABC)

The dominant stream of cycling research originates in transport research and aims to understand cycling through a series of sociopsychological determinants, using concepts such as attitudes, behaviour and choice or "ABC". This approach considers cycling at the individual level as a rational behaviour which can be explained by psychological constructs including perceptions (estimations or beliefs regarding the environment, or cyclists), attitudes (preference or dislike for cycling or driving, motivations or barriers to cycling), and the influence of the social environment (relatives, friends, workplace colleagues) (Willis et al., 2015). Underpinning these approaches is the theory of planned behaviour (Ajzen, 1991, 1985) which sees a person's intentions, or their willingness to try cycling, as the most important factors in predicting cycling behaviour. These intentions are affected by the attitude towards a given behaviour (either favourable or not), the subjective norm (pressure to conform to a behaviour) and the degree of perceived behavioural control (the perceived ease of performing a behaviour) (Willis et al., 2015).

Several studies have investigated the influence of perceived benefits of cycling on the decision to cycle, including health and exercise, economic benefits, convenience, avoiding traffic congestion, environmental benefits, flexibility (De Geus et al., 2007; Heinen et al., 2011b; Akar & Clifton, 2009). Various studies have also addressed the negative effect of perceived barriers on the decision to cycle, including lack of skills, health problems, obstacles, lack of time or interest, faraway destinations, personal barriers, lack of facilities at the workplace, physical discomfort, and the need to wear complicated clothing (De Geus et al., 2007; Titze et al., 2008; Winters et al., 2011; Emond & Handy, 2012).

There have also been several studies on the role of attitudes on cycling. Attitudes refer to favourable or unfavourable psychological tendencies related to an object or entity (here, cycling) (Willis et al., 2015). Attitudes which have been shown to be positively associated with cycling include enjoyment, physical activity, concern for the environment, or a favourable consideration of cycling (Dill & Voros, 2007; de Bruijn et al., 2009; Handy et al., 2010; Heinen et al., 2011b; Emond & Handy, 2012). Meanwhile, attitudes which have a negative effect towards cycling include strong preference for the car, and the enjoyment of driving (Dill & Voros, 2007; Xing et al., 2010).

Another factor considered as influencing the decision to cycle is "self-efficacy", or a person's perceived comfort or ability to cycle. Being unaffected by external obstacles such as weather, also known as external self-efficacy, has been positively associated with cycling for transport (De Geus et al., 2007). Confidence in one's cycling abilities, or "perceived behavioural control" has also been correlated to cycling for transport (de Bruijn et al., 2009; Emond & Handy, 2012; Heinen et al., 2011b). Some studies have associated cycling to school with children's ability to cycle alone without a parent (Trapp et al., 2011). Holding an image of oneself as being a cyclist, and of other cyclists as normal people (rather than high-performance athletes or activists) has also been associated with cycling more (Gatersleben & Appleton, 2007).

The perception of the environment has been identified as another important factor related to cycling. Low perceived cycling safety (see section 2.5) has been shown to discourage from cycling (Winters et al., 2011), as well as personal safety from theft or from aggression (Titze et al., 2007). The perception of the cycle route has also been shown to affect the decision to cycle, with people who are satisfied with available cycle infrastructure more likely to cycle than others, while other characteristics such aesthetics, scenery, and separation from traffic are also important (Dill & Voros, 2007; Winters et al., 2011).

There has also been a focus on the role of the social environment, or the influence of other people on the individual decision to cycle. The subjective norm refers to the pressure to perform or not cycling which manifests itself through the encouragement (or discouragement) of friends, partners, parents, or co-workers (De Geus et al., 2007; Titze et al., 2008; Willis et al., 2015). Meanwhile, the descriptive norm refers to the typical behaviour, relative to cycling, of surrounding people within a social network (De Geus et al., 2007; Emond & Handy, 2012; Titze et al., 2008; Willis et al., 2015). Greater social acceptance of cycling as a mode of transport that is normal, and a lower acceptance of driving, have been related to cycling (Xing et al., 2010; Emond & Handy, 2012). Furthermore, having a favourable workplace affects the decision to commute by bicycle, either through the influence of co-workers who commute by bike, through benefits offered for cyclists (e.g. incentives), or the presence of amenities like bicycle parkins, showers or clothes-changing facilities (Heinen et al., 2013).

2.2.3.2 Social-ecological models

Within behavioural approaches, research coming from the health and physical activity domains has focused on the social and environmental determinants of cycling. These approaches view both cycling and walking as forms of healthy behaviour (Pikora et al., 2003; Saelens et al., 2003). Although transport and health research have different objectives - for transport, switching to sustainable travel modes, and for health research, increasing healthy behaviour – these approaches have tended to converge (Krizek et al., 2009).

Social-ecological models hold the view that cycling can be understood best by a combination of psychosocial (individual) and "ecological" (environmental) factors (Sallis et al., 2013). Healthy behaviour is considered to be influenced by a series of overlapping and interacting contexts, including the individual (intrapersonal), the family, the social circle, the community, the built, natural and cultural environment, and the policy and planning contexts (Saelens et al., 2003). Social-ecological models aim to account for the widest range of influences related to cycling behaviours, in order to determine which factors are the most likely to incite cycling. Literature reviews on the subject (e.g. Sallis et al., 2013, Lanzini & Khan, 2017) suggest that psychosocial variables are more significant in predicting cycling behaviour than environmental variables. Recent social-ecological frameworks, such as that proposed by the European PASTA consortium (physical activity through sustainable transport approaches) (Götschi et al., 2017) cover a wide array of factors at the micro level (individual), the meso level (social practices, activities, community, cultural environment), and the macro level (built environment, physical environment, planning context).

Although they consider a variety of influences on cycling, behavioural approaches share a common consideration of cycling as the outcome of an individual (mostly) rational modal choice decision process, even though some frameworks also consider unreasoned behaviour linked to habit or impulse (Götschi et al., 2017; Sulikova & Brand, 2021). A first criticism of these approaches is their "static" view of cycling at a specific point in time, and their failure to account for the dynamic changes in cycling over time (H. Jones et al., 2014). As we will see in section 2.3, biographical approaches fill this gap by enabling a longitudinal view of cycling as a practice performed throughout the life course. A second criticism relates to their failure to explain why, after all, so few people cycle. This is because traditional modal choice approaches are not sufficient for analysing the specificity of cycling (in terms of effort, sensibility to weather), and understanding the barriers faced by cyclists in a given territorial context (Rérat, 2019). Thus, a different approach is needed which goes beyond cycling as a modal choice, to understand the meanings and experiences associated with the practice of cycling. This approach comes from the social sciences.

2.2.4 Social science approaches to cycling

2.2.4.1 The mobility turn

The assumptions of traditional approaches to transport have been challenged since the turn of the century by increasing attention from social scientists. Within the social sciences, a so-called "mobility turn"[9] (Sheller & Urry, 2006, 2016) has led to growing research on mobilities at all scales of movement, from international migration to daily mobility. The emergence of this "new mobilities paradigm" (Sheller & Urry, 2006) has had far-reaching implications for transport research, as it has spurred the interest of social scientists in a field traditionally reserved to engineers, economists or transport geographers.

[9] The "new mobilities" paradigm appeared in the social sciences at the turn of the millennium. This paradigm aimed to go beyond the static consideration of societies, by viewing movement in all its forms – mobility - as the main phenomenon of modern societies, and called for it to become the main object of enquiry of the social sciences (Urry, 2007). The mobilities paradigm aimed to explore new objects of research such as the study of new places of social life including as transport nodes, airports, or in our case, cycling (Sheller & Urry, 2006).

For Cresswell (2006, 2010), mobility can be conceptualized as an entanglement of three dimensions: mobility as movement from A to B (1), mobility as meaning (2), and mobility as an embodied experience (3) (Cresswell, 2010, p. 19). One of the main criticisms towards transport approaches to cycling is that they only focus on the first dimension of mobility as movement, or cycling as a way to reach activities (a means to an end). By doing so, they do not take into account the meanings (political and symbolic) and experiences (sensory, kinaesthetic) associated with cycling in a given spatial and cultural context (Spinney, 2009). Furthermore, they tend to hold a prescriptive view of what cycling should be[10], focusing only on "desirable" forms of utilitarian cycling, while underestimating other "less useful" forms of cycling as recreation or as a social activity (Spinney, 2009).

Cycling research related to the "mobility turn" has analysed cycling from a diversity of viewpoints including geography, sociology, urban design, architecture, cultural studies, and anthropology, with various themes widening the view of cycling beyond just transport. This includes work on the technology of cycling (Rosen, 1993; Cox & Van De Walle, 2007), bicycle activism (Furness, 2007), urban cycling (Cox, 2019), or road racing (Spinney, 2006).

One focus of mobilities research has been what Cresswell calls the "politics of mobility" (Cresswell, 2010, p. 20), or the power relations and struggles related to mobility and immobility. In the case of cycling, research has focused on the practice of cycling within the dominant system of automobility, for example through the critical mass movement (Furness, 2007), or through the power struggles in modern transport planning (Koglin, 2015; Koglin & Rye, 2014). Other studies have sought to consider relations of gender, ethnicity, and social class within cycling (Ravensbergen et al., 2020)

At the individual level, a particular focus has been on the embodied experience of cycling, with cycling viewed as a "kinaesthetic" experience (Spinney, 2009). This has led some researchers to pursue new "mobile methods" of analysing cycling which go beyond statistical analyses, surveys and the like, to understand the sensory nature of the performance of cycling, for example through "ride-alongs" with cyclists (Spinney, 2007; van Duppen & Spierings, 2013; Popan, 2020).

2.2.4.2 Social practice theory

Within the mobility turn, a certain number of approaches from the social sciences have gained recognition, with social practice theory being one of them (Sheller & Urry, 2016). By contrast with behavioural approaches to transport, social practice theory refutes the view of transport as an individual activity, criticizing public policies which put the blame on individual choice within a transition towards sustainable mobility (Shove, 2010; Barr & Prillwitz, 2014). From the viewpoint of social practice theory, cycling is seen as a social practice which has a life of its own and is carried out by individuals (practitioners) who engage in it and perpetuate it over time (Shove et al., 2012). Both cycling and car driving are "systems of practice" which compete for the same limited resources, namely users' time and the city's traffic infrastructures. These systems also include institutions, manufacturing processes, discourses and representations (Watson, 2012). Social practices are composed of three interconnected elements: materials, meaning, and skills or competences (Reckwitz, 2002; Shove et al., 2012). In the case of cycling, these elements can be defined as follows:

Materials firstly refer to bicycles and their equipment, an essential element for the practice of cycling (Lovejoy & Handy, 2012). Bicycles, whether electrically assisted or not include a diversity of shapes,

[10] This also applies to criticism of e-bikes for not being "real cycling", which was widespread among environmental and bicycle activist groups in the first years of their diffusion.

from classic "Dutch" bikes to mountain bikes, road bikes, folding bikes, cargo bikes, speed-pedelecs. Materials also refer to the environments where cycling takes place (urbanity, topography), the types of roads (width, traffic volumes, speeds) and cycling infrastructures on which it is practised on (cycle lanes, cycle paths, mixed-use paths, trails, cycle highways), the amenities provided (parking, showers, lockers), the external conditions (weather) (Spotswood et al., 2015). Lastly, materials include the cyclists' own body, age, health, and fitness level, which are essential for cycling as a human-machine connection (Cox, 2019; Larsen, 2017).

Competences include the skills, expertise, and techniques required for cycling. Competences for cycling include physical ability such as steering and balance, manoeuvring skills such as interaction with the environment and rapid decision-making, as well as strategic skills such as preparation of cycling gear, knowledge of local roads, estimation of the duration of a trip and route, and risk management (Spinney, 2007; Spotswood et al., 2015; Wierda & Brookhuis, 1991). Cycling competences also include "tactics", which are the subversive ways of doing through which individuals navigate the context of everyday life (Certeau, 1994). Cox (2019) argues that contrary to driving, which follows a set of known rules and takes place on a uniform road network, city cycling requires informal knowledge of unwritten rules and practices because of the discontinuity of cycling infrastructure. An example of tactics are the "coping strategies" [11] used by cyclists, such as asserting their place on the road or avoiding danger (Chataway et al., 2014; Kaplan & Prato, 2016)

Meanings refer to symbolic meanings and aspirations (Shove et al., 2012) associated with cycling. Cycling can be at once a practical, fast, cost-effective mode of transport, a way to avoid congestion, or a form of recreation providing pleasure and exercise (Spotswood et al., 2015). In high-cycling countries, it is practised on networks of dedicated paths which are physically separated from traffic. It is a "normal", safe, practical form of transport practised by children and older people alike, and often carried out in groups (Pucher & Buehler, 2008b). By contrast, in low-cycling countries, where infrastructure is less developed, cyclists are expected to cycle on the road with cars and other motor vehicles (Pucher & Buehler, 2008b) and cycling is largely seen as a dangerous individual practice, carried out by a minority group composed of young, in-shape, mostly male people wearing expensive cycling equipment (helmets, high-visibility jackets) (Horton, 2007; Aldred, 2013a; Prati et al., 2017; Spotswood et al., 2015). In the most low-cycling countries, the mere presence of cyclists on the road may be considered illegitimate, leading to tensions with motorists and harassment of cyclists (Heesch et al., 2011; O'Connor & Brown, 2010).

Within social practice theory, e-bikes can be seen as a new material form which changes the practice of cycling, by modifying the materials, but also the skills which are required to cycle (Behrendt, 2018). In particular, e-bikes reduce the importance of physical ability for cycling. While in low-cycling contexts, cycling is often viewed as a masculine practice, requiring intense physical effort, and related to sports rather than a credible mode of transport, e-bikes contribute to changing the meaning associated with cycling as a fast, efficient mode of transportation in the city adapted for all ages, and a convenient way of carrying groceries or children.

Having outlined the main approaches to cycling research, we will now present our chosen theoretical approach for analysing e-bike adoption. This approach combines a biographical approach to cycling (section 2.3), as well as a systemic approach to cycling (section 2.4).

[11] For De Certeau (1994), tactics and strategies are two different things. Strategies are used by those who dominate, while tactics are used by the dominated.

2.3 A biographical approach to cycling

2.3.1 Background

Traditional approaches to transport have three main limitations (Lanzendorf, 2003). Firstly, they postulate the rationality of human behaviour, which is put into question by the role of habits (Aarts et al., 1998). Habits, rather than choices, shape much of individuals' behaviour, and as a consequence, stability of travel behaviour is the norm, rather than change. Secondly, most transport research adopts a cross-sectional view of mobility at a given moment, rather than a longitudinal view of mobility across time. This limits our ability to understand the effects on mobility of long-term decisions such as residential relocations, of how and when travel habits change, and effects of causality which might explain why changes happen. Thirdly, transport research is too reliant on quantitative data and statistical correlations, and does not offer enough explanation for relations of causality between different factors (Lanzendorf, 2003).

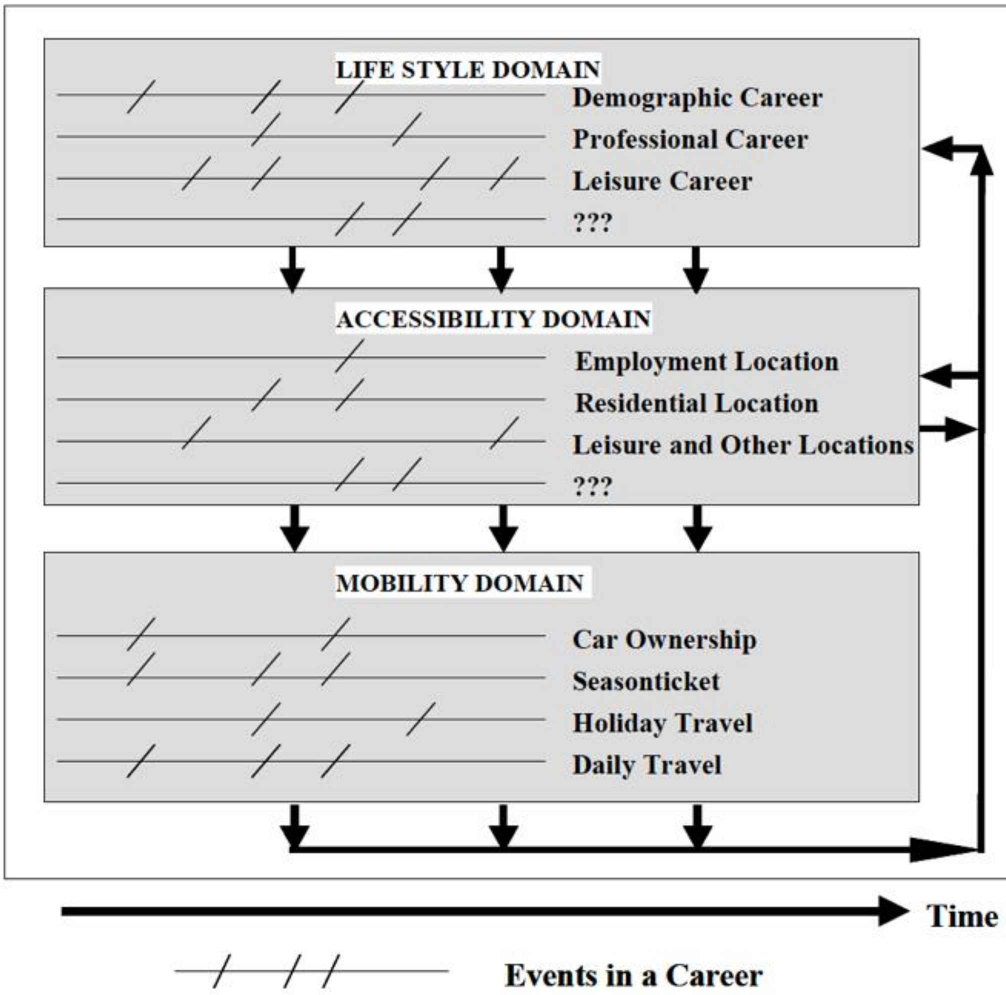
This thesis argues that traditional, cross-sectional approaches to cycling provide only a limited understanding of the reasons why people adopt e-bikes. Inspired by biographical approaches to mobility, we view the e-bike as part of a person's relationship to cycling over their life course. This biographical approach provides a dynamic (rather than static) understanding of e-bike adoption, and its wider relevance for a person's relationship to cycling. This theoretical framework is the focus of the first, second and third articles.

2.3.2 Mobility biographies research

Mobility biographies research (MBR) originated as a way of overcoming the limits of cross-sectional data in transport (for a review, see Müggenburg et al., 2015; Schoenduwe et al., 2015). This field of research is inspired by life course studies, which are common in sociology, psychology, health, and migration studies. The concept of life course can be defined as "the interweave of age-graded trajectories, such as work careers and family pathways that are subject to changing conditions and future options, and to short-term transitions ranging from leaving school to retirement" (Elder, 1985 mentioned by Elder Jr, 1994, p. 5). The notion of a life course trajectory is a central component of life course studies, where current behaviour is seen as the cumulative outcome of a trajectory of past behaviour (Elder Jr et al., 2003). According to Giele and Elder (1998), "Any point in the life span must be viewed dynamically as the consequence of past experience and future expectation as well as the integration of individual motive with external constraint". The "mobility biography" itself refers to an individual's life course trajectory in the domain of mobility (Lanzendorf, 2003), where present travel behaviour is seen as the cumulative outcome of past actions over the life course (Elder Jr et al., 2003).

Mobility biographies research rests on a series of principles, four according to Holz-Rau & Scheiner, (2015) or five for Scheiner & Rau (2020). First, the life course of individuals is embedded within a wider social and historical context which affects social groups differently, leading to differences in the life course depending on gender and generational cohort (Giele & Elder, 1998). Second, much of daily mobility is habitual and varies very little throughout the life course, with stability being the norm rather than change (Aarts et al., 1998). This means that there are a limited number of moments throughout life when travel behaviour changes. Third, mobility is related to other domains of life which are outside the focus of traditional transport surveys, such as family, work, health (Figure 5). For Lanzendorf (2003), these domains are lifestyle and accessibility, while for Scheiner (2007), they include employment, household and residence. Fourth, certain events called "key events" or "transitions" happening in other domains of the life course may lead to a reconsideration of mobility practices by acting as “windows of opportunity” for a change in habits (Klöckner, 2004). Fifth, individuals cannot be considered separately from the life courses of others. People whose life course is closely related (e.g. partners or children) are called “linked lives”, because events happening to them can indirectly affect the individual’s travel habits (Giele & Elder, 1998; Rau & Sattlegger, 2017). Finally, the more long-term influence of parents, friends or colleagues in shaping an individual’s mobility habits is called “mobility socialization” (Döring et al., 2014).

Figure 5: Schematization of the relation between domains of the life course, including the mobility domain. Source: Lanzendorf, 2003



2.3.2.1 Key events and mobility milestones

In the context of a transition towards sustainable mobility, travel behaviour research has shown an interest in how and when mobility behaviours change. While research on the role of habits suggests that most travel behaviour is stable over time (Aarts et al., 1998), it is hypothesized that certain “key events” (also called “life events”, “turning points”, or “transitions”) may break these routines and act as a “window of opportunity” for individuals to reconsider their travel behaviour (Klöckner, 2004; Verplanken et al., 2008). According to Müggenburg, Busch-Geertsema, and Lanzendorf (2015) key events can be grouped in different categories.

A first category of key events includes "life events" which fall outside the scope of transport. The events which have been the most studied in MBR and which are seen as having the most impact on travel behaviour are residential relocation and changes in employment, which are both related, and change the spatial distribution of activities, and the context of mobility (Beige & Axhausen, 2012; Schoenduwe et al., 2015; Rau & Manton, 2016). Changes in the family or relationship status, also have consequences on mobility by affecting the organization of the household (Lanzendorf, 2010; McCarthy et al., 2021). Most life events happen during youth, between the ages of 20 and 35, as well as in the transition to retirement, whereas middle age is generally seen as a period of stability (Beige & Axhausen, 2012; Lanzendorf, 2010).

A second category of key events are events which are directly related to mobility. For Müggenburg et al. (2015) "long-term mobility decisions" such as acquiring a car, or moving to a new apartment, represent adaptations to other life events. However, these key events also have an effect on mobility by themselves. Acquiring a car (Prillwitz et al., 2006; Oakil et al., 2014) implies a substantial cost and has implications for travel habits over several years (Clark et al., 2016). Some mobility-related key events are considered "mobility milestones" because they influence mobility habits over the whole life course, including the acquisition of a drivers' licence, or the purchase of the first car (Klöckner, 2004; Rau & Manton, 2016). These car-related milestones have traditionally represented a generational rite of passage marking the entry into adulthood, but their status may have changed in recent years with a tendency for younger people to delay their passing of a drivers' licence (Rérat, 2018), suggesting a decline in the status of the car.

A third category of key events are "exogenous interventions" or unplanned events such as road closures, a transport strike, or the COVID-21 pandemic, which affect travel behaviour by breaking existing routines (Buehler & Pucher, 2021c; Marsden & Docherty, 2013). For example, in the case of COVID-19, the wish to avoid social contacts in public transport pushed many people to cycle. Improvements in cycling conditions such as the construction of a new cycling route may also trigger increases in cycling, also fall into this category.

Mobility biographies research has focused much on key events because of their potential to change mobility habits. However, some scholars have criticized a lack of attention towards more gradual or long-term processes such as changes in the cultural meanings of transport, for example the status of the car, or of cycling, in western societies (Rau & Scheiner, 2020; Sattlegger & Rau, 2016). Moreover, the definition of what constitutes a key event or a long-term process remains unclear. For instance, the entry into adult working life, raising children, or retirement arguably represent more gradual transitions or processes which happen over several years, rather than key events (Müggenburg et al., 2015).

2.3.2.2 Mobility socialization

In addition to key events, socialization processes influence the individual's mobility habits over the life course. The role of social influences in mobility biographies has been comparatively under-researched (Scheiner, 2017), but potentially has an important impact in developing travel habits for the rest of an individual's life.

Mobility socialization (or travel socialization) refers to a process by which societal and cultural values and norms regarding transport, but also residential preferences (Döring et al., 2019) are transmitted to the individual within the family, or through the influence of friends and partners (Döring et al., 2014; Tully & Baier, 2011). Mobility socialization can also be defined as the process through which an individual becomes a part of the mobile society (Tully & Baier, 2011). In psychology, primary socialization refers to the influence of parents on their children, while secondary socialization refers to the influence of peers, for example through school or peers at adolescence. Döring et al. (2014) make a distinction between socialization through the influence of agents (e.g. parents) on a person's preferences at the time of interest (e.g. cycling because my father does it), and reverse socialization, or reproducing the behaviour of an agent at a later stage (e.g. using the car because one's mother advised to do so during pregnancy).

The impact of socialization is especially important among children or teenagers, whose travel habits are strongly influenced by socialization agent including family members, school, media and peer groups (Baslington, 2008; Tully & Baier, 2011; Döring et al., 2014). According to Baslington (2008), children from a young age are influenced by their parents' behaviour and cultural preferences for the car, implying that their future transport mode attitudes and preferences are not purely a choice, but are embedded in childhood. Children brought up in carless households show less interest in travelling by car than adults, and are able to travel more independently than those in car-owning households (Baslington, 2008; Devaux & Oppenchaim, 2013). Parental influence also has an effect on cycling, with children cycling more if their parents also did, or if they were afforded more independence (Driller et al., 2020).

Socialization is related to gender, with some studies finding that girls are more influenced by their mothers' travel habits (Klöckner & Matthies, 2012). Gender differences may also be observed in socialization processes related to cycling, with teenage girls facing more barriers to travelling by bicycle than boys (Sayagh, 2018, 2017; Sayagh et al., 2022). For girls, this period of life often leads to the abandonment of cycling due to peer pressure (Bonham & Wilson, 2012; Underwood et al., 2014).

In later stages of life, socialization to cycling may continue to happen through more or less direct influences related to life course opportunities, cycling with a partner, as a family activity, but also through the knowledge of colleagues or friends who also cycle, and at a larger level, through the community context or workplace cycling culture (Bonham & Wilson, 2012; Sherwin et al., 2014).

Socialization also acts through the broader social and cultural context within which individuals evolve over the course of their lives. The city or country's "mobility culture" (see also section 2.4.5.5) thus shapes people's view of travel modes (Deffner et al., 2006; Klinger et al., 2013). As a result, people living in "cycling cities" such as Copenhagen tend to view cycling as a safe and normal activity (Haustein et al., 2019).

2.3.3 Biographical research on cycling

Most research on cycling is based on cross-sectional rather than longitudinal data, and views cycling at a given moment rather than over time (Handy et al., 2014). Because cycling remains a minority practice (Prati et al., 2017) which varies in frequency over the course of people's lives and is affected by seasonality, travel surveys have often underestimated its importance relative to other modes of transport. However, a few studies have adopted a biographical perspective to understand which factors lead to variations in cycling over the life course.

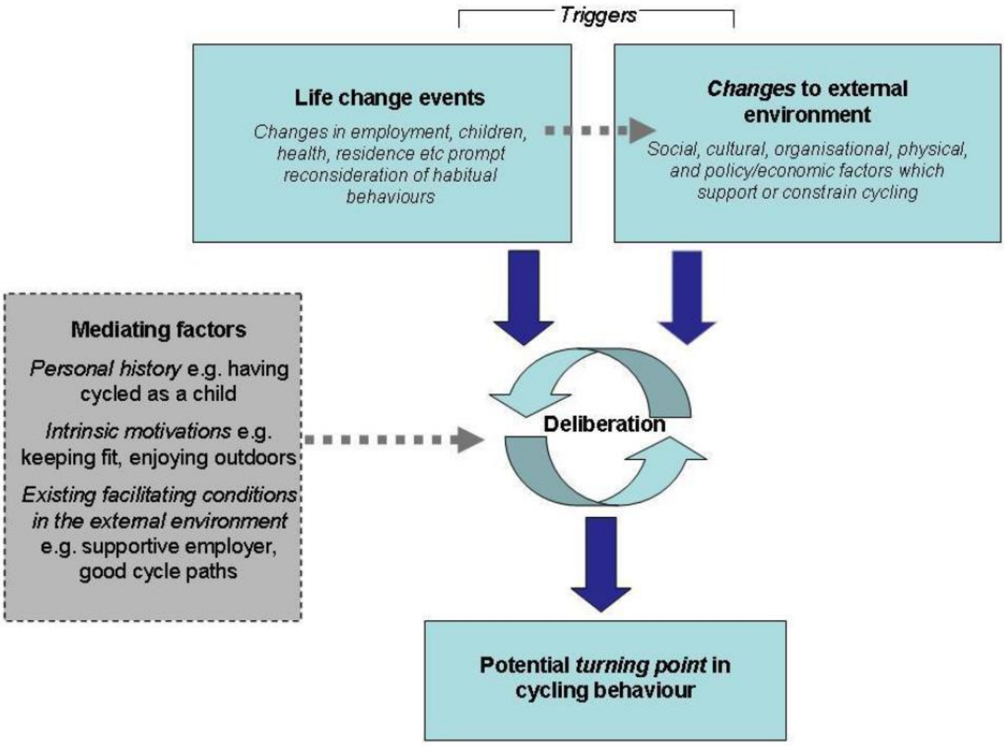
2.3.3.1 Key events and cycling

A study in Great Britain by Chatterjee et al. (2013) found that the majority of changes in cycling frequency (increases or decreases) were triggered by one or many life events in the domains of education, employment, relationships, residential location, children's development, physical health, or leisure and fitness interests, while transport-related events (car and bicycle availability) or changes to the cycling environment had less of an effect. The events which influenced cycling varied depending on age. While younger people were more affected by residential relocation or childbirth, older cyclists were more affected by health issues. A study by Oakil et al. (2016) in the Netherlands found that the most frequent key events related to taking up cycling for commuting were residential relocations and job changes which resulted in shorter trips. In the United States, Janke and Handy (2019) found that the key events most frequently associated with changes in cycling were parenthood, residential relocations and changes in partnership. In Germany, a study conducted among cyclists and non-cyclists found that the same key events (health, childbirth) or mobility milestones (access to a car, transport pass, e-bike, or cycle training) could have mixed effects on cycling, leading in some cases to reductions and in others to increases (Rau et al., 2020).

Through which mechanism do key events influence cycling? According to Chatterjee et al. (2012), "life change events" (i.e. key events), changes to the external environment or transport-related events trigger a deliberation process which can lead to changes in cycling (i.e. "turning points") (Figure 6). During this deliberation, mediating factors including the personal history of cycling, intrinsic motivations (e.g. fitness) and facilitating conditions (e.g. the presence of cycle paths) play a role.

For Oakil et al. (2016), key events affect cycling through two main mechanisms: a change in life circumstances impacting commuting trips (e.g. longer distances to work), or a change in responsibilities and daily activity patterns (e.g. childbirth). Meanwhile, Janke and Handy (2019) find key events to influence cycling through four processes: (1) by interrupting habitual behaviour and forcing a reconsideration of exiting travel routines; (2) through changes to the physical and social environment which force individuals to adapt their behaviour; (3) by changing conditions and unleashing a latent demand or interest for cycling; (4) by triggering interests for new destinations and activities which support or discourage cycling (Janke & Handy, 2019).

Figure 6: Conceptual model for explaining turning points in travel behaviour. Source: Chatterjee et al. (2012).

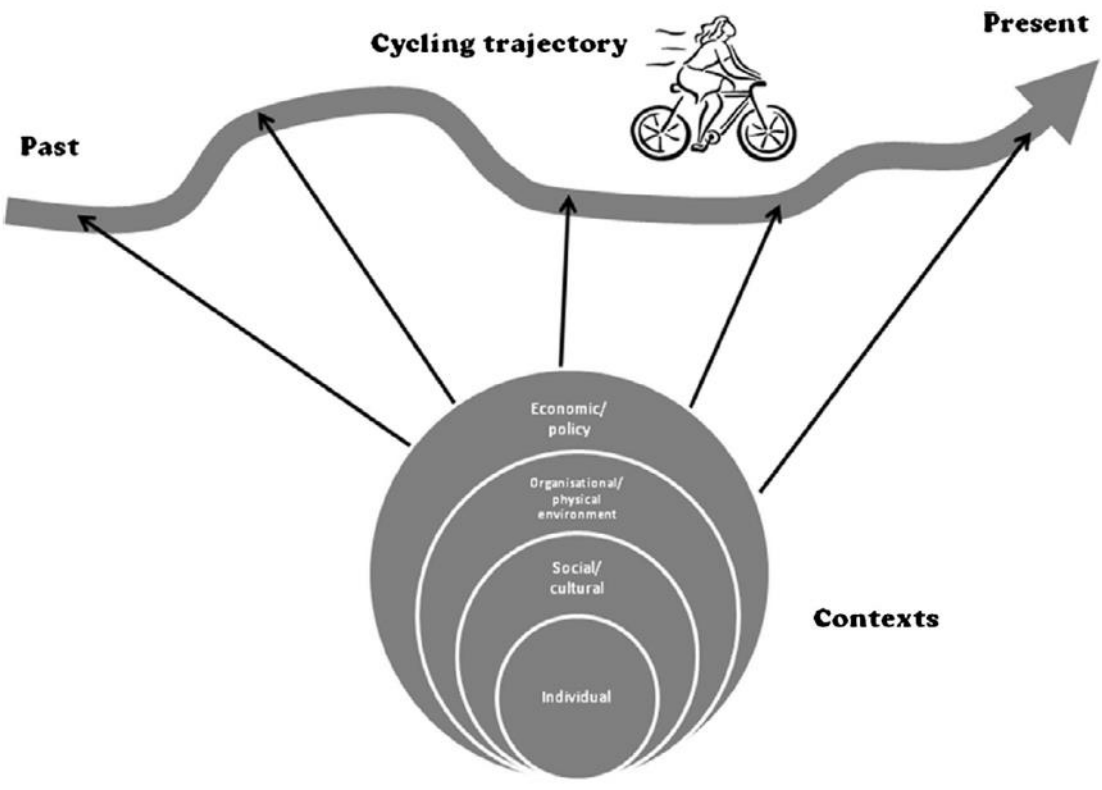


2.3.3.2 Cycling trajectories

Going beyond key events, some studies have used retrospective qualitative data to analyse life course trajectories of cycling, or “cycling trajectories”. Chatterjee et al. (2012, 2013) define the notion of “cycling trajectory” as the application of a life course approach to cycling. This approaches considers that "people arrive at their current cycling behaviour within trajectories that are developed over the course of their lives and shaped by transitions (or life-change events) that they have made and the contexts that they encounter" (Chatterjee et al., 2012, p. 5). The cycling trajectory (Figure 7) represents “a person’s thoughts, feelings, capabilities and actions related to cycling” (Chatterjee et al. 2012:5) over the life course.

The concept of a cycling trajectory considers cycling practices to be influenced throughout time by both personal and environmental contexts. Jones et al. (2015) suggest that “the individual acts within an unfolding structure of opportunities and constraints for walking and cycling”. Within this trajectory, cycling is influenced, on the one hand, by a micro context which is shaped by “life events and transitions pertaining to locations, interpersonal roles, mobility resources and health” (H. Jones et al., 2015, p. 128) . On the other hand, by a macro context which includes “attributes of the physical settings and social norms around mobility and safety, and the timing and content of the life course” (H. Jones et al., 2015, p. 128). In this thesis, we consider the cycling trajectory to bring a dynamic perspective to the adoption of the e-bike.

Figure 7: Cycling trajectory. Source: Chatterjee et al. 2012



A few studies have considered cycling trajectories over the whole life course. In Australia, Bonham and Wilson (2012) analysed the “start-stop experiences of cycling” of women who were returning to cycling. They showed that women had often practised cycling at childhood but interrupted it at various periods throughout their life course, most often during their adolescent years, or, when raising children.

However, during later life, women made many attempts at returning to cycling linked to changing life circumstances (e.g. changes in partnership, residential relocations, workplace changes), or as a form of leisure, social activity, or exercise. By proving that returns to cycling could happen throughout life, this research challenged a linear vision of mobility as a progression from cycling to car use.

Different groups of cycling trajectories can be found among cyclists. A series of studies in Great Britain (H. Jones, 2013; H. Jones et al., 2014, 2015) analysed individual walking and cycling trajectories over the life course by using life history calendars. Cycling was affected by periods of uncertainty at the time of entering adulthood and during the transition to retirement, in contrast to longer periods of stability during middle age (H. Jones et al., 2014). They identified eight types of cycling trajectories, depending on the life course and the purpose of cycling (recreational, transportation or mixed): "no cycling beyond childhood", "cycling in early adulthood", "one-off experiences in adulthood", "unsuccessful return as adults", "twenties dabblers", "leisure purists", "revolving returners" and "committed commuters" (H. Jones et al., 2014). These trajectories were also categorized as either resilient (stable), restorative (increasing) or diminishing (decreasing) in the long term. Although these studies focused on conventional cycling, the e-bike was mentioned for older users as constituting either an "adaptive change", to maintain cycling, or a "restorative change", as a way of taking up cycling again (H. Jones et al., 2014).

2.3.3.3 E-bike adoption

Due to the novelty of e-bikes, few studies have explicitly considered the role of key events for their adoption. In Germany, Le Bris (2016) found that most e-bike users previously had cycling experience, with e-bike adoption having three objectives: conserving an existing cycling practice (1), reactivating it (2), or facilitating an increase in cycling (3). Existing e-bike research also suggests that specific key events may trigger the adoption of the e-bike. Among older users, health problems, a loss of muscular strength or balance may encourage the switch to an e-bike to facilitate cycling (T. Jones, Harms, et al., 2016; Leger et al., 2018). Among younger users, childbirth and parenthood and the need to carry young children may motivate people to adopt an e-bike or a cargo bike to cope with the additional weight (Le Bris, 2016). A change in the spatial environment may lead to shorter distances to work and encourage a switch to commuting by e-bike (Plazier et al., 2017). Alternatively, a change in social environment such as moving to a new neighbourhood or “mobility culture” may also lead to reconsidering travel behaviour and serve as a trigger for the adoption of the e-bike (Le Bris, 2016). Lastly, external interventions and particularly test rides or subsidies may also serve as triggers encouraging the purchase of an e-bike (Le Bris, 2016; Rérat, 2021c).

2.4 A systemic approach to cycling

2.4.1 The system of vélomobility

After analysing e-bike adoption, we shift our focus to how e-bikes are being used. Adopting an e-bike does not necessarily translate into e-bike use, with some e-bikes used only a few times per year, while others are used every day. Moreover, e-bike uses (frequency, distance purpose of trips) may vary to a high degree between people with different characteristics and rhythms of life. Barriers may also deter people from using their e-bike in certain circumstances (e.g. at rush hour). Understanding how e-bike users appropriate this new mode of transport within their existing mobility habits is thus important.

One of the drawbacks of traditional behavioural cycling research is their focus on individual attitudes as the main determinant of cycling. However, this viewpoint underestimates the extent to which individuals are unequally gifted in their ability to cycle (e.g. due to age, physical limitations, or a fear of cycling on the road). Moreover, more than other forms of transport, cycling depends on a spatial context which is often unwelcoming for the practice of cycling (Rérat, 2021c). Unlike car driving, which relies on a well-developed system of automobility including a wide range of infrastructures (from roads to petrol stations) and institutions (Urry, 2004), cycling relies on a system of cycling or "vélomobility" which is still incomplete in many places (Watson, 2013; Koglin & Rye, 2014; Koglin, 2015). The term "vélomobility" refers to both a system of mobility centred around the bicycle (Watson, 2013; Koglin & Rye, 2014; Koglin, 2015), as well as to the practice of cycling itself (Furness, 2007; Behrendt, 2018; Cox, 2019).

In this thesis, we choose to consider cycling within a systemic approach as the interplay between individuals and territorial contexts, which shapes the opportunities and constraints related to cycling. Following Rérat (2021a, 2021b), e-bike uses are considered within a system of vélomobility as the meeting between, on one hand, an individual potential for cycling, and on the other hand, a territorial hosting potential or "bikeability".

In the next section, we define these two potentials. Thereafter, we review the literature on the environmental determinants (section 2.4.5), and the individual determinants of cycling (section 2.4.6) through the lens of vélomobility.

2.4.2 Individual mobility potential

The idea that individuals hold a certain potential for mobility can be traced to the sociologist Vincent Kaufmann's concept of "motility" (Flamm & Kaufmann, 2004; Kaufmann et al., 2004; Kaufmann, 2007; Kaufmann et al., 2016). Motility is considered as a potential to be mobile, which does not necessarily translate into actual mobility. Originally, the idea of a potential for mobility which is unequally distributed among individuals comes from the notion of "capital" in the sense of Bourdieu (1979), who identified three types of capital: an economic capital (assets and income), a social capital (social relations), and a cultural capital (knowledge of languages, education, etc.). Kaufmann argues that in contemporary society, an additional capital, mobility, or the ability to be mobile, has become indispensable for social insertion and serves "to feed other capitals (moving to earn money, moving to cultivate oneself, moving to maintain/expand social networks.)" (Kaufmann, 2014b, p. 187). In this sense, the potential for mobility is related to the notion of "spatial capital" (Lévy, 2000) or "network capital" (Urry, 2007), which is the ability "to engender and sustain social relations with those people who are mostly not physically proximate and which generates emotional, financial and practical benefit" (Urry, 2007, p. 197). This notion thus combines the two historical definitions of mobility, social mobility (movement within a social hierarchy) and spatial mobility (movement through space).

Motility, according to Kaufmann, includes "The set of characteristics specific to an actor that allow him or her to be mobile, i.e. physical abilities, income, aspirations to be sedentary or mobile, social conditions of access to existing technical transport and telecommunication systems, acquired knowledge, such as training, a driver's license, international English for travel, etc." (Kaufmann, 2014b, p. 61). These characteristics can be summed up in three dimensions: access, skills, and appropriations (Kaufmann, 2007). This potential has been applied to refer to an individual cycling potential (Mundler & Rérat, 2015; Rérat, 2019). In the case of e-bikes, we draw on Rérat (2021) to define these three dimensions as follows.

Access refers to the range of opportunities for mobility that are available to the individual, given a certain socio-spatial context, and constrained by certain options and conditions (Kaufmann et al., 2004). Options refer to available means of transport and communication, services and equipment. Conditions include location, cost, and other constraints. Access is unequally distributed depending on an individual's spatial location and socio-economic position. Kaufmann uses the term of "portfolio of access rights" to denote the right to use a set of transport means, rather than just its ownership (Flamm & Kaufmann, 2006). In the case of e-cycling, access may be understood as the e-bike itself (pedelec/speed-pedelec), accessories such as panniers, lights, mudguards, child seats, charging equipment, clothing such as rain/winter clothes and safety equipment (e.g. helmet), as well as the range of other vehicles, public transport passes, or services (e.g. carsharing) a person has access to in the household.

Skills or competences refer to both individual and social skills or abilities for mobility (Kaufmann et al., 2004). This includes the *physical ability* for movement, *acquired skills* related to norms and regulations and knowledge of the environment (e.g. owning a driver's license), and *organizational skills* (e.g. the ability to plan activities). In the case of e-cycling, skills include the physical ability required to pedal and maintain one's balance on the bike, cycling ability or know-how (experience of traffic situations, ability to control the e-bike, knowledge of spatial context), repair and maintenance skills, battery management, and organizational skills (trip planning, activity chaining, ability to estimate the duration of journeys). E-bikes reduce the need for physical ability when cycling, but require new skills for battery management (selecting pedal assistance levels, checking battery range, removing the battery when parking, recharging), mechanical skills (e.g. changing disc brake pads, cleaning, greasing, etc.), and cycling skills, such as anticipating motorists' reactions or learning to master the handling, longer braking time and stronger acceleration of the e-bike (Haustein & Møller, 2016b; Hertach et al., 2018).

Appropriation refers to the way in which individuals evaluate the mobility options available to them and act upon them, given their access and competence (Kaufmann et al., 2004). Appropriation is related to individual strategies, norms and values, perceptions, and habits (Kaufmann et al., 2004; Kaufmann & Widmer, 2005). More so than the other components, appropriation relates to individual agency, the freedom to travel or not, and to lifestyle, or the needs, aspirations and constraints which guide individuals in their daily mobility (Kaufmann, 2007). In the case of e-bikes, we define appropriation as composed of the image of e-cycling (e.g. as efficient, safe, or dangerous) and of other transport modes, the motivations for using an e-bike (e.g. to cycle uphill) and the sensitivity to barriers refraining from e-bike use (e.g. traffic conditions, trip distance, weather).

2.4.3 Territorial hosting potential or bikeability

The concept of "territorial hosting potential" (or "spatial hosting potential") represents the contextual counterpart to the individual mobility potential (Kaufmann, 2014, 2016). It refers to "how receptive or suitable [a space] is for certain modes of transportation" (Rérat, 2021c, p. 4).

Kaufmann defines the territory not as a purely physical object, but rather, a socio-spatial context which includes the spatial structure, but also social institutions, norms and regulations (Kaufmann, 2014, p. 79). The physical component of the territory is made of material "artefacts" (i.e. the built environment) which are inherited from the actions of past actors and provide "affordances" (Gibson, 1979) for individuals' actions. In this sense the territorial hosting potential is "relational" because it influences individual's mobility potential over time by shaping their access, appropriation, and competences

(Rérat, 2021c). As a result, the territorial hosting potential can favour certain modes of transport such as cycling, while discouraging others.

The territory's hosting potential for cycling can be defined as its "bikeability" Rérat (2021). The term bikeability was coined by reference to "walkability", to define an environment's suitability for cycling. Several quantitative indexes have been developed to measure bikeability (Sorton & Walsh, 1994; Harkey et al., 1998; McNeil, 2011). According to Lowry et al. (2012), an environment can be suitable to cycling at three different levels. Firstly, at a street level, *bicycle suitability* refers to "the perceived comfort and safety of a linear section of bikeway" (Lowry et al., 2012, p. 3). Secondly, at the network level, *bikeability* refers to "an assessment of an entire bikeway network in terms of the ability and perceived comfort and convenience to access important destinations" (ibid.). Thirdly, at the community level, *bicycle friendliness* refers to "an assessment of a community for various aspects of bicycle travel, including bikeability, laws and policies to promote safety, education efforts to encourage bicycling, and the general acceptance of bicycling through the community" (ibid.).

Based on Rérat (2019, 2021), we distinguish three main dimensions for the territorial hosting potential or bikeability: the territorial structure (1), cycling infrastructure (2), and rules and norms (3). The ***territorial structure*** refers to the spatial context in which cycling is practised, which can be separated into the built and natural environment. The built environment includes density, land-use diversity, urban form (urban, suburban, peri-urban), and proximity to activities. Dense, compact, and diverse built environments lead to shorter distances which encourage cycling over driving (Heinen et al., 2010; Handy et al., 2014; Rérat, 2021c). The natural environment includes topography, climate, landscape, and the presence of green space. Its impact on cycling is more mixed, as cycling is widespread in a variety of natural environments and climates, warm or cold, and in flat as well as hilly cities.

Cycling infrastructure can be separated into trip-related facilities and end-of trip facilities (Pucher et al., 2010). Trip-related facilities include bike lanes and paths, their level of separation from traffic, continuity and maintenance (Pucher et al., 2010), as well as traffic-calming (e.g. 30 km/h zones) and intersection treatments (e.g. bike boxes or cycle-specific lights). End-of-trip facilities at the home or destination include bicycle parking and its level of security and protection from weather (Heinen & Buehler, 2019), workplace showers and clothes lockers (Buehler, 2012; Heinen et al., 2013). Lastly, the presence of bicycle stores and repair facilities can be considered as part of the infrastructure needed to maintain bicycles (Handy et al., 2014).

Rules include road traffic regulations for bicycles and pedelecs (which are considered as bicycles), and specific laws for speed-pedelecs which are considered as mopeds (see 2.1.2). In Switzerland, bicycles must use cycling infrastructure, ride on the right side of the road, and cannot ride two abreast or use the sidewalk. New laws give bicycles a few advantages, such as the possibility to turn right at red lights if indicated (OFROU, 2021).

Social norms are rules or prescriptions that people have assimilated, and which guide their behaviour. This includes the influence of the social environment (see 2.4.5.5 below) and the attitudes towards cycling of relatives, friends, partners, or work colleagues (Willis et al., 2015), and relates to processes of mobility socialization (see 2.3.2.2). At a broader level, the cultural norms associated with cycling are related to the cycling culture of a city or country (Haustein et al., 2019). They include stereotypical representations of cyclists (e.g. as "lycra-clad men") and how "good cyclists" should act (Gatersleben & Haddad, 2010; Aldred, 2013a). Negative representations of cyclists are prevalent in low-cycling cultures where cyclists are a minority group (Prati et al., 2017). E-bikes hold both positive connotations an efficient and sustainable mode of transport, and a pleasant form of recreation or exercise, but also negative connotations associated with "laziness" or old age (Popovich et al., 2014; T. Jones, Harms, et al., 2016), or as a dangerous mode of transport.

2.4.4 Determinants of cycling

Understanding the key factors or determinants which affect cycling is one of the central questions of bicycle research, because it can help to formulate measures to promote cycling (Handy et al., 2014). Consequently, there has been a significant amount of literature covering the determinants of cycling. The factors affecting cycling can be studied at an aggregate level, between cities or areas (Parkin et al., 2008; Rietveld & Daniel, 2004; Vandenbulcke et al., 2011), through the mode share of cycling trips, or the percentage of households owning a bicycle. At the disaggregate (i.e. individual) level, the factors affecting cycling can be measured directly for each individual or household, through the ownership of a bicycle (e.g. Handy et al., 2010), use of cycling for certain trip purposes such as commuting to work (De Geus et al., 2007; Handy & Xing, 2011; Heinen et al., 2011b), the frequency of cycling in a given week (Ma & Dill, 2015; Sallis et al., 2013; Stinson & Bhat, 2004), or whether a person cycled on a given day (e.g. in a census) (Heinen et al., 2011a).

Traditionally, the determinants of cycling can be summarized into five main categories according to Heinen et al. (2010). Firstly, determinants related to the *built environment* including urban form (trip distance, network layout, functional diversity, and density), *bicycle infrastructure* (separation, continuity, presence of car parking, number or car lanes, presence of traffic signs) and workplace infrastructure (secure bicycle parking, showers and lockers). Secondly, determinants related to the *natural environment* such as hilliness, attractiveness of the environment, seasonality, lighting, rain, and low temperatures. Thirdly, *socio-economic variables* such as income, employment, age and gender, and national differences in cycling culture. Fourthly, *psychological factors* such as attitudes and social norms, perceived behavioural control (Ajzen, 1991), values and norms (Schwartz, 1977), and habits (Aarts et al., 1998). Finally, *trip-related determinants* such as cost, effort, travel time, and safety.

Within the system of vélomobility, we classify the determinants of cycling between two potentials: the territorial hosting potential, and the individual mobility potential (Table 1).

At the level of the ***territorial hosting potential***, these determinants can be separated into three further categories: (1) the territorial structure, which includes the built environment and natural environment; (2) cycling infrastructure, which including trip facilities and end-of trip amenities; (3) social norms and rules, which refer to the social environment or the influence of peers, colleagues, and the community.

At the level of the ***individual mobility potential***, cycling determinants fall into four categories: (1) the profile of cyclists, namely socio-demographic characteristics (age, gender, etc.) and socio-economic status (income, education, etc.); (2) access, which refers to ownership of vehicles and transport passes; (3) skills, which refer to cycling skills, abilities and experiences; (4) appropriation, which includes motivations and barriers to cycling, as well as images of cycling and other modes.

Table 1: Determinants of cycling separated by dimension of vélomobility. Adapted from Rérat, 2021.

Territorial hosting potential (Bikeability)	Territorial structure	• Built environment/urban form: density, connectivity, land-use mix, trip distance • Natural environment: green space, aesthetics, hilliness, weather
	Cycling infrastructure	• Trip facilities (lanes, paths, intersection treatments) • End-of-trip amenities (parking, showers, lockers) • characteristics of the road (presence of car parking, number of lanes, traffic lights)
	Social norms and rules	• Social environment: workplace, peers, community
Individual potential for mobility	(transversal) Profile[12]	• Socio-demographic characteristics: age, gender, household structure • Socio-economic status: income, education, ethnicity
	Access	• Vehicle ownership • Transport passes
	Skills	• Cycling skills & Experiences • Physical abilities
	Appropriation	• Motivations • Barriers • images of cycling

2.4.5 Environmental determinants of cycling

2.4.5.1 Background: Travel and the built environment

In the 1990s, Newman and Kenworthy identified a link between low-density urban planning and the level of car use (measured through fuel consumption per capita). Across the world, cities with the lowest density of land use in North America and Australia had the highest car use (measured in gallons of fuel) per capita, while cities with the highest densities in Asia and Europe had the lowest car use, and the highest transit (i.e. public transport) use (Kenworthy & Laube, 1999; Newman & Kenworthy, 1989). The reliance of cities on car use for personal transport was named "automobile dependence", a situation "where cities assume the use of an automobile in their design, infrastructure, and operation" (Newman

[12] We have chosen to include the profile of cyclists in the individual potential, because it is widely considered within cycling literature as a determinant which explains cycling use. However, at an aggregate level, the profile of cyclists (e.g. the gender makeup) can also be viewed as a variable of outcome resulting from of the meeting of individual potentials and territorial potential (Rérat, 2021c). This choice is therefore also due to our research question, which aims to understand the factors affecting the frequency of e-bike use.

& Kenworthy, 1999). This situation has several negative effects: economic inefficiency of infrastructure, transport costs, consumption of land (1), environmental externalities (vulnerability to oil shocks, greenhouse gas emissions, traffic fatalities, noise) (2), social equity and accessibility issues for the carless (3), and a loss of human liveability (community and urban vitality, safety) (Newman & Kenworthy, 1999).

At the same time, several studies have confirmed that residents of high-density, mixed-use neighbourhoods tend to walk more and drive less than residents of low-density, suburban areas (Ewing et al., 1994; Kitamura et al., 1997). Moreover, transport engineers and urban planners have long sought to influence the relationship between the environment and individual travel, in other words, to "moderate travel demand by changing the built environment" (Ewing & Cervero, 2010, p. 267). This objective is related to the emergence of new approaches of urban planning favouring dense, compact developments such as "new urbanism" (Duany et al., 2001) and "TOD" (transit-oriented development) (Cervero, 2004). In Europe, it is related to the emergence of the model of a compact city and a new urban planning paradigm which emphasizes the densification of urban areas (Burton et al., 2003; Bibri, 2020). To leverage this effect, research has attempted to determine the environmental factors associated with travel by sustainable modes (e.g. walking and cycling) rather than driving.

According to Cervero and Kockelman (1997), travel demand is influenced by the 3 "D"s of the built environment : its ***density*** (e.g. population or job density), ***diversity*** (e.g. land-use mix or presence of retail), and ***design*** (e.g. road network density and connectivity). Cervero and Kockelman (1997) suggested that « density, land-use diversity and pedestrian-oriented design reduce trip rates and encourage non-auto travel in statistically significant ways ». Further studies (Cervero et al., 2009; Ewing & Cervero, 2001) considered the importance of two further variables, ***distance to transit*** and ***destination accessibility***.

However, some studies have argued that the relation of causality between the individual and the environment could be inversed, and that people with a predisposition towards certain types of travel behaviour may choose to locate within a neighbourhood that enables this kind of travel. This phenomenon, called residential self-selection, sees residential location choice as reflecting one's attitudes, lifestyle and travel patterns (Cao et al., 2009; Mokhtarian & Cao, 2008). The effects of residential self-selection may reduce those of the built environment on travel behaviour. However, reviewing the results of the literature, Cao et al. (2009) found that although residential self-selection had an observable effect, the effect of the built environment remained even after accounting for it. According to Ewing & Cervero (2010), the effect of the built environment is much greater than that of residential self-selection (attitudes and residential preferences), accounting for more than 50% of differences (and in some cases, up to 90% for Zhou & Kockelman, 2008) in terms of vehicle miles travelled (i.e. car use) between households.

A second field of research in public health has also been interested in the relationship between the built environment, the social environment and physical activity behaviours, specifically walking and cycling. Researchers made the hypothesis that specific environments could increase the individual's level of physical activity (Srinivasan et al., 2003), and consequently, that it might be possible to influence people's health by acting on their environment. This hypothesis is based on social-ecological models (see section 2.2.3.2) which consider individual health behaviour as influenced at multiple levels by the physical environment, and the social environment (Sallis et al., 2006).

Pikora et al. (2003) developed a conceptual framework of the influence of physical environment factors on walking and cycling, both for transport and recreation. They identified four main factors which influence walking and cycling. Firstly, ***functional factors*** related to the physical attributes of the street and path (structural aspects of the local environment), including the presence of paths, street type and width, traffic volume and speed, and directness to destinations. Secondly, ***safety-related factors*** or the need to provide safe physical environments, both at the personal level (lighting, passive surveillance), and for traffic (crossings). Thirdly, ***aesthetic factors*** which provide a pleasing physical environment for walking and cycling, such as the presence of trees, of parks and gardens, the level of pollution, the diversity and interest of natural and architectural designs in the neighbourhood. Fourthly, ***destination factors*** related to the availability of community and commercial facilities in the neighbourhood, including post boxes, parks, schools, shops, transport facilities (bus & train stop).

For Saelens et al. (2003), the choice to use nonmotorized rather than motorized transport is related to two factors. ***Proximity*** (the distance between origin and destination) which is determined by density and land-use mix, and ***connectivity*** (the directness of travel between two destinations), which is determined by street layout. These factors affect both walkability and bikeability.

A review of the literature by Ewing & Cervero (2010) found that destination accessibility (to jobs or activities) was the strongest factor related to motorized and non-motorized travel (car use and walking). Density had the lowest effect on travel choices, presumably because it is related to other determinants such as land-use mixture, distance, and location, which all shorten trips and encourage walking. Among design variables, intersection density was found to be more important for walking than street connectivity. Among diversity variables, jobs-housing balance (linking where people live and work) was found to be a stronger predictor of walking than land use mix.

2.4.5.2 Built environment: Density, connectivity, land-use mix, trip distance

The built environment can favourably influence cycling through urban form, which relates to several characteristics including shorter travel distances, street network layout, functional diversity, and density (Heinen et al., 2010). Consistent with the travel behaviour literature, several studies have found cycling to be positively influenced by high population density (Fraser & Lock, 2011; Saelens et al., 2003; Winters et al., 2010). Greater street connectivity, measured through the density of intersections, is positively associated with cycling (Winters et al., 2010; Yang et al., 2019). This indicator relates to the directness of trips and ease of access to destinations. In the North American context, typically, street connectivity is lower in low-density residential "cul-de-sac" neighbourhoods than in central districts with "grid-iron" street layouts. Land-use mix, or the proximity of shopping, work, and non-residential uses, has also been favourably associated with cycling (Saelens et al., 2003; Sallis et al., 2013; Winters et al., 2010). However, others have found only a weak effect of land-use mix on cycling (Titze et al., 2008; Yang et al., 2019). Distances to destinations, which is associated to lower land-use mix, has a negative effect on cycling (Handy et al., 2010; Handy & Xing, 2011). Conversely, shorter trip distances, and a higher number of destinations within cycling distance, are associated with more cycling trips (Fraser & Lock, 2011; Ma & Dill, 2015). For commuters, distance to work has a negative effect on frequency of cycling (Stinson & Bhat, 2004), whereas working in an urban location increases cycling (Handy et al., 2010).

Both walking and cycling are encouraged by the three D's of the environment, which make driving less attractive. Some authors have found an association between walkability (a combination of residential density, retail floor area ratio, land-use mix, and intersection density) and bikeability (Saelens et al., 2003; Sallis et al., 2013), suggesting that walking and cycling are positively affected by similar built environment characteristics. However, cycling and walking are very different. Compared to walking, cycling is affected by other factors, including the presence of bicycle paths and lanes. Cycling is also affected differently by spatial factors due to its longer trip distances, which poses methodological issues when comparing it to walking (Muhs & Clifton, 2016; Yang et al., 2019). Thus the main difference between bikeability and walkability is that the former puts much more emphasis on infrastructure and topography, while the latter is more focused on land use, population and density (Muhs & Clifton, 2016). Moreover, the effects of the built environment may also vary for different purposes of cycling, between recreational cycling and utility cycling (Cervero & Duncan, 2003; Yang et al., 2019).

There is some disagreement among authors about the magnitude of the effects of the built environment on cycling. Some have argued that perceived environment variables, such as perceived safety, are more important in determining cycling (Moudon et al., 2005; Sallis et al., 2013). According to Moudon et al. (2005, p. 245), "cycling is only moderately associated with the neighbourhood environment. It appears to be an individual choice that is independent from environmental support". Meanwhile, others have suggested that environmental determinants have more effect on the frequency of cycling rather than the decision to cycle itself (Ma & Dill, 2015).

2.4.5.3 Natural environment: Green space, aesthetics, hilliness, weather and seasonality

The effect of the natural environment on cycling relates to both the attractiveness of cycling routes, but also, the barrier effect of hilly topography and seasonality (darkness, rain and cold temperatures) (Heinen et al., 2010). The presence of green space and of trees has been positively associated with cycling (Mertens et al., 2017; Yang et al., 2019). This can be related to cyclists' preference for separation from motor traffic, and increased well-being related to interacting with the outdoor environment. Moreover, aesthetically attractive environments which include architectural or natural features have been shown to encourage cycling (Kerr et al., 2016; Titze et al., 2008). One of the most well-known barriers to cycling, topography, has a negative effect on cycling, with slopes over 5% grade considered to be difficult for most people to cycle on (Fraser & Lock, 2011; Winters et al., 2010; Yang et al., 2019).

Weather conditions can also have a significant effect on cycling. Generally speaking, cycling decreases in cold or wet conditions and in the winter season (Nankervis, 1999). Precipitation (i.e. rain) has a negative effect on cycling, even if it happens in the previous hours or days (Miranda-Moreno & Nosal, 2011). Higher temperatures generally encourage more people to cycle, although when heat becomes too intense and humidity increases, ridership can also decrease (Miranda-Moreno & Nosal, 2011). As it is generally planned in advance, recreational cycling is more sensitive to weather than utility cycling (Brandenburg et al., 2007). In terms of seasonality, winter has been associated with a lower likelihood and frequency of cycling, as many people reduce cycling trips or interrupt cycling altogether. However, weather impacts cyclists in different ways and is related to personal perceptions. Utility cyclists who cycle in winter are generally well equipped and able to cycle even in very low temperatures, although a lack of snow clearance can be an obstacle for cycling (Brandenburg et al., 2007). Recent studies have shown that sensibility to weather is lower in cities with higher shares of cyclists, and with denser cycle route networks. In other words, "A higher resilience to bad weather reveals that cycling is already ingrained as an accepted and sometimes even indispensable mode of transport for daily trips." (Goldmann & Wessel, 2021, p. 9).

2.4.5.4 Cycling infrastructure: Lanes, paths, amenities, traffic-calming

A second category of environmental determinants is cycling infrastructure, which includes the presence of trip facilities (cycle lanes and paths), as well as end-of trip amenities (lockers, showers, parking) at the destination and at home. At an aggregate level, the presence of cycle lanes and paths in cities is associated with a higher modal share of cycling (Buehler & Pucher, 2012a). The causal effect of infrastructure on cycling is bidirectional; infrastructure encourages people to cycle, and when there are more cyclists, this encourages investment in cycle infrastructure (Heinen et al., 2010).

According to the Dutch bicycle planning manual, cycling infrastructure must fulfil five criteria: ***cohesion*** (i.e. continuity, lack of interruptions), ***directness, attractiveness, safety and comfort*** (i.e. smooth, flat surfaces) (CROW, 2016). Both the presence and proximity to dedicated cycle routes or paths have been associated with an increased likelihood of cycling (Saelens et al., 2003; Fraser & Lock, 2011; Yang et al., 2019; Sallis et al., 2013). Cycling infrastructure plays two roles: cycle lanes or paths provide safety for riding a bicycle for utility trips to activities, while mixed-use paths or trails serve as a destination when cycling for recreation (Sallis et al., 2013). Separation from traffic, through off-road cycle paths, trails or tracks, is known to provide a higher level of perceived safety and to increase cycling (Fraser & Lock, 2011). A majority of cyclists prefer separated paths to on-street lanes, especially women and older people (Aldred et al., 2017; Heinen et al., 2010). However, some studies found off-street bicycle paths to be linked with a lower cycling frequency (Ma & Dill, 2015), because such paths, which often take indirect routes, are used by recreational cyclists, while utility cyclists prefer to cycle on the street or on cycle lanes. In this regard, it is important to consider the design but also the directness of cycle infrastructure. Continuity, or the presence of a connected network of cycle lanes or paths, has a positive impact on cycling by reducing interruptions and increasing connectivity (Handy et al., 2010; Handy & Xing, 2011; Mertens et al., 2017; Titze et al., 2008). This relates to bikeability (see section 2.4.3) as a measure of bicycle accessibility to daily travel destinations (McNeil, 2011; Muhs & Clifton, 2016), or "the assessment of an entire bikeway-network in terms of the ability and perceived comfort and convenience to access important destinations" (Lowry, 2012, p. 3).

The continuity of cycling infrastructure extends to origins and destinations. Thus, it is important to focus not only on trip facilities but also on "end-of-trip facilities". To date, studies have mainly focused on workplace amenities, with few considering amenities at the home or at other destinations (e.g. schools, shops, etc.). Workplace amenities including bicycle parking (from racks to protected bicycle garages), showers and lockers have been associated with an increased likelihood of cycling for commuting purposes (Buehler, 2012; Heinen et al., 2010). Other studies have only found bicycle parking to have an effect on commuting frequency, but not the presence of showers and lockers (Stinson & Bhat, 2004). Regarding bicycle parking at public transport stations and at home, both the amount and quality (i.e. secure, sheltered, convenient) of bicycle parking is associated with an increase in the likelihood of cycling (Halldórsdóttir et al., 2017; Heinen & Buehler, 2019). Conversely, the provision of free car parking has been shown to negatively affect commuting by bicycle, while public transport benefits had no effect on cycling (Buehler, 2012). More generally, the perceived bicycle friendliness of the work environment has been positively associated with commuting by bicycle (see section 2.4.5.5 below).

Road characteristics and traffic conditions strongly impact cycling, especially when no cycling infrastructure is provided to separate cyclists from motor vehicles. An increase in the speed and volume of motor traffic, and the presence of arterial roads have a negative effect on the likelihood of cycling (Winters et al., 2010). Higher traffic volumes negatively affect cyclists' perceived safety, and risk of crashes (Aldred et al., 2018; Teschke et al., 2012; Vandenbulcke et al., 2014) (see section 2.5.3.2). As a consequence, the presence of traffic-calming measures such as speed humps, traffic islands, or 30 km/h zones has been positively linked with cycling (Mertens et al., 2017; Winters et al., 2010).

Moreover, the perceived presence of quiet and minor streets has also been associated with a higher frequency of cycling (Ma & Dill, 2015).

2.4.5.5 Social norms and rules: Influence of workplace, peers, community

Beyond the built and natural environment, the social environment also plays an important role in encouraging cycling. This is especially the case for commuting, where a work environment perceived to be favourable to cycling, with incentives to cycle, clothes changing facilities and the like, increases the likelihood of commuting (Heinen et al., 2013).

Within attitudinal approaches, perceived social support for cycling or "subjective norm" (i.e. pressure to perform) is considered to positively influence cycling (Willis et al., 2015). Perceived support for cycling from colleagues and friends increases the likelihood of cycling (De Geus et al., 2007; Titze et al., 2008). The perception of cycling as a normal practice among one's peers (or descriptive norm) also positively affects cycling (Handy & Xing, 2011; Willis et al., 2015). Having friends or a partner who cycles is associated with cycling regularly (Titze et al., 2008; Emond & Handy, 2012; Willis et al., 2015). Through the process of mobility socialization (see section 2.3.2.2), parental influences may also play a role in influencing an individual's propensity to cycle (Willis et al., 2015). Children with parents who have a positive perception of cycling safety are more likely to cycle, while conversely, those with parents who perceive traffic as too dangerous and driving as convenient are less likely to do so (Ducheyne et al., 2013; Trapp et al., 2011; Willis et al., 2015).

At a larger scale, the perceived bicycle friendliness of the community or city positively influences cycling (Handy & Xing, 2011; Willis et al., 2015). This is related to the concept of mobility culture, which "encompasses both material and symbolic elements of a transport system as part of a specific socio-cultural setting, which consists of mobility-related discourses and political strategies on the one hand and institutionalised travel patterns and the built environment on the other hand" (Deffner et al., 2006, mentioned In Klinger et al., 2013, p. 18). In other words, mobility cultures express differences in both objective and subjective terms between cities' culture of getting around (Klinger et al., 2013). Therefore, moving to a city or neighbourhood with a different mobility culture could strongly influence a person's mobility habits (Klinger & Lanzendorf, 2016). The concept of cycling culture directly follows that of mobility culture (Aldred & Jungnickel, 2014; Cox, 2015; Haustein et al., 2019). In the Netherlands, the cycling culture can be understood as a "national habitus" (Kuipers, 2013) where cycling is an established form of transport used for daily activities such as commuting, rather just a recreational practice (Harms et al., 2014). A successful cycling culture also represents the normalization of cycling as part of a city's identity, or when cycling becomes something that all kinds of people just do, rather than just cyclists (Gössling, 2013).

2.4.6 Individual determinants of cycling

2.4.6.1 Socio-demographic characteristics: Age, gender, household structure

The effect of age on cycling is not universal to all cycling cultures (Heinen et al., 2010). Generally speaking, cycling levels tend to decline with age, as elderly people may be physically incapable of cycling because of reduced strength, balance, and eyesight or unwilling to cycle in traffic or at night (Van Cauwenberg, Clarys, et al., 2018; Van Cauwenberg et al., 2012). Younger people tend to cycle more often than older people, because they also engage in a greater number of trips for work or studying purposes (Sallis et al., 2013). However, some studies suggest that older age (>65 years) can also be positively associated with transportation oriented regular cycling (Handy & Xing, 2011). In the

Netherlands, where cycling is much more widespread among the population, cycling still accounts for one quarter of trips among people aged over 75 (Pucher & Dijkstra, 2003). Moreover, several biographical studies have shown that returning to cycling is possible at various moments throughout the life course, including at retirement (Bonham & Wilson, 2012; Winters et al., 2015). Lastly, age differences may also indicate a generational change in the image of cycling for younger generations, for whom car driving holds a less positive image. However, the success of e-bikes among mature and older adults seems to suggest that cycling remains popular among older adults as well.

Gender shapes mobility through activity patterns (linked to division of labour), access to resources (time, money, skills), experience of embodiment, symbolic meanings of mobility practices, and the relationship to the environment and public space (Law, 1999). The effect of gender on cycling, like that of age, depends much on the sociocultural context. Heinen et al. (2010) suggest that although many studies have found men to cycle more than women (Sallis et al., 2013; Stinson & Bhat, 2004), this is only true in low-cycling countries, whereas in high-cycling countries like the Netherlands, women of working age cycle just as much, if not more, than men (Witlox, 2004). However, the nature of trips undertaken by women differs from men. Due to traditional familial roles and lower rates of employment, women are overall less likely to cycle to work than men (Heinen et al., 2010; Law, 1999). They tend to cycle to different destinations than men, accomplishing more short trips for shopping and service purposes, and multi-trip chains or service trips (Garrard et al., 2012; Prati et al., 2019). Conversely, men tend to cycle more for recreational and sports cycling than women (Heesch et al., 2012; Goodman & Aldred, 2018).

Lastly, cycling is also strongly influenced by the organization of the household. People living in households which are composed of young children tend to cycle less often and rather for recreational purposes, whereas couples who live in households without children, as well as students, tend to cycle more (Ryley, 2006). Young parents' cycling may be lower because of organizational constraints linked to parental escort trips for bringing children to school and to activities (Scheiner, 2016).

2.4.6.2 Socio-economic status: Income, education, ethnicity

Socio-economic status affects cycling through two contradicting mechanisms according to Heinen et al. (2010). In low-cycling countries, having a higher income is related to cycling more because it enables the purchase of cycling equipment and is associated with a stronger focus on personal health and recreational cycling (Dill & Voros, 2007; Stinson & Bhat, 2004). Conversely, having a low income may reduce the likelihood of cycling because of difficulties in having access to a bicycle, problems with bicycle storage, crime, and holding a negative image of cycling (Parkin et al. 2008). In Great Britain, people living in lower-income households tend to cycle less for commuting than those in high-income households (Tortosa et al., 2021).

However, higher income (and education as a proxy) is related to increased car ownership, which in turn has a negative effect on cycling for utility trips (Parkin et al., 2008; Witlox, 2004). At the population level, income has a different effect as high-income municipalities tend to have higher modal shares of cycling due to better infrastructure (Goodman & Aldred, 2018).

Ethnic background has been shown to have an effect on cycling. In the Netherlands, people of Dutch origin are more likely to cycle than those of migrant origin in the Netherlands (Harms et al., 2014; Van der Kloof, 2015; Haustein et al., 2020). Meanwhile, non-white individuals tend to cycle less in the United Kingdom (Goodman & Aldred, 2018).

2.4.6.3 Access to vehicles and transport passes

Having access to other vehicles in the household has a negative effect on cycling frequency because they compete with cycling for users' time and a limited number of trips (Pucher & Buehler, 2006; Stinson & Bhat, 2004). Owning fewer cars in the household, or none at all, is related to cycling more as a result of a lack of other transport options. However, the causality could be inversed. Some people may cycle more because they have fewer cars, or they may have fewer cars because they cycle a lot (Heinen et al., 2010). Conversely, car ownership (related to income) appears to be associated with increased recreational cycling (Goodman & Aldred, 2018).

2.4.6.4 Skills and experience

As we have seen, individuals accumulate cycling experiences throughout their life course, resulting in a "cycling trajectory" (Chatterjee et al., 2013). Having greater cycling experience is related to commuting by bicycle and increased cycling frequency (Stinson & Bhat, 2004). This may be due to a strong cycling habit, or to greater comfort or preparedness for cycling in different (and potentially adverse) circumstances (Heinen et al., 2010). Having greater cycling experience may increase cyclist's level of perceived ability, and in turn, reduce their sensitivity to barriers to cycling, which positively influences the amount of cycling. According to De Geus et al. (2007), people who have a high level of external self-efficacy (i.e. are not affected by external barriers) are more likely to cycle for transport. Similarly, perceived behavioural control and confidence in one's cycling abilities have been shown in several studies to be correlated with cycling for transport (de Bruijn et al., 2009; Heinen et al., 2011b; Emond & Handy, 2012).

2.4.6.5 Motivations

Motivations are what "moves" somebody to cycle, and can be seen as either intrinsic (cycling for its own sake) or extrinsic (related to an external goal) (Rérat, 2019). Among commuter cyclists, intrinsic motivations include *physical well-being* through exercise and staying healthy, *mental well-being* (i.e. pleasure) through the sensory experience derived from cycling and bodily movement in an outdoor environment; the ability to *disconnect from work* ; cycling as *independence*, speed and flexibility compared to the car or public transport (i.e. avoiding traffic congestion) (Rérat, 2019). Extrinsic motivations include *civic engagement* or cycling for the environment and as a way to reclaim the streets (Gatersleben & Appleton, 2007; Rérat, 2019). The lower cost of cycling compared to car use (ownership, parking, gasoline) is also an important motivation for cycling (Akar & Clifton, 2009; Damant-Sirois & El-Geneidy, 2015).

However, not all motivations have the same effect on the frequency of cycling. Being motivated by concern for the environment, or by enjoyment, has been found to be associated with cycling more (Dill & Voros, 2007; Gatersleben & Appleton, 2007; de Bruijn et al., 2009; Handy et al., 2010; Emond & Handy, 2012; Willis et al., 2015). The perceived rapidity of cycling and other "direct benefits" (time-saving, comfort, flexibility, lifestyle, pleasure), or the low cost of cycling have also been associated with regular cycling for transport (Titze et al., 2008; Heinen et al., 2011b; Damant-Sirois & El-Geneidy, 2015). Meanwhile, other motivations are associated with cycling less often. Cycling for health and physical activity concerns tends to be more associated with recreational cycling, and thus a decreased frequency of cycling (Damant-Sirois & El-Geneidy, 2015; Handy & Xing, 2011).

2.4.6.6 Barriers

In a broad sense, barriers refer to any issues or things (general or specific) which deter people from cycling. Barriers to cycling strongly depend on the relationship between the individual and the territorial context in which cycling takes place. Personal sensibility to barriers varies strongly among individuals, with people least sensible to barriers generally cycling more (De Geus et al., 2007). Barriers also vary in intensity. While long-term barriers affect cycling in general, short-term barriers only apply to certain trips or periods (Rérat, 2019).

Barriers which are more related to the person include a perceived lack of skill or confidence, health problems (age-related or otherwise), effort and physical discomfort (sweating), organizational constraints (lack of time) or logistical constraints (difficulty in carrying heavy or bulky items) (Rérat, 2019), or holding a negative image of cycling (e.g. impracticality of cycling for transport) (Titze et al., 2008; Willis et al., 2015).

Among barriers which are related to the cycling environment, long distances and hilly topography strongly influence cycling (Parkin, Ryley, et al., 2007), although they can be partly mitigated by e-bikes. One of the most important barriers to cycling is lacking perceived safety (see section 2.7), related to the risk of a collision with a car and of lacking cycling infrastructure (Rérat, 2019; Titze et al., 2007; Winters et al., 2011). Other forms of personal safety linked to crime, aggressions, also have a negative effect on cycling frequency (Heinen et al., 2010; Titze et al., 2007), as well as risk of theft (Heinen et al., 2010; Rérat, 2019). A lack of parking at home or destination may also deter from cycling (Manaugh et al., 2017).

Short-term barriers linked to specific situations or environments (perceived or objective) include conditions linked to weather (rain, ice and snow), slippery surfaces, glass/debris, absence of lighting (Winters et al., 2011). Such conditions are linked to seasonality, with many cyclists being deterred from cycling in winter (Winters et al., 2011). They may also be related to a fear of falling on the road and thus to perceived safety, and/or to health problems or age.

2.4.6.7 Image of cycling and other transport modes

Psychological theories consider that an individual's image of a travel mode affects his use. This includes the influence of perceptions (i.e. individual beliefs) and attitudes (i.e. psychological tendencies) towards cycling (Willis et al., 2015). In general, having positive perceptions or attitudes towards cycling increases the propensity of cycling (for a review, see Willis et al., 2015). Perceiving other cyclists as being normal, everyday people rather than sports cyclists is related to cycling more (Gatersleben & Appleton, 2007). Conversely, holding a negative perception of cyclists (e.g. as poor or as children) has been shown to be related to not cycling (Handy et al., 2010). Moreover, the perception of a lack of alternative transport modes, and having a need for a car, is related to lower cycling (Akar & Clifton, 2009; Emond & Handy, 2012). Holding negative attitudes towards cycling or strong pro-car attitudes is associated with cycling less for transport (Dill & Voros, 2007; Xing et al., 2010).

2.5 Cycling safety

2.5.1 Cycling safety as friction

As we have seen, the adoption of the e-bike is not an end in itself but merely a part of cycling trajectory over the life course (section 2.3). Moreover, the use of the e-bike depends on a system of vélomobility which comprises both the individual's cycling potential and the territory's hosting potential (section 2.4). To keep e-bike users in the long term, it is therefore necessary to consider the barriers which prevent its use. Cycling safety is the barrier with the most negative effect on cycling (Winters et al., 2011), and arguably the number one factor which prevents the wider population from engaging in cycling (Dill & McNeil, 2013). It represents a "friction", slowing mobility down or forcing it to stop (Cresswell, 2010). Within the system of vélomobility, safety is highly relational because it is linked to both the individual (to personal fears and negative experiences), and to the environment (a lack of cycling infrastructure, conflicting relations with motorists, or external conditions).

Cycling safety represents a lens through which to analyse cycling, both at the micro and macro levels. At the macro level, it varies to a strong degree between different contexts. Cycling safety is lacking in low-cycling contexts, while it is high in contexts where most people cycle. Thus, the level of cycling safety is also the product of power relations within space and of decades of urban planning (Koglin & Rye, 2014). Cycling safety also varies among individuals. Perceived safety does not affect all cyclists equally, depending on their profile and characteristics (age, gender for example). Consequently, cycling safety represents an important topic to observe the inequalities and differences between cyclists, and how to make cycling more equitable.

This section presents the theoretical framework related to our fifth article. It is structured as follows. We start by examining the state of research on cycling safety and define what safety represents (section 2.5.2). Thereafter, we make a distinction between objective safety or crashes (section 2.5.3), and perceived safety (section 2.5.4). Focusing on perceived cycling safety, we show how it varies between individuals and cycling environments (section 2.5.5). Lastly, we offer a critique of existing approaches to cycling safety promotion (section 2.5.6).

2.5.2 Defining cycling safety

2.5.2.1 Goals of cycling safety research

According to Jacobsen and Rutter (2012), cycling safety research has two main objectives which are pursued by different bodies of research. The first objective, pursued by medical and road safety research, is to reduce cycling crashes and their severity. This research focuses on risk, or the likelihood of cycling crashes and their causes and consequences. The second objective, pursued by transport and health research, is to increase the share of cycling by reducing the safety-related barriers which deter some groups of people from enjoying its benefits (e.g. health and sustainability). This research investigates the negative effects of a lack of safety on cycling, and the policies which could increase safety. Due to their differing objectives, these two bodies of literature have not communicated much. However, it is important to link them in order to combine measures which reduce the risk of cycling crashes, and have a positive effect on promoting cycling (Schepers, Hagenzieker, et al., 2014).

2.5.2.2 Objective and perceived safety

Cycling safety can be conceptualized as an iceberg (Juhra et al., 2012), because only the "tip", or the most serious events, are actually reported to the police, while the vast majority remain unknown. This model is also known as the Heinrich Safety Triangle (Figure 8), a gradient which considers that the most serious events are very rare, while the least serious events happen the most frequently (Heinrich, 1941, mentioned by Hamann & Peek-Asa, 2017).

Figure 8: The Heinrich Safety Triangle, or crashes as the "tip of the iceberg" of cycling safety. Adapted from Hamann & Peek-Asa (2017).

When talking about cycling safety, we distinguish two types of safety. On one hand, objective safety, which refers to crashes. On the other hand, perceived safety, which is the cyclist's subjective evaluation of safety, or the risk of cycling in a given situation (Chaurand & Delhomme, 2013).

At the tip of the triangle, objective safety is what most people see when talking about cycling safety. It refers to cycling crashes (see section 2.5.3 below). Among these are fatalities (i.e. deaths) and serious injuries[13] where hospital treatment is needed for more than 24 hours. These events represent a minority of overall crashes, and most of them are reported to police, and recorded in official statistics. By contrast, crashes which cause minor injuries or property damage are much more common but are rarely reported. Compared to cars, where most crashes are recorded for insurance purposes, the majority of bicycle crashes are not reported to the police (Juhra et al., 2012; Winters & Branion-Calles, 2017). In Switzerland, the Swiss Council for Accident Prevention (BPA) estimates that only 10% of cycling crashes are recorded in official statistics (BPA, 2019).

The broad base of the triangle represents perceived safety, a collection of subjective experiences and perceptions shared by cyclists. This domain falls outside of the scope of road safety, which has the goal of reducing crashes, but has a profound effect on the development of cycling as a practice. Perceived safety includes negative experiences such as "near-misses", a range of dangerous situations which did not result in a crash, but nonetheless heavily affect cyclists (Sanders, 2015; Aldred, 2016). Finally, the lowest level of the safety triangle is the feeling of safety related to cycling, an individual but also collective image of the danger of cycling which affects not only cyclists but the whole population.

[13] Switzerland distinguishes two separate categories: life-threatening injuries and serious injuries (BPA, 2021).

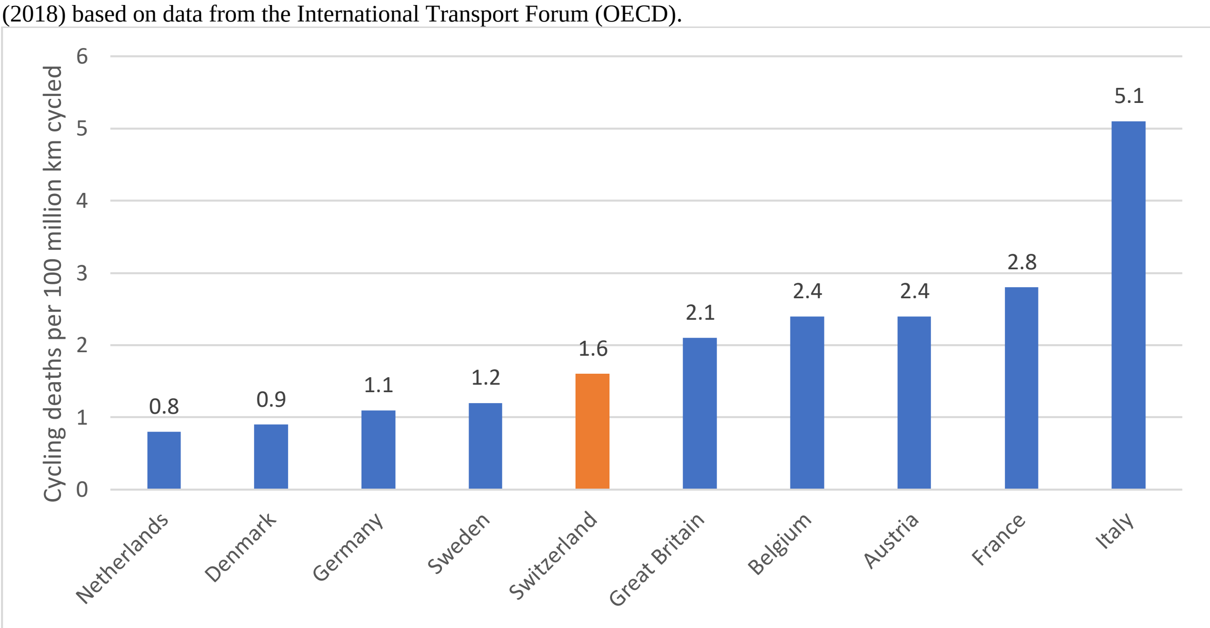
2.5.3 Cycling crashes or accidents[14]

2.5.3.1 Crash risk

In accident prevention research, safety is conceptualized as the risk of experiencing a bicycle crash. This risk represents a ratio between the number of reported crashes and the exposure to risk, in other terms, how many crashes have happened for a given quantity of cycling. Exposure can be measured as the amount of cycling traffic (volume, distance, duration), but is also sometimes measured through the volume of motorized traffic, or by a period of time or population (Götschi et al., 2016). However, using population data for exposure is highly misleading as there are large differences in the number of cycling trips between countries. In low-cycling countries, the number of cycling crashes may be very low because few people cycle at all. Rather, the ideal way to calculate exposure-adjusted risk is by using the number of kilometres travelled by bicycle, using travel census data (Götschi et al., 2018).

Because cycling crashes result from a combination of exposure to risk (i.e. the number of kilometres travelled) and crash risk, it is essential to consider exposure-adjusted measures such as the number of cycling crashes per distance travelled, rather than absolute values. Buehler and Pucher (2017) analysed exposure-adjusted risk and found that the United States had significantly higher cycling fatalities per 100 million kilometres cycled (4.7) than Germany (1.1). Severe injuries in 2008-2009 were also more frequent in the United States (207.2 per 100 million) compared to Germany (44.2). A European comparison of the risk of fatality per 100 million km cycled (Figure 9) suggests that Switzerland[15] has lower risk (1.6 deaths per 100 million km) than in neighbouring countries such as Italy (5.1), France (2.8) and Austria (2.4). However, the lowest level of risk is found in the Netherlands (0.8), Denmark (0.9), Germany (1.1) and Sweden (1.2) (Castro et al., 2018).

Figure 9: International comparison of cycling fatality rates per 100 million km cycled. Source: Castro, Kahlmeier, and Götschi (2018) based on data from the International Transport Forum (OECD).



[14] The term 'accident' is banned by the British Medical Journal because it implies random action and lack of causation - more precise terms are preferred: collision, fall, etc. (Davis & Pless, 2001)
[15] There are also important differences among Swiss cities, with a significantly lower risk of cycling in Basel (0.04) than in Lausanne (0.5) between 2009 and 2013 (Sutter, 2014).

The lower fatality rate of cycling in high-cycling countries can be attributed to a higher exposure (distance cycled), as well as the presence of separated cycling infrastructure which reduces the risk of deadly collisions with motor vehicles (Pucher & Buehler, 2008a; Pucher & Dijkstra, 2000). In the Netherlands, interactions between bicycles and cars are reduced by the structure of the road network which redirects of car traffic onto motorways rather than local urban roads (Schepers et al., 2017). However, there are large differences in crash rates within population groups, with children and older adults being overrepresented among fatalities and serious cycling injuries (Buehler & Pucher, 2017). Moreover, having a low fatality rate does not mean that all crashes are reduced, as minor cycling injuries may remain quite frequent due to falls, alcohol consumption, or distraction (as for other modes of transport) (Schepers, 2012).

An interesting phenomenon which has been observed is the "safety in numbers" (SiN) effect (Jacobsen, 2003, 2015). When the number of cyclists grows, the crash rate for bicycles follows a non-linear curve and drops rather than increasing. It is hypothesized that this increase in safety comes not from cyclists themselves, but from the changing behaviour of motorists who become more careful and accustomed to the presence of bicycles. Further studies have successfully confirmed the existence of a safety in numbers effect through different case studies, between spatial contexts and historical periods (Aldred et al., 2019; Elvik & Bjørnskau, 2017). However, the explanations for this effect have been debated. Some have suggested that the safety in numbers effect may be due to a change over time in the profile of cyclists, or to the development of cycling infrastructure related to increases in cycling levels (Wegman et al., 2012). Others have contended that the effect may only concern serious injuries and collisions with cars, but not necessarily minor injuries which might even increase, past a certain threshold, due to congestion of cycling infrastructure (Elvik & Bjørnskau, 2017). Moreover, increasing cycling levels among older age categories who are more vulnerable to injuries may actually increase crash rates for the whole population (Stipdonk & Reurings, 2012).

2.5.3.2 Factors affecting crash risk

According to the Haddon Matrix used in accident research (Haddon, 1980), crashes are not due to a single cause but the result of a confluence of circumstances involving the human, vehicle, and road, and at multiple time points (before, during, and after a crash). Schepers et al. (2014) defines cycling safety as a system which rests on interactions between three components: users (i.e. cyclists and other road users), vehicles (i.e. type of bicycle, accessories), and infrastructure and regulations (i.e. cycling infrastructures, standards and legal requirements). Users are subject to human factors including driving behaviour, physiological state (e.g. alcohol or drug use), but also age, with children and older adults more prone to cycling crashes (Schepers, Hagenzieker, et al., 2014).Vehicle-related factors include the size and type of vehicle present (e.g. car, bus, truck, bicycle or e-bike), and its condition. Infrastructural factors include the type of road, intersection or bicycle facility, but also traffic conditions (volume and speed) and environmental conditions (weather) (Vandenbulcke et al., 2014).

Cyclists are overrepresented in crashes happening at intersections, and especially roundabouts (Daniels et al., 2008; Reynolds et al., 2009). Roundabouts with multiple lanes and a small central island which encourages higher speeds pose an increased risk for cyclists (Brüde & Larsson, 1993; Reynolds et al., 2009; Schoon & van Minnen, 1994). Car drivers tend to focus their attention on visual information about cars, which present a greater risk to them, rather than cyclists (Summala et al., 1996). Even when looking into the cyclists' direction, drivers approaching a roundabout may not detect the cyclist, a situation known as "looked-but-failed-to-see" incidents (Herslund & Jørgensen, 2003). Traditional intersections with or without traffic lights are more dangerous for cyclists as their size and width increases, with increasing numbers of lanes for motor traffic (Reynolds et al., 2009; Y. Wang & Nihan, 2004). The main risk for cyclists at intersections comes from motorists turning and crossing cycle lanes (Vandenbulcke et al., 2014). Motorists often fail to yield to bicycles at intersections when stopping or turning right at a traffic light. To force motorists to slow down when turning at junctions, raised bicycle crossings have proved an efficient solution (Garder et al., 1998; Reynolds et al., 2009). Another possibility is to make cyclists more visible to motorists, such as by using coloured markings (Jensen, 2008; Reynolds et al., 2009), or to move cycle tracks closer to motorized traffic (Thomas & DeRobertis, 2013).

Cycle tracks or paths which are separated from traffic generally offer lower risk of crashes than cycle lanes which are adjacent to traffic (Teschke et al., 2012). Two-way tracks pose a greater danger for cyclists because motorists tend to look in only one direction when crossing them (Räsänen & Summala, 1998; Thomas & DeRobertis, 2013). Cycle lanes with adjacent parking, or parking entrances/exits are also less safe due to a risk of dooring (Teschke et al., 2012; Vandenbulcke et al., 2014).

In general, greater volumes of car traffic has a negative effect on cycling safety (Aldred et al., 2018; Teschke et al., 2012; Vandenbulcke et al., 2014). Local streets with lower speeds and volumes have a lower crash risk for cyclists (Teschke et al., 2012). Meanwhile, the increased presence of other cyclists is related to lower crash risk due to the safety in numbers effect (Aldred et al., 2018).

Single-vehicle crashes, in contrast to collisions, refer to crashes involving just the cyclists themselves, such as falls or slippages. It is estimated that single-vehicle crashes account for 60% to 95% of cyclists admitted to hospital depending on the country (Schepers et al., 2015). However, these crashes may be related to cycling infrastructure (Schepers & Wolt, 2012), such as the quality of the pavement or the presence of ice (Nyberg et al., 1996), poor visibility and road lighting (Reynolds et al., 2009; Schepers & den Brinker, 2011; Twisk & Reurings, 2013), road characteristics including width, bends, gradient, and surface conditions, lack of central splits or one-way streets (Reynolds et al., 2009), the presence of crossings, tunnels, bridges or obstacles such as public transport stops (Teschke et al., 2012).

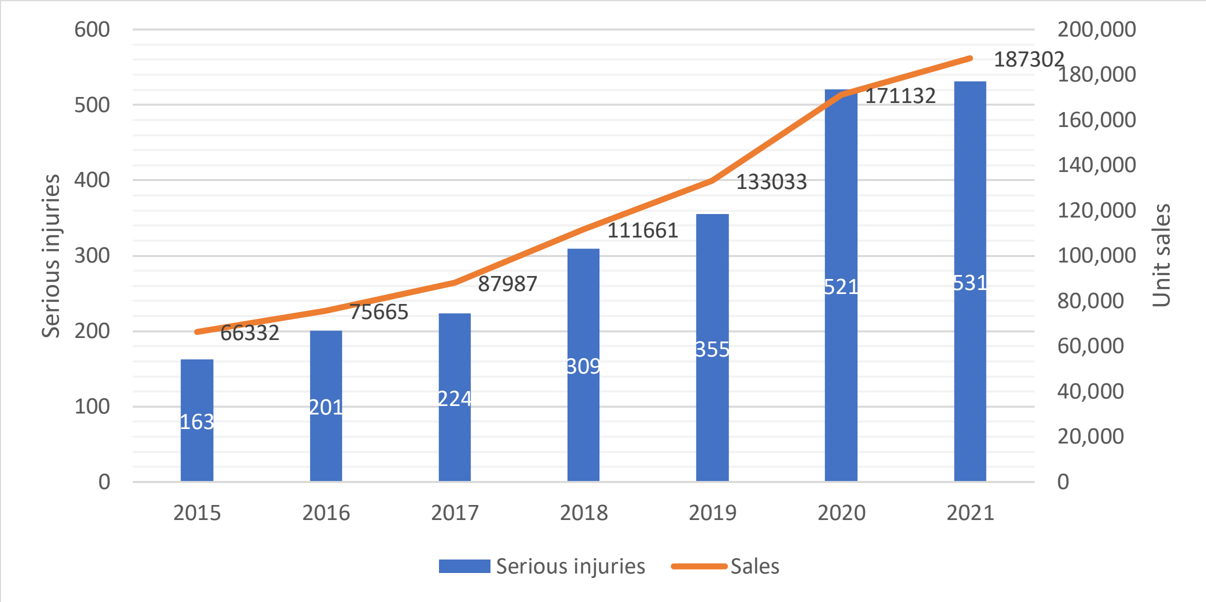
In a majority of bicycle crashes in Switzerland, statistics suggest that the responsibility lies within the cyclist himself (OFROU & OFS, 2022). However, once single-vehicle crashes are excluded, which include crashes at night due to darkness, alcohol, or inadequate infrastructure, cyclists are not at fault in three out of four collisions with other road users, especially cars (Bosshardt, 2016). This is especially true at roundabouts where one third of all collisions involve cyclists, and where 86% of collisions involving cyclists are due to other road users (mostly cars) not respecting their right of way (BPA, 2021).

2.5.3.3 E-bike crashes

In Switzerland, the number of e-bike crashes between 2015 and 2019 increased for serious injuries (+118%) as well as for minor injuries (+111%). However, when compared to the growth in e-bike sales, which have grown by +101% e-bike crashes follow a similar curve (OFROU & OFS, 2020; Velosuisse, 2020) (Figure 10).

Most research on e-bike safety has focused on crashes, because of a higher crash rate than conventional bicycles (Schepers, Fishman, et al., 2014). Most e-bike crashes have been found to be “single-vehicle crashes” where no other vehicle is considered to be involved (Hertach et al., 2018; Schepers, 2012). Compared to conventional cyclists, individual crashes due to loss of control are more frequent for e-bike users, likely due to a higher speed, acceleration, combined with a greater weight (Hertach et al., 2018). Slipping or crossing a threshold such as a tram track is the most frequent type of crash recorded in Switzerland (Hertach et al., 2018).

Figure 10: Comparison between serious e-bike injuries and sales in from 2015 to 2021. Data: OFROU & OFS (2022), Velosuisse (2022)



2.5.4 Perceived safety

Objective safety measured through crash statistics alone is not enough to understand cyclists' experience of safety. Perceived safety can be defined as a subjective evaluation of the risk of cycling in a given situation (Chaurand & Delhomme, 2013). Cyclists' feeling of safety is related to a "fear of traffic" and of a potentially deadly collision with a motorized vehicle (Jacobsen & Rutter, 2012). According to Jacobsen et al. (2009), motor traffic is responsible for the danger of cycling : "The real and perceived danger and discomfort imposed by traffic discourage walking and bicycling" (Jacobsen et al., 2009, p. 369). The presence of cars, and higher speeds and volumes of traffic, are associated with decreases in walking and cycling (Jacobsen et al., 2009).

Low perceived safety is one of the main barriers preventing people from cycling more frequently (Akar & Clifton, 2009; Heinen et al., 2010; Winters et al., 2011). Moreover, lacking safety impacts not only existing cyclists, but also a larger part of the population (i.e. potential cyclists) who do not currently cycle, resulting in their "fear-based exclusion" (Chataway et al., 2014). Perceived safety affects cyclists' route choice, on-road behaviour and road positioning (Manton et al., 2016). It could be argued that perceived safety is a better indicator of cyclists' experiences than crash statistics, as most crashes are under-reported and exposure-adjusted data is lacking in many places. Perceived safety is also affected by experiences of crashes, although they have differing effect. While falls due to a loss of control have relatively little effect on perceived safety, crashes involving a vehicle have a traumatic effect on a person's motivation to cycle, even when they only involve an acquaintance rather than the person itself (Lee et al., 2012).

On a theoretical level, risk perception is composed of both a cognitive dimension and an emotional dimension (Møller & Hels, 2008). The cognitive dimension is an assessment of the risk of a crash in a given situation, which cyclists tend to overestimate for collisions with motor vehicles compared to other kinds of crashes (e.g. falls), because they are out of the person's control (Schepers et al., 2020). Meanwhile, the emotional dimension refers to "risk as a feeling" (Slovic et al., 2004), or a fear of motorized traffic. This fear is related to different situations. Firstly, it refers to a lack of safety due to the volume and speed of motorized traffic, and lack of bicycle facilities to escape from it (Dill & Voros, 2007; Winters et al., 2011). Secondly, a fear of encountering dangerous behaviour from motorists (Winters et al., 2011). Thirdly, a fear of cycling in certain conditions such as snow, ice, or unlit streets, which is related to the fear of falling on the road while other motorized vehicles are present (Winters et al., 2011). Fourthly, a fear of being harassed or judged, of showing one's body in public, and of being discriminated against, which particularly affects women or ethnic minorities (Aldred, 2013a; Heesch et al., 2011; Horton, 2007; O'Connor & Brown, 2010; Prati et al., 2017). This is what Horton (2007) calls the "fear of cycling" as a social construction related to the broader stigmatization of cyclists in society.

2.5.4.1 Near misses and dangerous situations

Every day, cyclists experience a range of situations or behaviours which could potentially lead to crashes, and which shape their perception of safety. The frequency of these risky situations has been found to be much higher than for other road users (Joshi et al., 2001; Joshi & Smith, 1992). Near misses include situations such as dooring, hooking, close passes, driving at, and being blocked by a vehicle or object (Aldred, 2016). They are estimated to happen much more frequently than crashes and thus may play a larger role in shaping cyclists' perception of safety (Aldred, 2016; Sanders, 2015). Moreover, almost all cyclists are affected by them, including infrequent cyclists. The emotional consequences of near misses go beyond fear of injury, as they highlight the lack of recognition of cyclists by other road users and threaten their identity as legitimate road users (Aldred, 2016).

Most near misses or "safety critical events" were found to be related to other road users (either a motor vehicle, a pedestrian, or another cyclist) while a minority were related to the infrastructure or an object blocking the road (Werneke et al., 2015). These events happen more often at intersections, where a building or object blocks the field of view, on ill-maintained roads, and at pedestrian and cycle crossings (Dozza & Werneke, 2014; Werneke et al., 2015). Some of these events may also happen on cycle tracks or paths shared with pedestrians (Schleinitz et al., 2015). For e-bikes, the risk of conflicts is twice as high as for conventional bicycles at intersections as a result of failure to yield from other road users (Schleinitz et al., 2014). This is linked with the underestimation of e-bikers' speed when approaching an intersection, which leads motorists to accept small gaps when crossing (Petzoldt, Schleinitz, Krems, et al., 2017).

Lastly, other situations which affect perceived safety include inattention by motorists, aggressive behaviours – physical or verbal harassment (Lawson et al., 2013; O'Connor & Brown, 2010; Sanders, 2015). Harassment of cyclists is particularly common in countries with low cycling rates such as Australia (Heesch et al., 2011).

2.5.4.2 Coping strategies

Cyclists adopt different coping strategies as a way to deal with perceived cycling safety and a lack of infrastructure. Unfortunately, many cyclists resort to avoiding to cycle in certain situations (e.g. in mixed traffic or at rush hour) (Aldred, 2016; Chataway et al., 2014; Kaplan & Prato, 2016; O'Connor & Brown, 2010). The opposite strategy consists in asserting one's place on the road and confronting danger, for example by riding in the middle of the road, which is riskier and leads to confrontations with motorists (Aldred, 2016; Kaplan & Prato, 2016; O'Connor & Brown, 2010). Another strategy is minimizing risk, for example by increasing vigilance, cycling on the pavement rather than the road, wearing helmets and high-visibility clothing, or riding in groups rather than alone (Aldred, 2016; Kaplan & Prato, 2016; O'Connor & Brown, 2010). However, for some cyclists, this may be seen as an acceptance of the current situation and a form of resignation (Kaplan & Prato, 2016; O'Connor & Brown, 2010).

Depending on their coping strategies, cyclists can be grouped into three types (Rérat et al., 2019): cautious cyclists, who seek to avoid hazards[16], foresighted cyclists, who adapt their behaviour to conditions by making a trade-off between safety and speed, and confident cyclists, who do not hesitate to assert their place in traffic (Rérat et al., 2019).

2.5.4.3 The role of infrastructure for perceived safety

The type of cycling infrastructure affects how safe cyclists feel. Cyclists' level of perceived safety can be measured through their preferences for certain kinds of infrastructure, their level of comfort or ease when using them, their feeling of safety associated with a type of facility, their perceived safety on a route, and their perceived risk of having an accident.

The perceived safety for cycling in a street is linked to the speed and volume of motor traffic, width of a street, number of lanes, or presence of parked cars (Sorton & Walsh, 1994; Parkin, Wardman, et al., 2007). Generally, cyclists generally prefer infrastructure that is separated from traffic, in other words, cycle paths rather than painted cycle lanes (Heinen et al., 2010). Visual separation from motor vehicles (cycle lanes) is less effective at improving perceived safety than physical separation (cycle paths or tracks) (Parkin, Wardman, et al., 2007; K. Wang & Akar, 2018a).

Intersections are considered less safe if they have higher complexity (i.e. more lanes), greater traffic volumes, and lack regulated traffic signals (Von Stülpnagel & Lucas, 2020; K. Wang & Akar, 2018b). Intersection facilities such as raised crossings, bicycle lanes and indirect left turns, as well as traffic calming measures such as crossing islands, chicanes and mini-roundabouts, and the presence of trees and greenery, all increase perceived safety (K. Wang & Akar, 2018b). Roundabouts are considered safer by cyclists if they have separated bicycle facilities and lower car traffic volumes (Møller & Hels, 2008). For some scholars, the presence of bicycle facilities in itself does not improve perceived safety (Parkin, Ryley, et al., 2007; Von Stülpnagel & Lucas, 2020). Rather, the most decisive for perceived safety is the volume of traffic and number of parked cars on the route, with traffic-free routes considered the safest.

Comparisons between objective safety (i.e. risk of crashes or critical incidents) and perceived safety, have found both to be strongly correlated. Thus, the type of road considered to be the most dangerous objectively and subjectively are main roads with strong traffic without cycling infrastructure, while cycle paths which are entirely separated from traffic are the safest (Teschke et al., 2012; Von Stülpnagel & Lucas, 2020). However, cyclists tend to underestimate the risk of falling (i.e. single-vehicle crash) when cycling on a separated bike path (Teschke et al., 2012).

Perceived safety may also be affected by external conditions (weather, road surface) and seasonality. Winter conditions (ice and snow, slippery surfaces and lack of lighting) detract many cyclists from cycling and increase the perceived risk of cycling (Kummeneje et al., 2019; Winters et al., 2011). However, as we have seen previously (see 2.4.5.3), the effect of weather depends on the cycling culture, with several northern cities having high winter cycling rates regardless of cold weather.

[16] However, this behavior can turn out to be more dangerous, such as when a cyclist positions himself too close to the edge of the road.

2.5.5 Individual differences in perceived cycling safety

Perceived safety differs strongly among cyclists depending on their age, gender, level of experience, and personal preferences. A famous typology in Portland (Oregon, USA) Geller (2006) classified the population into four groups depending on their interest in cycling and their requirements in terms of cycling infrastructure (measured as their level comfort). One third of the population would not cycle under any circumstances, because of a lack of interest or a perceived inability ("no way no how"). At the opposite end, a small group (less than 1%) were "strong and fearless" and would cycle even without any infrastructure. A slightly larger group (7%) were "enthused and confident" who were willing to cycle in current conditions, despite infrastructure that was not separated from traffic. Finally, the majority (60%) of the population, including both existing and potential cyclists, was "interested but concerned" by current cycling conditions, and preferred infrastructure separated from traffic[17]. This safety-conscious population was considered to hold the highest potential for increasing cycling, and to be the preferred target of policies to increase cycling (Dill & McNeil, 2013).

2.5.5.1 Gender

Gender differences between women and men's cycling experience (see section 2.4.6.1) extend to cycling safety. The rate of women cycling in a given context is considered to be indicative of cycling safety conditions (Baker 2009 cited in Garrard, Handy, and Dill 2012). Women are underrepresented among cyclists in countries where fewer people cycle, and equally or overrepresented in high-cycling countries (Buehler & Pucher, 2012b; Pucher & Buehler, 2008b). Because of this gender gap, most studies on gender differences in cycling safety have been undertaken in low-cycling countries, and it is possible that these differences are less important in high-cycling contexts. Compared to men, women have been found to express greater concern for cycling safety, have stronger preference for infrastructure separated from traffic (cycle paths), and to report lower levels of comfort for cycling in a diversity of infrastructure types (Aldred et al., 2017; Garrard et al., 2008).

These differences have been explained by the hypothesis that women have a greater aversion to risk, and are more likely to prioritize safety rather than other criteria such as speed when choosing a cycling route (Emond et al., 2009; Garrard et al., 2012).. To some extent, they may reflect a response bias whereby women tend to express lower confidence in their own skills, while men tend to repress their fears and over-evaluate their cycling abilities (Garrard et al., 2012). An additional explanation may be that women cycle on different routes than men, who often use commuting routes where more cycling infrastructure is present (Garrard et al., 2012). More generally, gender differences in cycling safety are also representative of underlying gender inequalities in society (Law, 1999), and specifically, of a different relationship to public space. Women who cycle are more likely to be harassed and judged for exposing their body in public, and to fear for their personal safety (Garrard et al., 2012; Heesch et al., 2012). Lastly, women's lower cycling safety may be linked to gendered socialization to cycling (see section 2.3.2.2). Emond, Tang, and Handy (2009) suggest that women are less confident because they have been given fewer opportunities for experiencing cycling during childhood than men.

2.5.5.2 Age

Perceived cycling safety varies significantly depending on age. Older adults above the age of 65 have higher crash rates because of their reduced visual capabilities and slower reaction times, as well as

[17] A post-survey assessed the respective shares of each group in the Portland population as follows: Strong and fearless: 6%, confident and enthused: 9%, interested but concerned: 60%, no way, no how: 25% ((Dill & McNeil, 2013, 2016).

lower muscle mass (Van Cauwenberg, de Geus, et al., 2018). They are more vulnerable in case of a cycling crash and overrepresented among cycling fatalities (Buehler & Pucher, 2017; Van Cauwenberg, de Geus, et al., 2018). Cycling in motorized traffic has been identified as a major concern for older cyclists (Van Cauwenberg, Clarys, et al., 2018; Winters et al., 2015; Zander et al., 2013). Like other age groups, they prefer to cycle in physically separated infrastructure (Aldred et al., 2017; Van Cauwenberg, De Bourdeaudhuij, et al., 2018; Winters et al., 2015). According to Chataway et al. (2014), older people are more likely to adopt avoidance strategies for cycling, choosing when and where to cycle. In contrast with younger cyclists, older adults do not only fear motorized traffic, but also interactions with other cyclists and pedestrians, which might cause them to fall (Winters et al., 2015).

2.5.5.3 Experience

Greater frequency of cycling and cycling experience increase one's confidence and perception of safety. Infrequent cyclists are more fearful of cycling in mixed traffic and prefer separated paths (Chataway et al., 2014). Meanwhile, regular cyclists who cycle often are less influenced by safety in their motivation to cycle (Sanders, 2015). However, experienced cyclists are also more exposed to risk, more likely to have had a bicycle crash and to be sensitive to detecting dangerous situations (Lehtonen et al., 2016; Sanders, 2015). According to Sanders (2015), cyclists have two types of fears. Novice or potential cyclists have a general fear of motorized traffic, whereas experienced cyclists have specific fears related to specific situations and experiences. This explains why cycle lanes increase existing cyclists' perceived safety, but have little effect on non-cyclists (K. Wang & Akar, 2018a).

2.5.5.4 E-bike users

Few studies have focused on e-bikers' perceived safety. Studies on e-bike users' experiences suggest that e-bikes help people feel safer than with conventional bicycles, due to the ability to keep up with the flow of traffic and accelerate from a stop (T. Jones, Harms, et al., 2016; Popovich et al., 2014; Rose, 2012). However, e-bikers may feel less safe when approaching an intersection, because they know that motorists tend to misjudge their speed (T. Jones, Harms, et al., 2016; Popovich et al., 2014), which has been shown to provoke crashes (Petzoldt, Schleinitz, Heilmann, et al., 2017). In Denmark, Haustein & Møller (2016b) found higher perceived safety among e-bike users was related to male gender, excitement of e-bike use, a riding style similar to that of conventional cycling, and greater e-bike experience. Meanwhile, lower perceived safety was associated with being female, older than 60, and cycling on longer distances.

2.5.6 Criticism of cycling safety policies

Approaches to cycling safety in Great Britain (but arguably also in other contexts) has been critiqued for their focus on individual safety solutions targeting cyclists (e.g. helmets, high-vis), and campaigns which have a tendency for victim-blaming cyclists (Aldred & Woodcock, 2015; Jacobsen et al., 2009). Road safety campaigns tend to portray cycling as a dangerous leisure activity, during which individuals are responsible for the risks they take, rather than a legitimate mode of transport (Aldred, 2012; Jacobsen et al., 2009). Even road safety education for children and helmet promotion campaigns may play a role in instilling a fear of cycling by constructing it as a dangerous activity (Horton, 2007). This reflects a broader marginalization of cycling in the context of the dominance of the automobile (Aldred, 2012; Koglin & Rye, 2014). Personal protective equipment may reduce the severity of injuries in the event of a crash, but it does not eliminate the danger which motorized vehicles pose for cyclists. Most cyclists see personal protective equipment as an impractical obligation linked to being considered as responsible cyclists, but do not feel any safer thanks to it (Aldred & Woodcock, 2015).

An extreme example of an individual safety measure is mandatory helmet laws for cyclists, which were introduced in Australia and New Zealand in the 1990s and have been debated fiercely within the scientific community ever since (Olivier et al., 2014, 2016; Radun & Olivier, 2018; Robinson, 1996, 2001, 2007). While helmets reduce the severity of head injuries when cycling, they are more effective for individual crashes than for collisions with motor vehicles (Hoye, 2018; Olivier et al., 2014, 2016, 2019; Olivier & Creighton, 2017; Radun & Olivier, 2018).

However, the main argument against mandatory helmet laws is that they reduce the attractiveness of cycling. Indeed, in high-cycling countries such as the Netherlands or Denmark, very few people feel the need to wear helmets (Pucher & Buehler, 2008b). Decreases in the number of cyclists have been observed at the introduction of this measure in Australia (Hoye, 2018; Robinson, 1996), although the long-term effects may be difficult to judge because there has been an overall increase in cycling in these countries since then (Olivier et al., 2016).

The introduction of such a measure may also lead to a change in the profile of cyclists, by favouring cycling as a sports practice, which would increase risk among cyclists (Fyhri et al., 2012). Furthermore, if such a measure were to cause a decrease in the number of cyclists, this would reduce the "safety in numbers" effect for remaining cyclists (Jacobsen, 2015). Some scholars have also suggested that mandatory helmet use might incite motorists to change behaviour, for example by overtaking closer, with one study showing that motorists were more careful when overtaking cyclists not wearing a helmet (Walker, 2007). Lastly, it is feared that such a measure could result in additional risk taking on the side of the cyclists, compensating for the additional safety provided (Adams & Hillman, 2001; Fyhri et al., 2018; Hedlund, 2000), although this has been disputed as those taking the most risks tend not to wear helmets (Hoye, 2018).

More importantly, from a population health perspective, the physical activity benefits of increased cycling (and less driving) trump those of a reduction in cycling crashes (Götschi et al., 2016, 2018). Therefore, a reduction in head injuries would not compensate for the negative effect in terms of physical activity resulting from a decrease in cycling and a potential shift towards motorized modes (De Jong, 2012; Fyhri et al., 2012; Grant & Rutner, 2004; Robinson, 2006). From a cycling standpoint, such individualized safety approaches create a climate of fear around cycling which contributes to making cycling seem unattractive, complicated and dangerous (Aldred & Woodcock, 2015; Horton, 2007). This contributes to a vicious circle of cycling by discouraging potential cyclists and worsening conditions for existing cyclists (Jacobsen & Rutter, 2012).

As a response to the shortcomings of current cycling safety approaches, Aldred & Woodcock (2015) have called for a move away from individual strategies such as personal protective equipment, towards population-level approaches such as cycling infrastructure and the promotion cycling as a "normal" activity. A rethinking of cycling safety approaches would require a more systemic approach of safety, where cycling is no longer considered as an individual activity, but as a system which must be designed to make cycling a safe practice for all. Such an approach was adopted in 1992 in the Netherlands under the name "sustainable safety vision". This strategy aims to ensure that the infrastructure reduces the risk of serious cycling crashes to zero, through a series of measures including a hierarchical road network, avoiding differences in speed and mass, predictability of infrastructure, forgiveness of human behaviour, and state awareness or helping users to estimate their ability (Koomstra, 1994; Wegman et al., 2008, 2012). This new approach to cycling safety confirms the need to consider cycling within a system, rather than as an individual activity (see section 2.4).

3. Methodology

This chapter presents the context, data and methods used in this thesis. It is structured as follows. We start by presenting the spatial context for this study, the city of Lausanne, Switzerland (section 3.1). We then present our methodological approach, which combines quantitative and qualitative data (section 3.2). The project within which our data was collected is presented in section 3.3. The quantitative data, consisting of a survey of e-bike users, is detailed in sections 3.4 (survey and recruitment), 3.5 (participants and main results) and 3.6 (analysis). For the qualitative data, the biographical interviews conducted with e-bike users are presented in section 3.7.

3.1 Study context: Lausanne

This thesis was conducted in Lausanne, the fourth-largest city in Switzerland with a population of 140'000 inhabitants (Canton of Vaud, 2018) and an urban area of about 415'000 inhabitants in 2017 (FSO, 2018). Located in the French-speaking Canton of Vaud in the south-western part of Switzerland on the shore of lake Léman, the city has the reputation of being notoriously hilly. Its elevation ranges from 373 metres above sea level to 600 metres within the city centre, where most of the population is located, and up to almost 900 metres in its highest neighbourhoods (Figure 11). For this reason, the city offers an interesting setting for e-bikes, which can help to overcome the topographical limitations of the city for cycling. An additional reason for conducting the study in Lausanne is my own experience of living and cycling in the city. Moreover, I had already previously studied the subject of e-bikes in Lausanne during my masters' thesis (Marincek, 2015).

Figure 11: Municipality of Lausanne (in grey), with contour lines for altitude. Note the territory extending to the North-east and the enclave in the North-west. Data: Canton of Vaud, Federal Office of Topography.

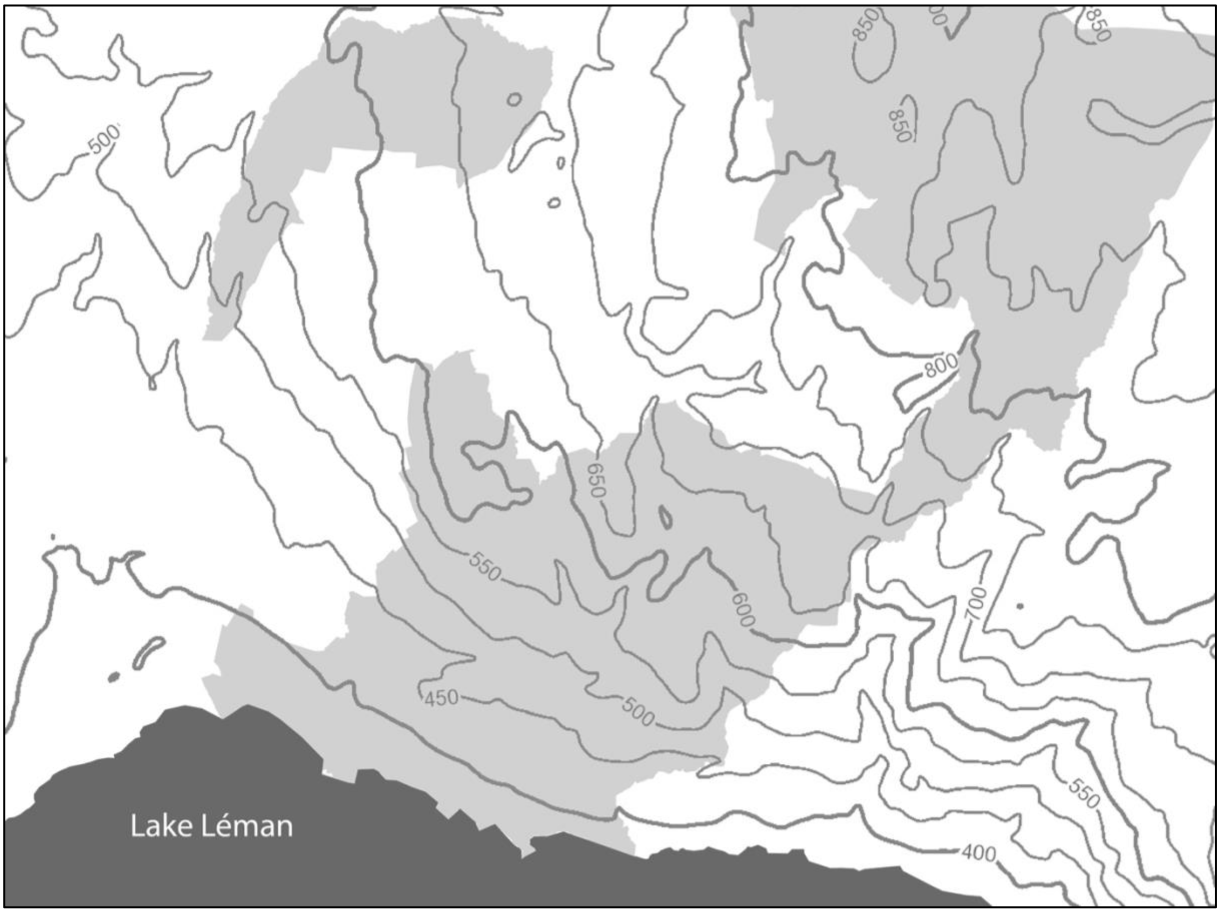
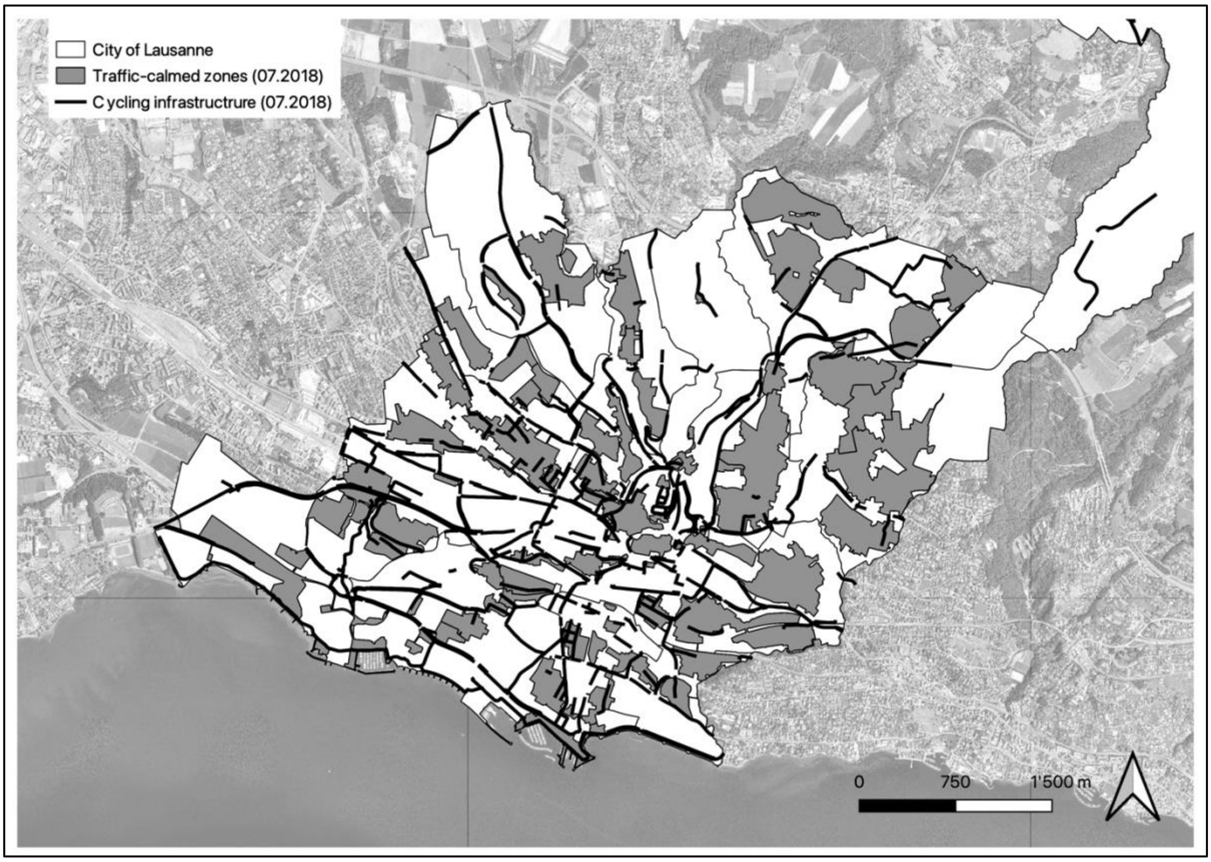


Figure 12: Close-up of the city of Lausanne with cycling network and traffic-calmed zones in 2018. Data: City of Lausanne and Federal Office of Topography.



Lausanne is a low-cycling city. According to the last available travel census data from 2015, it holds the lowest mode share of cycling among large cities in Switzerland. Only 1.6% of trips were made by bicycle in 2015 compared to the national average of 7%, much less than in other large cities in the German-speaking part of the country such as Basel (17%), Berne (15%) or Zurich (12%) (FSO & FOSD, 2017).

As a low-cycling city, several surveys attest that cycling conditions remain precarious. In a nationwide study of bicycle commuters, Lausanne ranked last for safety among 24 cities in the country (Rérat, 2021a; Rérat et al., 2019)[18]. One third (34%) of cycle commuters did not consider themselves safe (compared to 14% nationally) and over half (55%) did not feel respected by other road users, compared to 32% nationally. Still, this result likely understates the lack of safety, because only adults of employment age were surveyed (and not vulnerable groups such as older adults, children and teenagers) and because many participants used avoidance strategies (e.g. avoiding cycling during rush hour, in winter, on certain routes) (Rérat, 2021c, p. 12). Similarly, in the Swiss cycling cities survey "Villes cyclables"[19], Lausanne was the second-lowest city in terms of perceived safety, with only 34% of respondents agreeing to feeling in safety when cycling, compared to two thirds at the national level, and up to 84% in Basel and 80% in Berne.

Another sign of the city's recent cycling culture is the low rate of bicycle and e-bike ownership among the city's population, compared to the national average. In the 2015 mobility census, 3.1% of the

[18] The study was conducted in 2016 among 13'744 participants to a program called "Bike to work".
[19] The survey was conducted by the Swiss cyclists' federation (PRO VELO) and included 16'700 respondents.

households in the city owned an e-bike (2.4% a pedelec and 0.6% a speed-pedelec), compared to the national average of 7% (FSO & FOSD, 2017). Similarly, only 41.7% of households in the city owned a conventional bicycle compared to 65% nationally (FSO & FOSD, 2017). This reflects a cultural divide in cycling culture. Within the country, Lausanne is located in the French-speaking part which has traditionally had lower modal shares of cycling than the German-speaking part. Accordingly, the highest levels of e-bike ownership are in the German-speaking part of the country, as well as in rural areas rather than urban centres (Marincek et al., 2020; Ravalet et al., 2018).

The development of cycling policies in Lausanne is a recent affair, although much progress has been made of late. Most of the cycling infrastructure in Lausanne was built in the last decade. The length of cycle lanes in the city grew from only 9.8 km in the year 2000 to 71.5 km in 2019[20] (Ville de Lausanne, 2020b). However, there remain many gaps in the cycling network (Figure 12). Cycling infrastructure mostly consists mainly of on-road cycle lanes, with little physical separation from traffic provided. Things have changed in the years since the data for this thesis was collected in 2018, as there have been significant developments in the cycling network at the municipal and regional level.

3.2 Methodological approach

Qualitative and quantitative data have their own advantages and disadvantages. Quantitative data help to measure things ("how much") and are necessary to detect underlying trends within a population or sample, to test hypotheses or analyse associations between multiple factors, and to achieve statistical significance, but fail to take into account individual specificities or contextual elements. Qualitative data, meanwhile, can assess the quality of a relationship ("why") and offer a deeper understanding of the individual's strategies, experiences, and representations, which are crucial to understanding relations of causality, but are unable to provide results which can be generalized.

Mixed method research which combines both approaches, "provide(s) the strengths that offset the weaknesses of both quantitative and qualitative research" (Creswell & Clark, 2017, p. 12). This thesis uses a mixed-method approach with the goal of providing a greater number of viewpoints to e-bike adoption, and ultimately, providing more results. A further goal was to learn how to use two different research methodologies throughout the course of the thesis.

The qualitative and quantitative data used in this thesis were collected in a multiphase research design, as part of a broader e-bike project described below. The quantitative data was collected through a large-scale survey of 1466 e-bike users in Lausanne. Qualitative data was collected in 24 biographical retrospective interviews with e-bike users. The articles included in this thesis are based on both qualitative data (articles 1 and 3) and quantitative data (articles 4 and 5). Meanwhile, article 2 combines both qualitative and quantitative datasets in an "exploratory" mixed-method design (Creswell & Clark, 2017). Next, we describe the project through which our data was collected.

3.3 E-bike project

The data for this thesis was collected through a project funded by the Industrial services department of the city of Lausanne (Services Industriels Lausannois - SiL) through their "fund for energy efficiency" ("Fond pour l'efficacité énergétique").

[20] No data is available for the length of cycling infrastructure in 2018.

3.3.1 E-bike subsidy

The SiL offer a subsidy for the purchase of an e-bike, as well as for the purchase of a separate e-bike battery. The value of the subsidy has changed over time, but at the time of the survey (2018), was set at 15% of the price of an e-bike, with a maximum of 500 Swiss Francs. The smaller subsidy for the purchase of an e-bike battery was worth 100 Swiss Francs[21]. The conditions required to apply for the subsidy included (1) being a legal resident of the city, and (2) buying an e-bike in a physical shop (not online) located in Switzerland[22]. The goal of the subsidy was to encourage the adoption of e-bikes, both to trigger the decision to buy an e-bike, and as a way of helping low-income households afford the cost of one (an average e-bike costs 3'000 Swiss Francs). The subsidy was well known among the population as it had been running for over fifteen years. Given the fact that the subsidy represented a major selling point when buying an e-bike (a 15% discount), it was systematically proposed in cycle shops in the city and was thus well known.

3.3.2 Objectives of the project

The subsidy programme offered by the SiL for e-bikes (as well as for e-scooters) has been in place since the year 2000, well before the current e-bike "boom", which started around the year 2008 in Switzerland. More than four thousand (4'000) subsidies had been given out since this time, half of them between 2014 and 2018. However, this subsidy programme had not been the object of a formal study, and little was known about who e-bike users were, and how e-bikes were being used. At the same time, the success of e-bikes was becoming visible in the streets of Lausanne. Thus, the Institute for geography and Sustainability of the University of Lausanne approached the SiL with the proposition to launch a project called "The practice of the e-bike in Lausanne" ("La pratique du VAE à Lausanne"). This project identified five research questions:

- **Profile**: What are the characteristics of e-bike users? Has there been a diffusion to new audiences since the first wave of users?
- **Equipment**: What is the level of e-bike equipment? Which buying criteria were taken into account? Which other modes of transport do users own?
- **Uses**: How are e-bikes used? What is the place of e-bikes within people's mobility? How did the e-bike affect their travel patterns?
- **Motivations and barriers**: What are the motivations for buying an e-bike? What are its triggers in the individuals' biography? Which reasons motivate the use of an e-bike? Which advantages does the e-bike hold over conventional cycling? Which barriers are there to e-bike use in terms of conditions, logistics, and technical constraints? What was the impact of the subsidy of the city of Lausanne?
- **Experiences**: What are the skills of e-bike users, both in terms of comfort levels when cycling, and in terms of physical and mechanical abilities? How is e-bike use experienced in Lausanne?

The aim of the e-bike project was to understand how the subsidy was being used, and to gain knowledge about e-bike users and their uses, with the goal of accompanying the development of e-bikes in the city of Lausanne. To answer these questions, the project proposed two main approaches. On one hand, a quantitative analysis of e-bike users through a survey of e-bike owners, as well as an analysis of e-bike use in the Swiss micro-census on mobility and transport 2015 (FSO & FOSD, 2017). On the other hand,

[21] A separate subsidy for the purchase of electric scooters (mopeds) also exists, which has not had the same success

[22] The survey revealed that 79.5% had bought their e-bike in the city, 10.4% in the urban area, 5% in the region (Canton of Vaud), and 5.2% elsewhere in the country.

a qualitative analysis of e-bike users and their mobility biographies and experiences in Lausanne, through a series of interviews with e-bike owners.

3.3.3 Personal implication

Three people were implicated in the e-bike project from 2018 to 2020 within the Institute for Geography and Sustainability: Prof Patrick Rérat (project applicant), Dr Emmanuel Ravalet, and myself (Dimitri Marincek), alongside with the IT department of the University of Lausanne who helped to set up the online survey, and two assistant students who helped with data input.

My implication in the project consisted, for the quantitative part, in assisting in the development of the questionnaire survey alongside Prof Rérat and Dr Ravalet, collecting the postal surveys, and responding to inquiries by participants. The preparation and statistical analysis of the survey data was mainly done by Dr Emmanuel Ravalet, with assistance from myself. We both drafted the survey report and literature review on e-bikes under the supervision of Prof Rérat. For the qualitative part of the project, I was solely responsible for the interviews with e-bike users, including transcribing and analysing the data, and drafting the results in the final report (Marincek et al., 2020).

Lastly, I presented alongside both Dr Ravalet and Prof Rérat the results of the study to the members of the committee responsible for accompanying the research, which included two members of the SiL, a municipal bicycle planner within the roads and mobility section of the city of Lausanne, two members of NGOs active in the field of mobility (Association transports et environnement – ATE) and cycling advocacy (PRO VELO), as well as the owner of a bicycle shop in the city (Tandem).

In the next sections, we present each of these two data sources, starting with the e-bike survey (sections 3.4, 3.5, 3.6), and thereafter, the interviews with e-bike users (section 3.7).

3.4 E-bike survey

3.4.1 Recruitment

A database of beneficiaries of the e-bike subsidy was used to recruit participants to the survey. With the municipality’s approval, 4’292 e-bike users in the database were contacted through both an online and postal survey in June and July 2018. As e-mail addresses were not required for the subsidy before 2014, older recipients were contacted through a postal survey. The online survey was created using the software Limesurvey. To increase participation, two reminders were sent for the online survey in June and July.

Out of 2’119 postal addresses, 754 were returned by the postal service because of invalid addresses, due to residential relocation since the subsidy. Of the 2’173 electronic addresses, 107 were no longer active. The final sample of participants consisted of 3’431 people, with 1’365 valid postal addresses and 2066 electronic addresses. After deleting incomplete surveys (those who had answered fewer than two questions), 1’560 respondents answered the survey. A further 94 responses were deleted for participants who had applied for a subsidy but never bought an e-bike, who no longer owned one, or who were companies. The final number of valid respondents is 1’466, with 338 postal respondents and 1’128 electronic respondents.

After excluding invalid addresses, this amounts to a combined response rate of 43%, respectively 25% for the postal survey and 55% for the online survey. The higher response rate for online surveys is due to the two reminders and greater ease of participating online.

Table 2: Number of people contacted, valid participants, and survey respondents for postal and electronic survey. Source : Marincek et al. (2020)

	Postal survey		Electronic survey		Total
	N	%	N	%	N
Initial sample (subsidy database)	2119	49%	2173	51%	4292
Not delivered	*754*	*88%*	*107*	*12%*	*861*
Final sample (participants)	1365	40%	2066	60%	3431
Incomplete surveys	*9*	*56%*	*7*	*44%*	*16*
Non-responses	*995*	*54%*	*860*	*46%*	*1855*
Respondents	361	23%	1199	77%	1560
Invalid responses (do not own e-bike)	*22*	*24%*	*68*	*76%*	*90*
Invalid respondents (company)	*1*	*25%*	*3*	*75%*	*4*
Valid respondents	338	23%	1128	77%	1466
Response rate	25%		55%		43%

3.4.2 Survey contents

The survey language was French. The survey had a general scope of investigating e-bike use, user profiles and experiences, and contained four parts presented hereafter (for the full list, see appendix in section 11). It included open questions, multiple-choice questions and statements which could be answered on a four-point Likert scale (disagree, rather disagree, rather agree, agree).

The first part of the survey asked information about participants' ***household situation and mobility equipmen***t (number of vehicles, transport passes). Participants were asked about the type of e-bike they currently owned and for purchase information (place and year of purchase, price, model, and subsidies received). The perceived effect of the subsidy was asked (incentive to buy an e-bike; incentive to buy a higher-grade model). Motivations for e-bike use were assessed using a list of 8 potential reasons which could be answered a 4-point Likert scale: the ability to cycle more or continue to cycle (1); going further or faster than with a conventional bicycle (2); being able to cycle despite the gradient (3); having an alternative to the car and public transport (4); carrying children/goods (5); enjoying the pleasure of e-biking (6); adopting an innovative form of mobility (7); doing exercise while travelling (8). The substitution effect of e-bikes was measured by asking participants about whether the e-bike had led them to give up ownership of other travel modes (yes/no), and how the use of other modes had changed since using an e-bike (more, less, or no change). Previous travel habits were surveyed by asking the participants which modes of transport they had previously used for the trips which they now did by e-bike (walking, conventional cycling, motor two-wheeler, car, public transport, did not previously engage in these trips). The image of various travel modes (e-bike, car, public transport) was also compared by asking participants to rate the following adjectives (makes me free; practical; fast; comfortable; economical; ecological; safe) on a Likert scale.

The second part of the survey asked about ***travel habits***. For each trip motive (work/study, shopping, leisure, sports or recreation), the frequency of trips was asked (every day or almost, several times per day, a few times per month, a few times per year, never), and the mode of transport used (car, public transport, conventional bicycle, motor two-wheeler). The frequency of e-bike use was also asked as a stand-alone question, as well as the weekly duration of e-bike use (less than 30 minutes, 30 minutes to 1 hour, one to 2 hours, 2 to 4 hours, more than 4 hours). Participants were also asked whether they continued to cycle in winter (yes, like other seasons; yes, but less often; no). Nine proposed barriers to e-bike use were assessed, which could be answered on a Likert scale: have to use a road with strong traffic (1); have to carry children/goods (2); don't want to cycle at night (3); unfavourable weather (4); a long or tiring trip (5); difficult to carry e-bike in a train or metro (6); don't want to sweat (7); a risk of theft or vandalism (8); low battery or lack of range (9). Participants were also asked about the maximal distance acceptable for e-bike use and their fitness levels.

The third part of the survey touched on the ***experience of e-cycling***, including satisfaction levels and perceived comfort for cycling in different traffic situations. The experience of using an e-bike in Lausanne was surveyed through 7 statements answered on a Likert scale: I feel safe in traffic (1); there are enough cycle lanes (2); I feel respected by other road users (3); I encounter dangerous situations (4); I have good parking conditions at home (5); I have good parking conditions at my workplace/destination (6); I feel like a cheater for using an e-bike (7). The level of comfort for cycling was assessed for 9 situations, also on a four-point Likert scale (not comfortable at all, rather uncomfortable, rather comfortable, very comfortable): cycling in mixed traffic with cars (1); cycling on a bicycle lane with other cyclists (2); cycling on a sidewalk with pedestrians or a pedestrian area (3); cycling on a bus lane (4); cycling on a contra-flow lane (5); crossing an intersection or roundabout (6); managing the battery of my e-bike (7); repairing a flat tyre (8); doing mechanical maintenance (9). Lastly, agreement with the installation of charging point in the city and precautions against e-bike theft were asked.

The fourth and last part asked for ***socio-demographic characteristics*** including year of birth, gender, employment situation, place of residence and employment, distance to the workplace, education levels, income, and participation to the qualitative interviews.

3.5 Participant characteristics

This section describes the characteristics of the participants to the survey, and the main results of the survey in order to provide an overview of the study population, before moving to the articles which have a more detailed focus. For the complete results, we refer the reader to the final report (Marincek et al., 2020). We start by describing participants' socio-demographic profile and its evolution over time, the spatial location of their residence and workplace, their access to vehicles and transport passes. We then analyse how the e-bike is used in terms of frequency, duration, trip purposes, and seasonality, and the effects of e-bike adoption on the substitution of trips by other transport modes. Later, we focus on how e-bike users appropriate the e-bike for their projects through their motivations and barriers, their skills and level of comfort, and their experience of e-cycling in the context of Lausanne.

3.5.1 Socio-demographic profile

As Table 3 shows, our sample is composed of a slight majority of women (53%), compared to men (47%). This is comparable to the population of the city of Lausanne, where 52% of the inhabitants are women (Ville de Lausanne, 2019). In terms of age, children and teenagers under the age of 20 are absent due to both license requirements[23] and e-bike's high price, which represent a barrier for younger people.

The largest age category among e-bike users are middle-aged adults between 35 and 49 years (40%), which are largely overrepresented (23% of the city population), followed by mature adults from 50 to 64 (30%, compared to 16% of the population). While young adults from 20 to 34 years account for 20% and are underrepresented compared to the normal population (28%). At the other end of the spectrum, older people over 65 (11%) are also slightly less present than in the population (14%). This may be because of health issues which prevent them from engaging in cycling, or because of unsafe cycling conditions in the city.

Table 3: Participants' socio-demographic profile.

Variable	Categories	N	%	Population of Lausanne
Gender	Female	720	53%	52%[24]
	Male	639	47%	48%
Age	0-19	2	0.1%	-
	20-34	270	20%	35%[25]
	35-49	540	40%	28%
	50-64	399	30%	20%
	65 and over	142	10%	18%
Education	Compulsory school	39	3%	28%[26]
	Secondary degree (ISCED 2011 levels 3-4), including	258	19%	31%
	- *Apprenticeship*	*190*	*14%*	
	- *High school diploma or professional diploma*	*68*	*5%*	
	Tertiary degree (ISCED 2011 levels 5-8), including	1054	79%	42%
	- *Diploma, master's degree, higher vocational school*	*182*	*14%*	
	- *University, Polytechnic, University of Applied Sciences or Pedagogy*	*872*	*65%*	
Employment	Employed full-time	406	30%	41%[27]
	Employed part-time	705	52%	17%
	Unemployed	27	2%	6%
	Not working, including	220	16%	35%
	- *Homemaker*	18	1%	
	- *Retired*	152	11%	
	- *Student*	37	3%	
	- *Other*	13	1%	
Household type	Alone	261	18%	48%
	Alone with children	90	6%	8%
	Couple without children	424	29%	19%

[23] E- bikes in Switzerland can be ridden from 14 years with a moped license. Pedelecs (until 25 km/h) can be ridden from 16 years onwards without a license, while speed-pedelecs require one at all ages.
[24] Population aged 20 and over. Source: City of Lausanne. data from Federal statistical Office, 2018. Structural annual census.
[25] Population aged 20 and over. Source: City of Lausanne. data from Federal statistical Office, 2018. Structural annual census.
[26] Population aged 25 and over. Source: City of Lausanne. data from Federal statistical Office, 2018. Structural annual census.
[27] Population aged 15 and over. Source: City of Lausanne. data from Federal Statistical Office, 2018. Structural annual census.

Couple with children	621	42%	21%
Other (flat share, multi-family households)	68	5%	3%

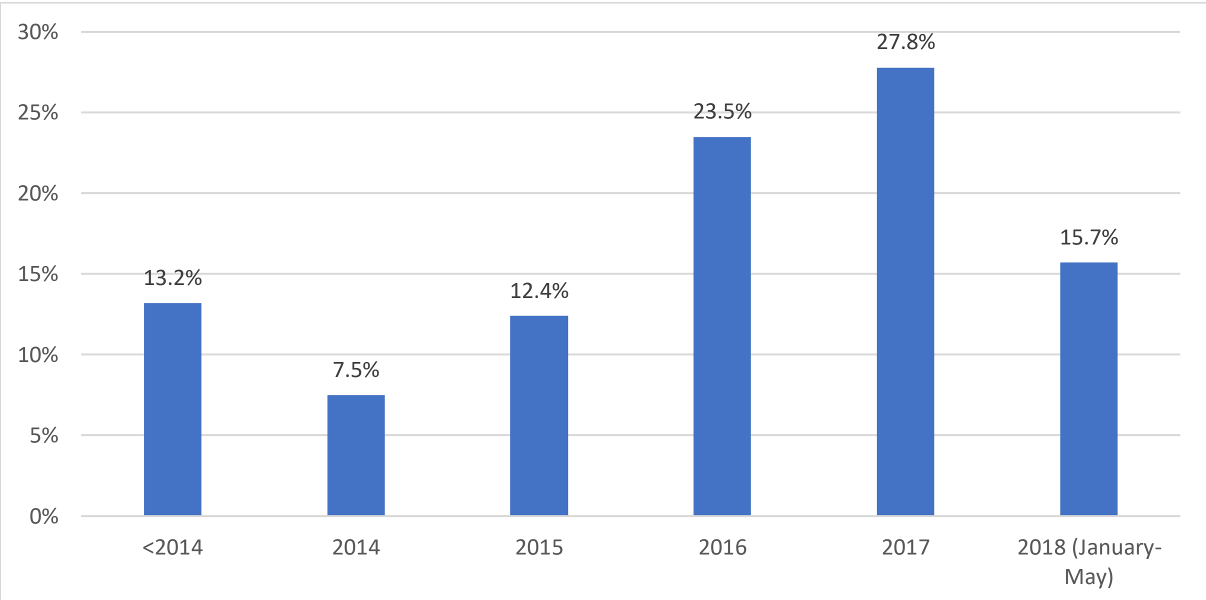
E-bike users have high socio-economic levels. A majority of them (79%) hold a tertiary degree[28] (equivalent to a higher vocational school or university), compared to just 42% of the population over the age of 25 (Ville de Lausanne, 2020a). The majority of e-bike users are professionally active, with 52% working full-time (compared to 41% in the population over the age of 15), 30% part-time (compared to 18%), 11% retired, 2.7% students, 1% homemakers and 1% other. Non-active people are underrepresented, accounting for only 16% of e-bikers compared to 35% in the population.

As a result of the over-representation of people in the active phase of life (i.e. fewer young people and older people), most e-bike users live in households composed couples with children (42% compared to 21% in the population) or couples without children (28% compared to 19%). People living alone (single-person households) are underrepresented (18% vs. 48% in the population), as are single parents with children (6% vs. 8%), and other households such as flat shares (5% vs. 3%).

3.5.2 Evolution of e-bike users' profile

The diffusion of the e-bike is still underway. Two thirds of surveyed e-bikers (67%) made their purchase in the two and a half years before the survey (2016, 2017, and January-May of 2018), 19.9% in 2014 or 2015, and only 13.2% in the period before 2014. This reflects the strong increase in e-bike sales in Switzerland in recent years (+ 94% from 2014 to 2018, Velosuisse, 2019). However, older e-bike purchases may be slightly underestimated because respondents who owned multiple e-bikes were instructed to indicate the date of purchase of their most recent one. Data for the year 2018 only accounts for the months from January to May.

Figure 13: Year of e-bike purchase. N= 1390. Note: Data for the year 2018 only refers to the first 5 months.



Over time, two trends can be identified: e-bike users have been getting younger, and the share of women has increased. The proportion of e-bike buyers aged under 35 (at the time of purchase) increased

[28] International Standard Classification of Education (ISCED 2011) (UNESCO Institute for Statistics, 2012)

gradually since 2014, before reaching 28.4% of e-bike buyers in 2017 (and 30.9% for the first five months of 2018). At the same time, the proportion of older adults (>65) has decreased from 13.5% in 2014 to 4.7% in 2017 (and 4.3% in 2018). This trend is confirmed by the mean age at the time of the purchase, which has dropped from 47.2 years in 2014 to 42.8 in 2017 (and 43 years for the first five months of 2018). The second trend is an increase in the percentage of women, which has risen to 54.8% in 2017 (55.3% in the first five months of 2018). This changing profile reflects the progressive diffusion of e-bikes from older adults to a younger population, or their "rejuvenation" (Peine et al., 2017), as well as their diffusion among women, who are generally underrepresented among cyclists in low-cycling contexts.

Figure 14: Age at purchase by year of purchase. N=1299. Note: Data for the year 2018 only refers to the first 5 months.

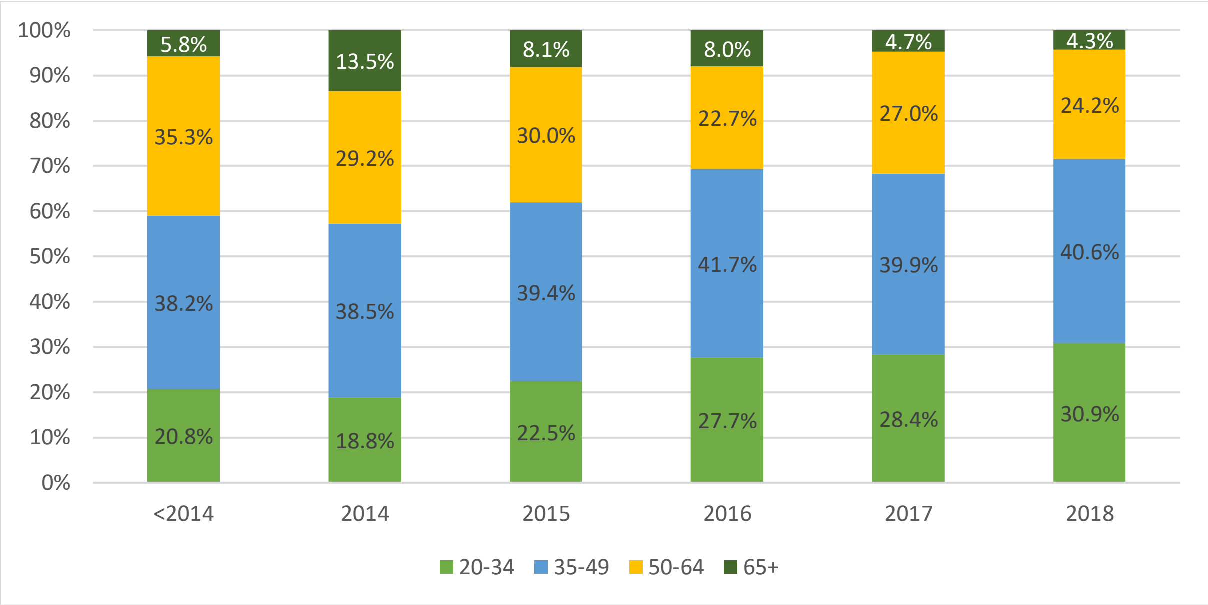
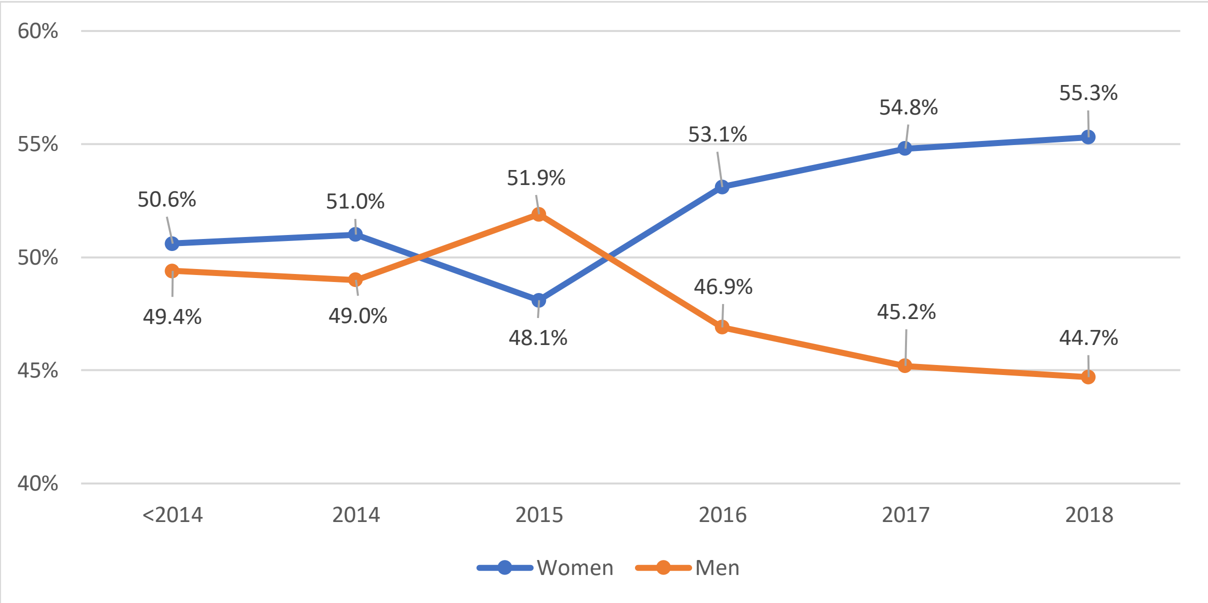


Figure 15: Gender by date of purchase. N=1314. Note: Data for the year 2018 only refers to the first 5 months.

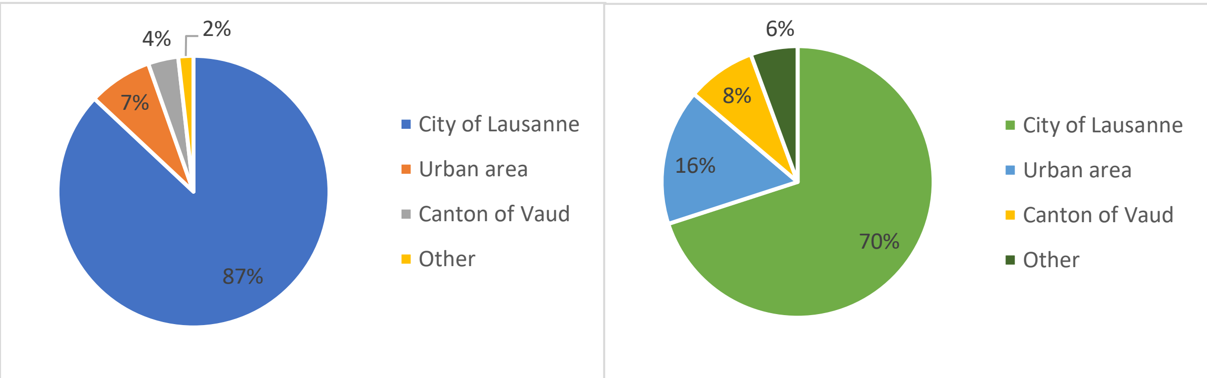


3.5.3 Residential and work location, distance to work

E-bike users who participated in the survey mostly live in Lausanne (87%), one of the conditions for obtaining the subsidy. However, due to the delay between the subsidy and the survey, 13% of users have moved to other municipalities. Among them, 7.6% live in the surrounding municipalities of the urban area (Agglomeration of Lausanne), 3.6% in the region (Canton de Vaud), and 1.8% elsewhere in the country. Among the people who are professionally active, seven in ten e-bike users (70%) work in the city of Lausanne, while 16.2% work in the urban area and 8.3% in the region. Only 5.6% work further away in the country. If we combine the place of residence and workplace, 95.8% of professionally active e-bike users either live or work in Lausanne, while only 4.1% do not live or work there.

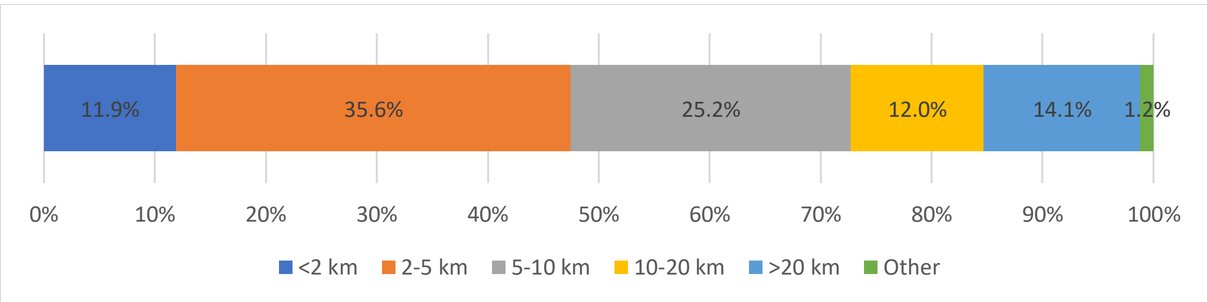
All participants' responses were included in the survey as there was an interest in knowing how they had used their subsidy, even if they no longer lived in Lausanne. Moreover, it was assumed that those who responded could still be using their e-bike when working in Lausanne or visiting the city for other activities, or that they had moved very recently and could thus answer retrospectively.

(Left) Figure 16: Residential location. N=1275. (Right) Figure 17: Workplace location. N=1135.



Due to a majority of e-bike users working within the city, distances to work are rather short. Roughly half of all e-bike users (47.5%) commute less than 5 kilometres to their workplace. One in four participants commute between 5 and 10 km, while the remaining quarter (26%) commutes over 10 km, among whom only 14.1% over 20 km. This suggests that the majority of e-bike users live within a feasible distance by e-bike from their workplace, even if, as we shall see, not all use their e-bike to go to work.

Figure 18: Distance to work. N=1121

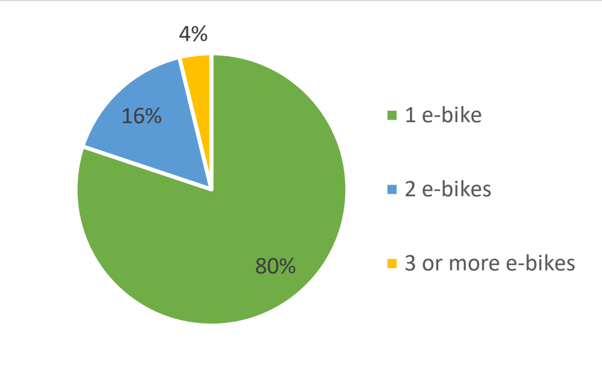


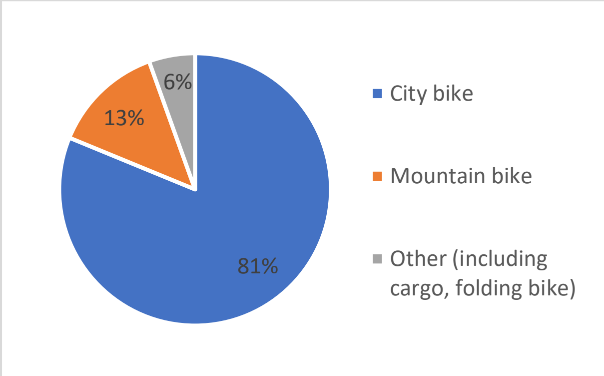
3.5.4 Access to vehicles and transport passes

The majority of e-bike users own a pedelec (84.9%), with an assistance limited to 25 km/h, rather than a faster s-pedelec (15.1%), which has an assistance until 45 km/h. Slower pedelecs are owned by more women still (57.9%), whereas faster s-pedelecs are mostly owned by men (73.2%). Pedelec users are also slightly older (mean age: 46.8 years) than s-pedelec users (45.9 years). People who work further away tend to buy more s-pedelecs: 40.5% of s-pedelec owners live over 10 km from their workplace, compared to 23.4% of pedelec owners.

While 80.2% of users have owned just one e-bike, 16.1% are onto their second, and 3.8% already their third e-bike. The price of e-bikes varies very strongly depending on the category. Although the mean price is 3’031 Swiss Francs overall, s-pedelecs cost on average 4’318 Swiss Francs while regular pedelecs are much less expensive, costing an average of 2’810 Swiss Francs. Eight out of ten (82.1%) s-pedelecs cost more than 3’000 Swiss Francs, compared to just one third (31.7%) of pedelecs.

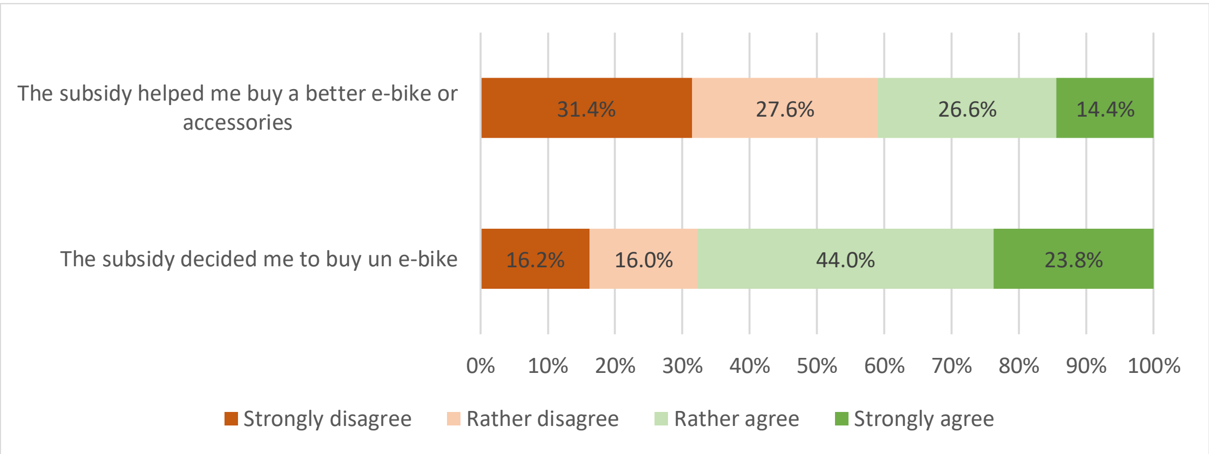
(Left) Figure 19: Number of e-bikes owned. N=1438. (Right) Figure 20: Type of e-bike. N=1427.





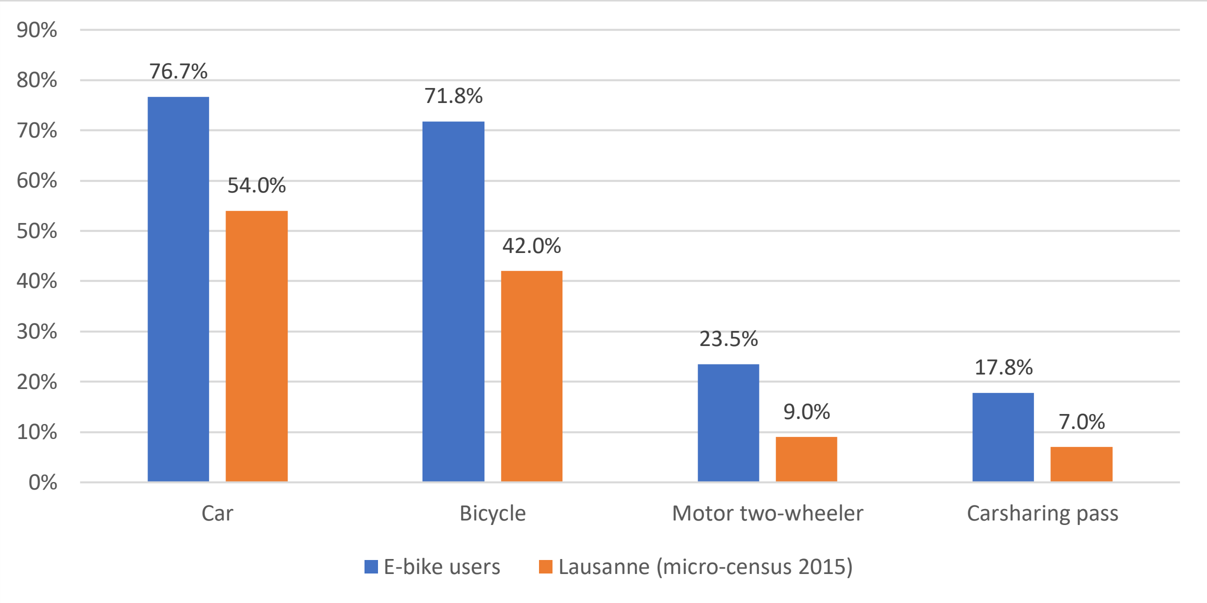
The effect of the subsidy on the adoption of the e-bike was evaluated through two statements. The first statement, “The subsidy decided me to buy an e-bike”, tests whether the subsidy played the role of a trigger for the purchase of the e-bike. Meanwhile, the second statement, “The subsidy helped me buy a better e-bike or accessories”, tests whether the subsidy was used as an incentive to upgrade to a higher-level e-bike. We find that two thirds of e-bike users (68%) agree or strongly agree with the “triggering” effect of the subsidy, while a smaller proportion (41%) agree with the “upgrade” effect. Moreover, the triggering effect on e-bike purchase is stronger for people who are onto their first e-bike (70% agree or strongly agree) than for those who have already owned two e-bikes (59% agree) or three or more (52%).

Figure 21: Role of the subsidy. N=1412.



E-bikers have a high level of vehicle ownership in the household, which is related to their specific profile and the over-representation of family households and population groups in the active phase of life (i.e. young people <20 years, older adults >75 years). Only a quarter of participants (23%) do not own a car, while 58% of participants own one, and 19% two or more cars. By comparison, 46% of households in Lausanne did not own a car in 2015 according to the Swiss micro-census on mobility and transport (FSO & FOSD, 2017). Moreover, almost all e-bike users hold a drivers' license (93.4%). In addition to their e-bike, 72% of participants also own conventional bicycles (24.4% one, and 47.4% two or more). The rate of bicycle ownership is higher than for households in the city (42%) and the canton of Vaud (56%) but comparable to the national rate of 65% (FSO & FOSD, 2017). The number of e-bike users who own motor two-wheelers such as scooters, motorcycles or mopeds is also high at 24%, compared to only 9% of households in Lausanne. A comparably high percentage of e-bike users own a subscription to a carsharing service such as Mobility carsharing (17.8% vs. 7%). This type of service is especially popular among those living without a car (53.4%), as it can give access to a car when needed, without requiring ownership.

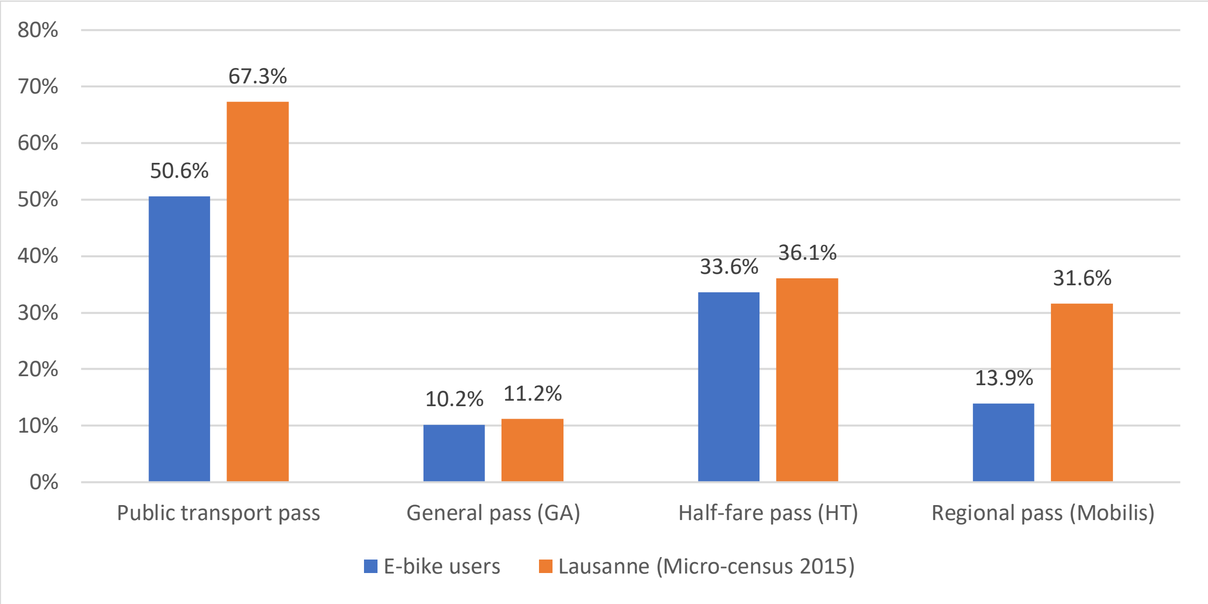
Figure 22: Vehicle ownership compared to the population of Lausanne (FSO & FOSD, 2017). N=1342.



Half of e-bike users own a public transport pass (50.6%), a low rate compared to the municipal population (67.3%). One in ten e-bike users (10.4%) owns a general pass from the Swiss Federal Railways (SBB)[29], and a third (32.8%) own a half-fare pass[30]. However, only 14.2% own a regional pass (Mobilis[31]) which gives access to local buses and trains within the urban area or region, a rate twice as low as in the general population (31.6%). This suggests that e-bike users are less reliant on the local public transport network.

[29] The general pass (GA) offers unlimited travel on all public transport means in the country (train, bus, some boats) and is favored by long-distance train commuters.
[30] The half-fare pass (HT) gives a half-price discount on tickets on all public transport means in the country. It is owned by most people who use public transport on an occasional or regular basis.
[31] The Mobilis (regional transport authority) pass gives access to public transport within one or several zones inside the region (Canton of Vaud). This option is favored by regular public transport users within the city and at the regional level.

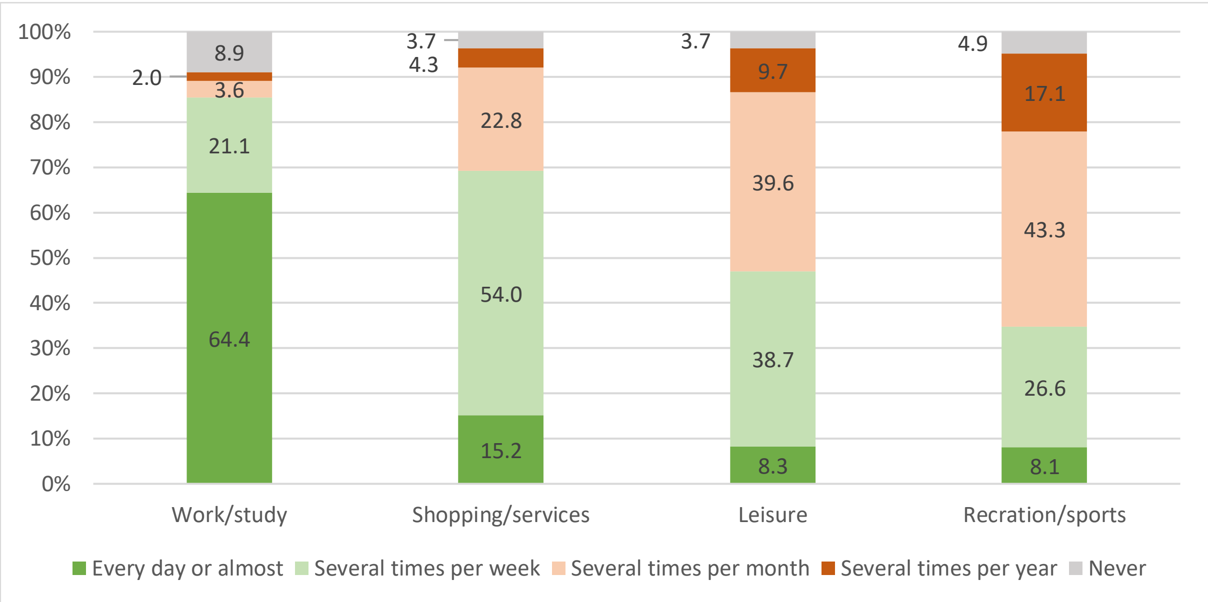
Figure 23: Public transport pass ownership compared to the population of Lausanne. N=973.



3.5.5 E-bike uses: frequency, purposes, duration, winter use

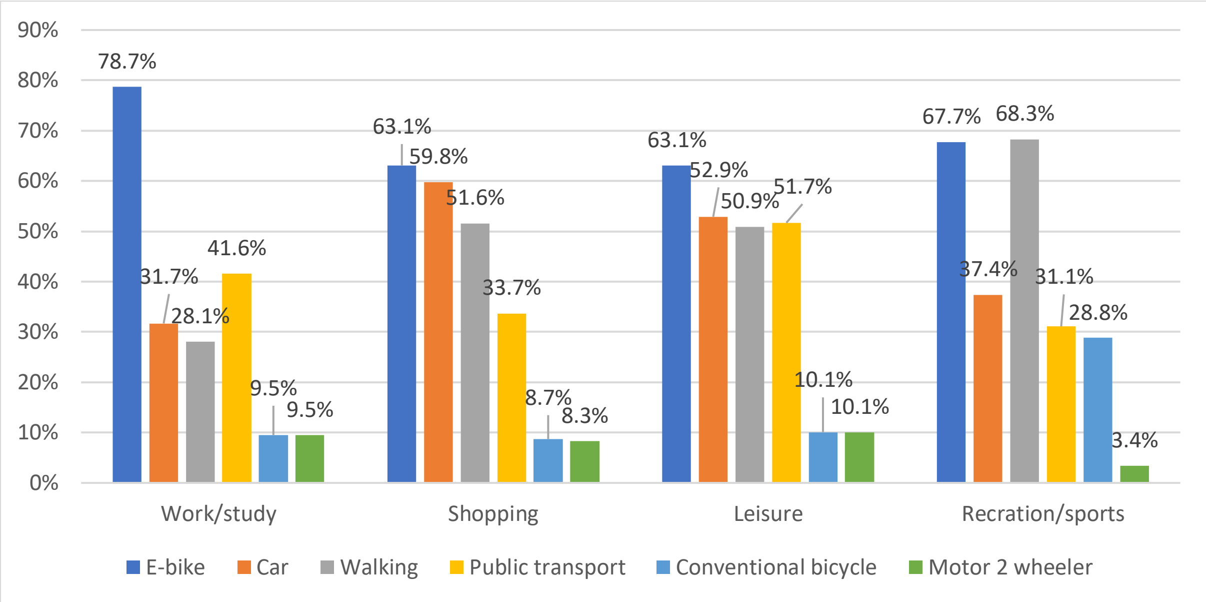
To analyse the mobility habits of e-bike users, we first give an overview of their trips regardless of whether they are conducted by e-bike or not. Among the four trip purposes considered in the survey, participants most frequently engage in work or study trips (64.4% every day). Two thirds of participants (69%) conduct shopping trips several times per week. Trips to go to leisure activities (e.g. cinema or restaurant) are made by less than half (47%) of e-bike users several times per week. Lastly, recreational trips or sporting trips are the least frequent, with only a third (34.7%) of participants conducting them during a given week.

Figure 24: Frequency of trips (by all modes). N=1349.



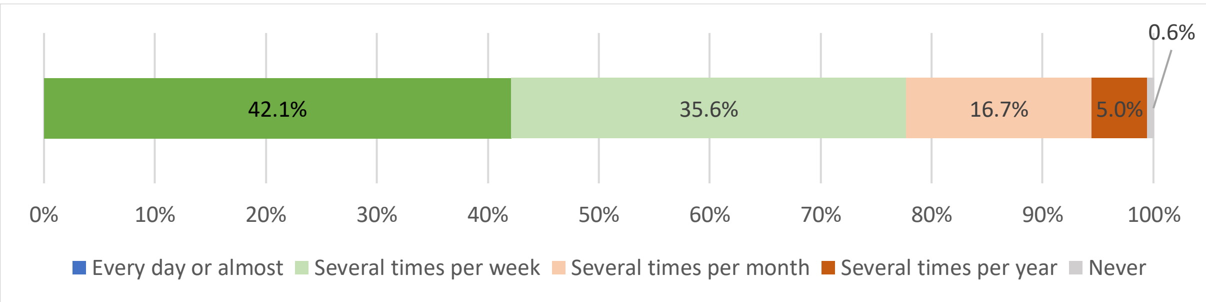
The e-bike is the main travel mode used by most participants for all trip purposes except recreation. For work or study trips, 78.7% of participants say they use their e-bike, and 41.6% public transport, while 31.7% drive a car. Shopping trips are conducted mainly by e-bike (63.1%), but also by car (59.8%) and by walking (51.6%), which may be due to the difficulty of carrying groceries, or to constraints due to trip chaining (e.g. picking up children at school). Trips to go to leisure activities are made by e-bike for 63.1% of participants, but also by car (52.9%) public transport (51.7%) or walking (50.9%). Lastly, recreational or sports trips not related to another activity are made mostly by walking (68.3%), and by e-bike (67.7%).

Figure 25: Travel mode use (%) by trip purpose. N=1214.



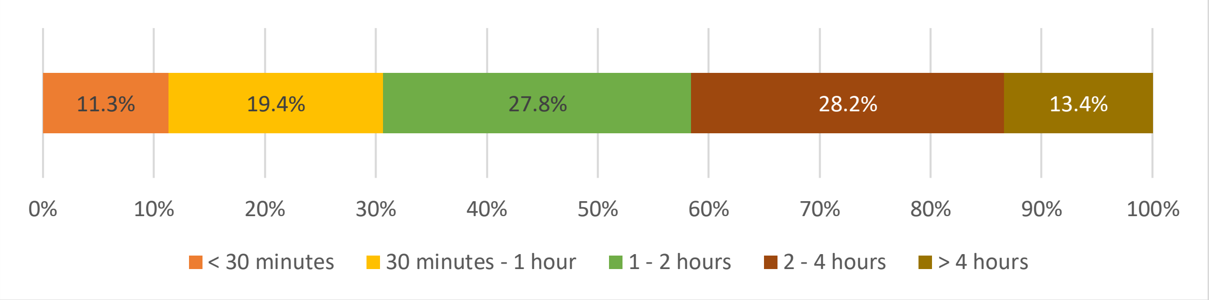
We now focus exclusively on trips made by e-bike. The frequency of e-bike use is very high among our participants. Four out of ten users (42.1%) say they e-bike every day or almost, 35.6% several times per week, and 16.7% a few times per month. The remainder only use it a few times per year (5%), and only eight participants (0.6%) say they never use it at all. Even if our respondents might have slightly overestimated their e-bike use due to the subsidy or the excitement of a recent e-bike purchase, this result remains very high, confirming that e-bikes are used as a mode of transport in their own right.

Figure 26: Frequency of e-bike use. N=1388.



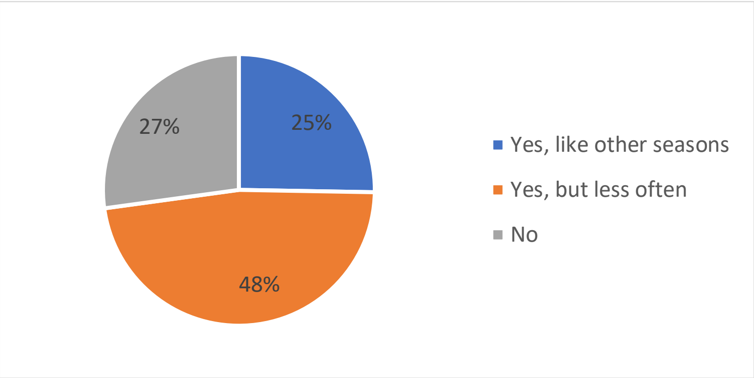
The weekly duration of e-bike use reflects this high intensity of use. Two thirds of respondents (69.4%) use their e-bike more than an hour every week, 27.8% between one and two hours, 28.2% between two and four hours, and a small minority cycling over four hours every week. To put this into perspective, a duration of just one hour translates into making, for example, two 15-minute round trips (or three 10-minute trips) every week by e-bike.

Figure 27: Weekly duration of e-bike use. N=1383.



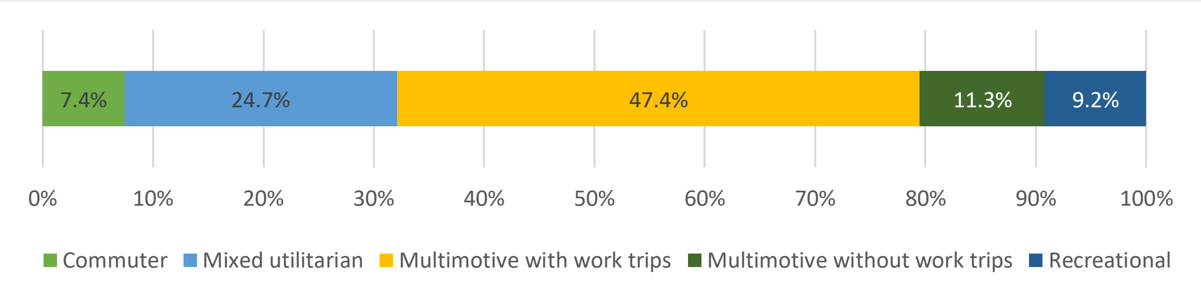
Cycling frequency is known to decline sharply during winter in many countries. Among e-bike users, the majority (74.8%) continue to cycle one way or another. One in four (25.3%) use their e-bike in winter like the rest of the year, while almost half (47.6%) continue cycling, but less often. This suggests that e-bikes may make cycling in winter more comfortable, for example due to reduced sweating when wearing winter clothes. Only 27.2% of participants stop using their e-bike entirely during the winter, but this number is higher among those who cycle only for recreational purposes (67.5%).

Figure 28: Winter e-bike use. N=1377.



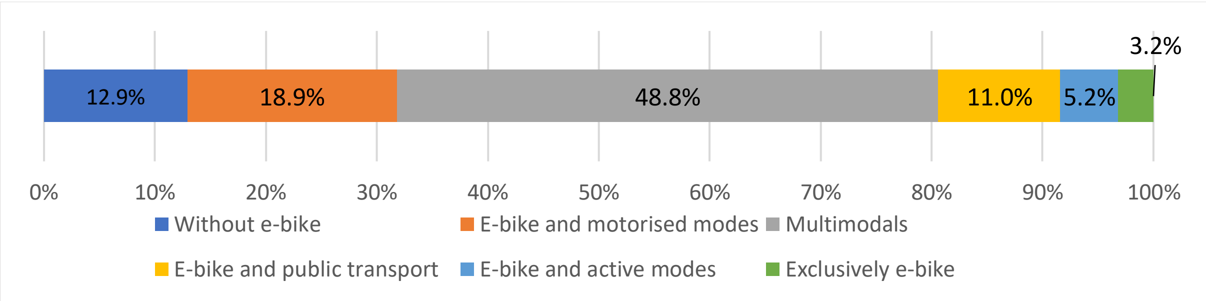
To better understand which trips our participants conduct by e-bike, we create a typology based on the purpose of e-bike use. Few e-bikers (7.4%) cycle exclusively for commuting (work/study). One in four (24.7%) use their e-bike only for utilitarian trips - commuting, shopping trips, and trips to leisure activities - but not recreational trips. The largest category are “multi-motives” who e-bike for both utilitarian and recreational purposes. Roughly half (47.4%) are multi-motives who also commute by e-bike, while 11.3% are multi-motives but do not commute by e-bike. Lastly, 9.2% of e-bikers are purely recreational users. These groups can also be condensed into three categories of users: utilitarian (32.1%), mixed (utilitarian and recreational) users (58.7%) and recreational (9.2%).

Figure 29: Typology of e-bike users depending on trip purposes. N=1243



We use another typology to categorize e-bike users depending on which combinations of transport modes they use for all trip purposes (work, shopping, leisure, or recreation). Relatively few respondents (12.9%) conduct these trips without an e-bike, although this does not mean they never use their e-bike, as evidenced by the frequency of use. One in five (18.9%) combine e-biking with motorized modes (cars and motor two-wheelers). The largest category (48.9%) are “multimodals” who combine both e-bikes, motorized modes, public transport, and active modes (cycling and walking). One in ten (11%) combine e-bike use with public transport exclusively, and 5.2% with active modes only. Lastly, 3.2% use only their e-bike as their sole mode of transport (though walking is likely underestimated). These results suggest that e-bike use mostly fits within multimodal travel patterns, rather than being a stand-alone mode.

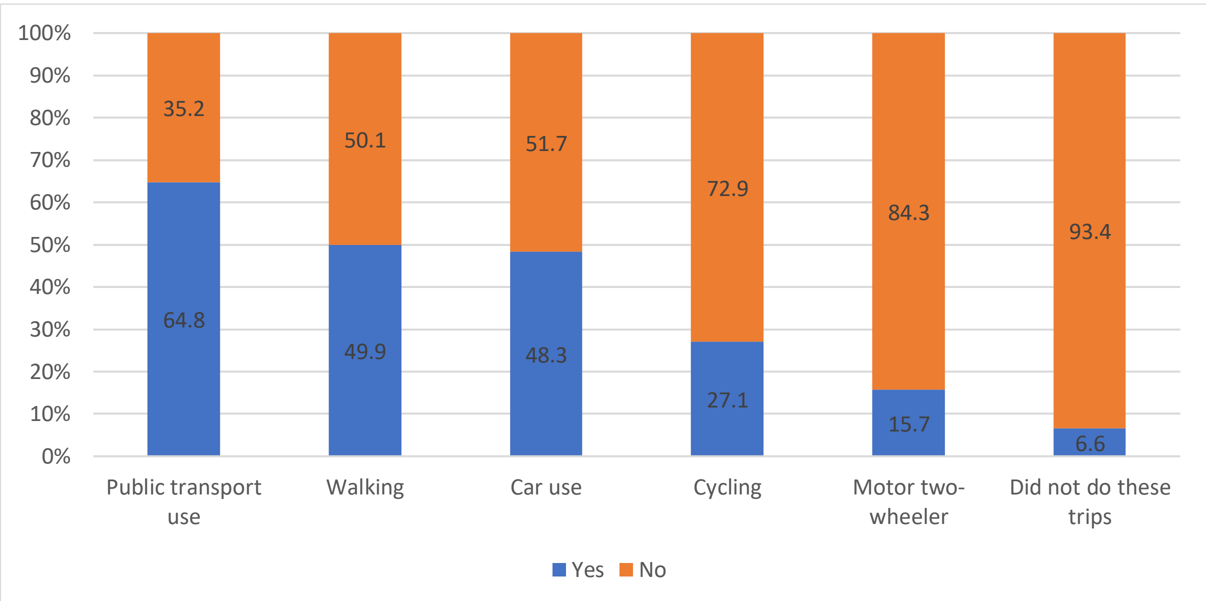
Figure 30: Typology of users based on combinations of travel modes. N=1264.



3.5.6 Substitution of other travel modes

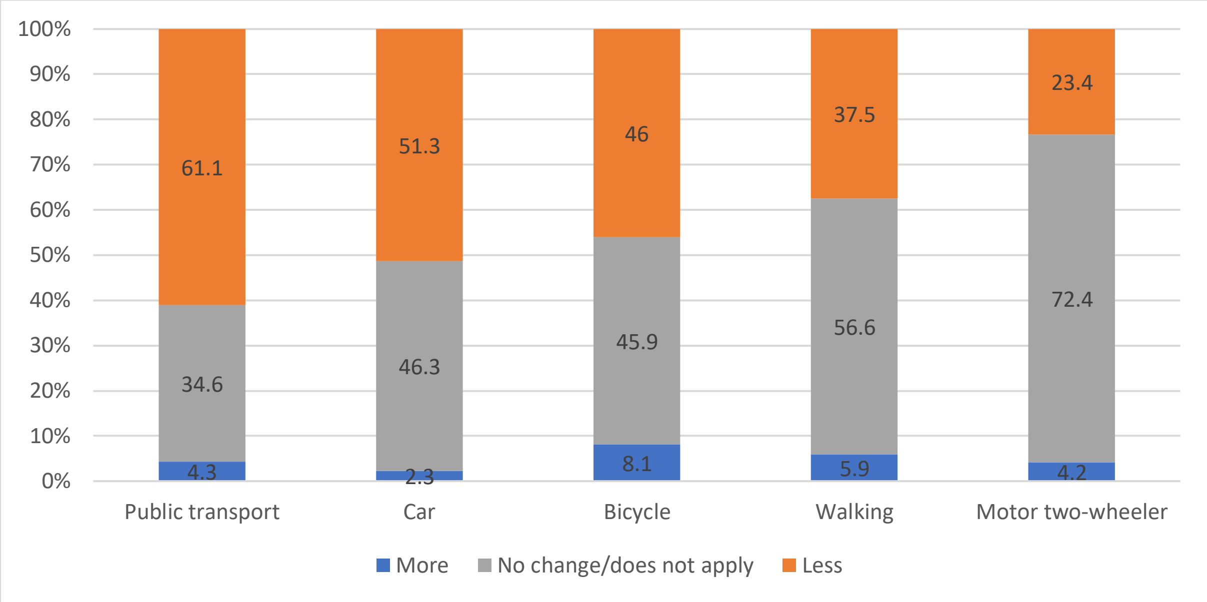
A first way of understanding the substitution effect of e-bikes is by asking which modes were previously used for the trips which are now conducted by e-bike. The mode most often previously used was public transport (64.8%), followed by walking (49.9%), car use (48.3%) and conventional cycling (27.1%), with few participants using motor two-wheelers (15.7%).

Figure 31: Travel modes previously used for trips now by e-bike. N=1417.



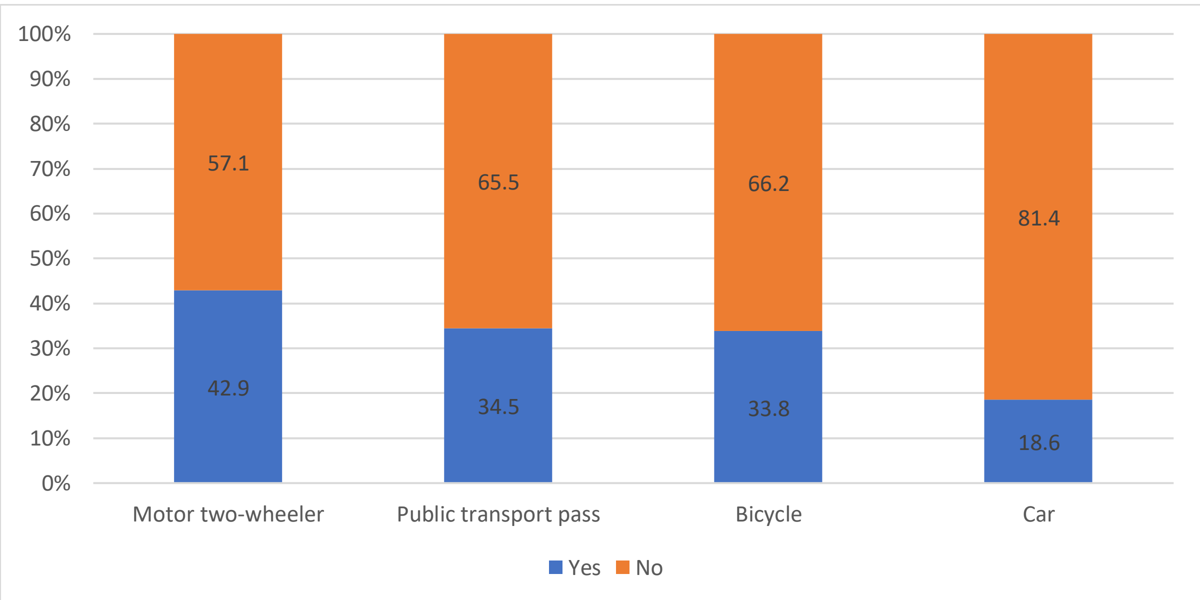
The second way consists in asking the relative changes (more, less, no change) in the use of different modes of transport since the adoption of the e-bike. The mode of travel which was most reduced is public transport (61.1%), followed by the car (51.3%). Forty-six percent of users reduced conventional cycling, but 8.1% also saw an increase, suggesting that e-bikes helped them people get back into cycling. Lastly, 37.5% of respondents reduced walking and 23.4% motor two-wheelers. Thus, e-bikes compete with longer trips by motorized modes and public transport, as well as shorter walking trips.

Figure 32: Change in travel modes since e-bike adoption. N=1365.



The third way to assess the effect of the e-bike is by asking which modes of transport were given up since its adoption. However, this renunciation may also be understood as postponing or abandoning a planned purchase, such as the renewal of a public transport pass, or replacing an older vehicle. Adopting an e-bike leads to giving up motor two-wheelers for 42.9% of users (more than motor two-wheeler owners), indicating that e-bikes offer similar performances. E-bikes also replace the need for a public transport pass for 34.5% of participants, suggesting they compete with public transport. For 33.8% of participants, e-bikes replace the need for a conventional bicycle. Last, but not least, 18.6% of respondents agree that adopting an e-bike led them to give up the car. This may be understood as either the sale of a car in the household or giving up the need to buy a car in the future.

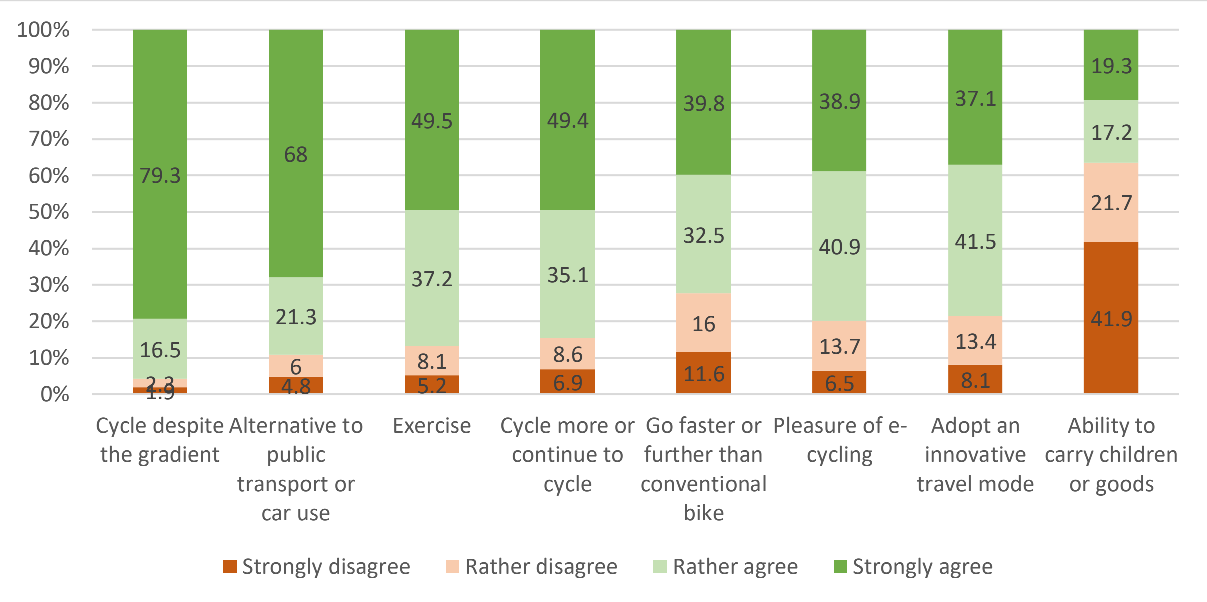
Figure 33: Renunciation to other travel modes since e-bike. N=1364.



3.5.7 Appropriation: motivations and barriers

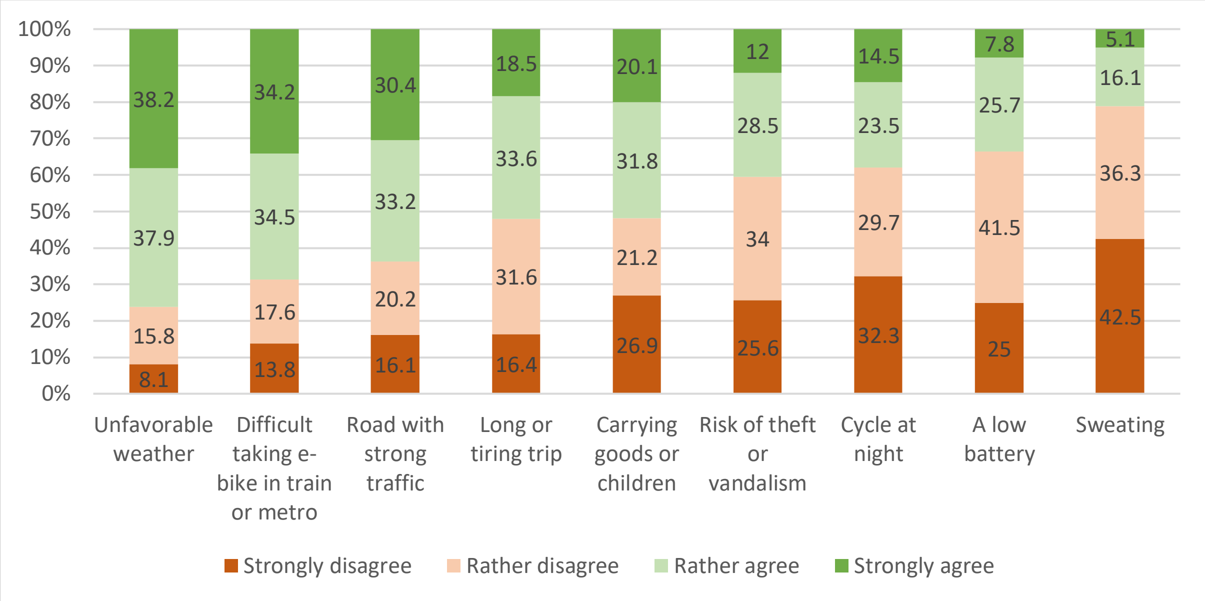
We now ask how the e-bike is appropriated within a person's projects, or the motivations for e-bike use. The most frequently cited motivation is the ability to cycle despite the gradient (95.8% rather or strongly agree), one of the main advantages in a hilly setting such as Lausanne. Having an alternative to public transport or car use is the second-highest motivation (89.3%), confirming the e-bike's usefulness as a travel mode. The third motivation is exercise (86.7%) which remains a priority for many users despite electrical assistance. The next two motivations are related to the benefits of e-bikes compared to conventional bicycles, namely the ability to cycle more or continue to cycle (84.5%), to go faster or further than a conventional bicycle (72.3%). The pleasure which e-biking brings is also an important factor (79.8%), as well as the possibility to adopt an innovative form of transport (78.6%). The only motivation which is shared by less than half of all e-bike users (36.5%) is the ability to carry goods or children, which mainly motivates young parents.

Figure 34: Motivations for e-bike use. N=1345.



Among the barriers which deter respondents from using their e-bike more often, the most important is unfavourable weather, which acts as a deterrent for three quarters of e-bike users (76.1% rather or strongly agree). About two thirds of e-bike users (68.7%) are deterred by having to carry their e-bike in the train or metro. Having to use a road with strong traffic is a barrier for 63.6% of e-bikers. A long or tiring trip deters about half of e-bike users (52.1%) from using their e-bike more. Needing to carry goods or children represents both a motivation for using an e-bike, but also a barrier for half of e-bike users (51.9%). The risk of theft is also perceived as a barrier to using the e-bike more often for four in ten users (40.5%). Cycling at night-time is considered a barrier for 38% of e-bike users. Lacking autonomy or an uncharged battery are seen as a barrier by one third of users (33.5%). Lastly, thanks to the assistance of the e-bike, sweating is the least important barrier, and only deters one in five e-bike users (21.2%).

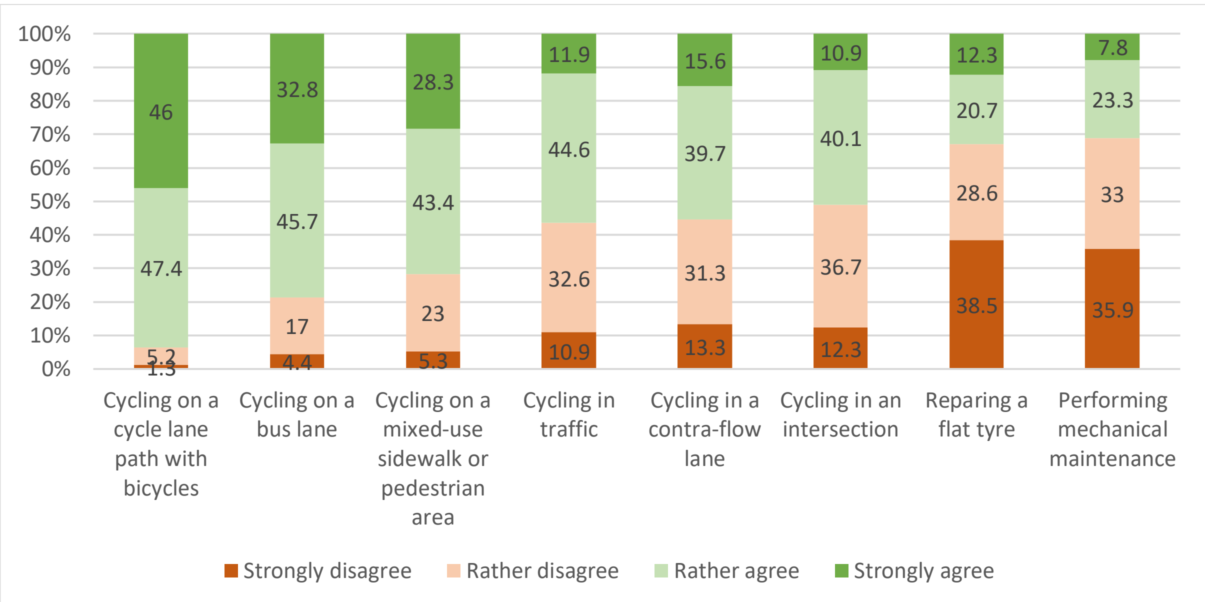
Figure 35: Barriers to e-bike use. N=1307.



3.5.8 Skills

Participants' skills were assessed through their level of comfort or ease for cycling in a range of different situations, as well as performing tasks related to e-bike use. Almost all e-bike users are at ease when cycling on dedicated cycling infrastructure (paths or lanes) (93.4% rather or strongly agree). A majority are still comfortable when using a bus lane (78.5%) or a mixed-use path or sidewalk (71.7%). However, only about half consider themselves at ease cycling in traffic with cars (56.5%), on a contra-flow lane against traffic (55.3%) or crossing an intersection or roundabout (51%). This suggests that e-bikers' comfort for cycling decreases when there is less separation provided from motor traffic. Another area where most e-bike users are uncomfortable is maintaining their e-bikes themselves. Only one in three participants feel comfortable performing maintenance tasks related to the e-bike such as repairing a flat tyre (33%) and mechanical maintenance (31.1%).

Figure 36: Comfort for cycling in different situations. N=1358.



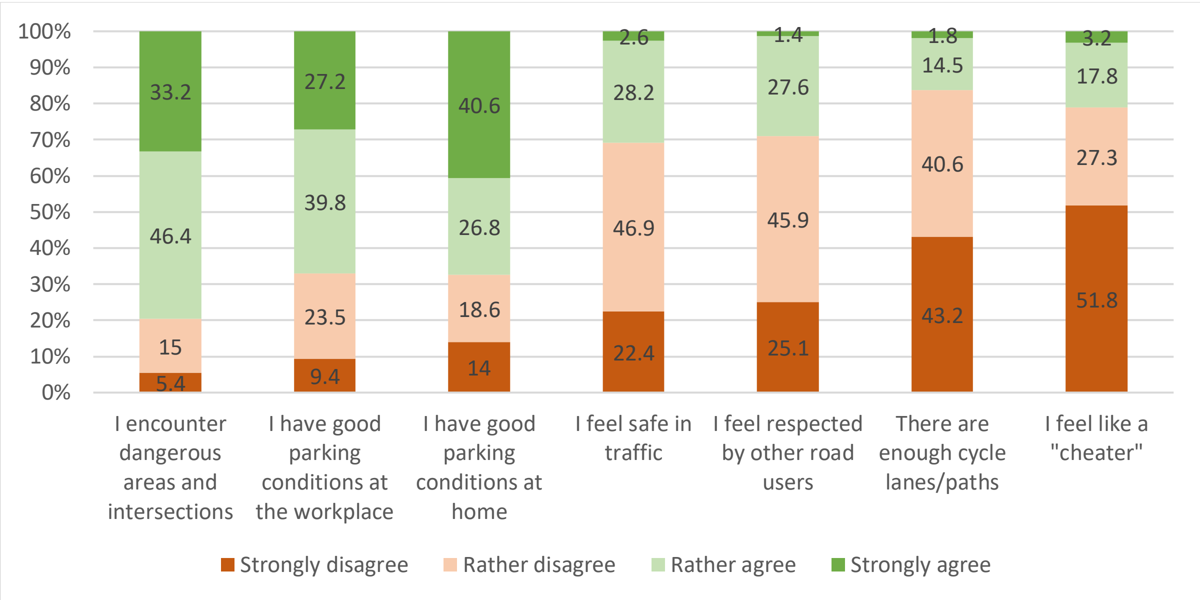
3.5.9 Experiences of cycling

A further dimension of the adoption of the e-bike is the experience of using an e-bike in the specific context (i.e. hosting potential) of the city of Lausanne. To evaluate their experience, participants were asked to express their agreement to list of statements regarding their perceived safety, relations with motorists, satisfaction with cycling infrastructure, availability of parking conditions, and social stigma regarding e-bike use.

Perceived safety appears to be particularly problematic in Lausanne, as most e-bike users agree (79.6%) that they encounter dangerous areas or intersections. Moreover, most e-bike users do not feel safe in traffic (69.3% rather or strongly disagree), or respected by other road users (71% rather or strongly disagree). One of the reasons for this low level of perceived safety seems to be a lack of cycle infrastructure. Indeed, the vast majority of e-bike users (83.8%) disagree that there are enough cycle lanes and paths in the city. On a more positive note, parking facilities are judged to be sufficient by two thirds of e-bike users both at the household level (67.4% rather or strongly agree), and at the destination or workplace (67%).

Lastly, to assess the image of the e-bike, and specifically whether e-bike use carried a negative connotation or social stigma, we asked participants whether they felt that e-bike was a form of "cheating". One in five few respondents agreed (21% rather or strongly), indicating that the image of e-cycling as a practice is mainly positive, at least regarding the use of electrical assistance.

Figure 37: Experiences of e-bike use. N=1334.



3.6 Statistical analysis

To analyse our quantitative data, we used the statistical software IBM SPSS version 26. Statistical significance was fixed at a level of 5%, or p<0.005. In addition to the descriptive statistics outlined previously, the following methods were used.

A first range of statistical procedures were used to test bivariate relationships between two variables. To test the relationship between two categorical variables (e.g. gender and type of e-bike), we use Pearson's Chi-square test. This test compares the observed and expected frequencies for each cell in a cross-table (Field, 2013). The test is considered significant if it results in a p-value of less than 5%, or .05. When testing the relationship between a continuous variable (e.g. density) and a categorical variable, we use ANOVA (analysis of variance). This test evaluates whether the mean values significantly differ between three or more groups.

To better understand the structure of a set of underlying dimensions, or "latent" (i.e. hidden) variables in a dataset, we use principal component analysis (PCA). Principal component analysis serves to extract a reduced number of factors, or components, from a set of variables. This is helpful in order to "reduce a large set of data to a more manageable size while retaining mas much of the original information as possible" (Field, 2013, p. 779). Moreover, by combining different variables together, this method avoids problems of multicollinearity for further statistical tests (e.g. logistic regression below). When calculating the degree to which different variables load onto the extracted factors, different techniques of "rotation" are used. Orthogonal rotation maximizes the variance between groups and minimizes it inside groups and helps to differentiate factors more clearly. Meanwhile, oblique rotation allows factors to be correlated between each other but is more realistic for psychological constructs.

To create typologies of users, we use cluster analysis, which is a way of grouping respondents based on their patterns of answering questions (Everitt et al., 2011). We use two types of clustering techniques. The Ward method is a hierarchical clustering technique which builds clusters incrementally, by merging the most similar groups at each step. This produces a tree diagram or "dendrogram", which is useful for analysing which number of clusters makes the most sense for the data. However, due to its hierarchical nature, it tends to produce a first larger group, and then successively smaller ones. To overcome this limitation, we also use k-means clustering, where individuals are assigned to a predefined number of groups. This technique has the advantage of producing groups with similar sizes.

To test the influence of multiple variables (or predictors) simultaneously on an outcome, we use logistic regression. Logistic regression is a model for predicting categorical outcomes from both categorical and continuous predictors (i.e. variables) (Field, 2013). We use both binary logistic regression when the dependent variable (i.e. outcome variable) has two categories (e.g. yes and no), and multinomial logistic regression when there are more than two categories. To interpret the result of logistic regression, we use the odds ratio "Exp(b)", which indicates a change in the odds resulting from a unit change in the predictor (Field, 2013). For each variable in the model, an odds ratio over 1 indicates a positive relationship (as the predictor increases, the odds of the outcome increase), while an odds ratio between 1 and 0 indicates a negative relationship (as the predictor increases, the odds decrease).

3.7 E-bike user interviews

3.7.1 Recruitment

We now present our qualitative data, which comes from 24 interviews conducted with e-bike users in Lausanne. Participants to the interviews were recruited among the respondents to the survey of e-bike users (see section 3.4) who had received a subsidy from the city of Lausanne. In the survey, 717 users had indicated an interest to participate in further interviews. A small sample of participants was randomly selected and contacted, and twenty of them agreed to be interviewed. Meanwhile, four additional users were recruited through staff and students on the campus of the University of Lausanne.

3.7.2 Participants

This sample of participants was meant to illustrate the diversity of situations of e-bike users in terms of age and gender. Due to its size (N=24), it did not aim for statistical representativeness. Table 4 shows the age, employment status and mobility equipment of our respondents. Men were slightly overrepresented (n=14) compared to women (n=10), with ages ranging from 25 to 81 years old at the time of the interview. A high proportion of users had a tertiary education, and most were professionally active, which reflects results from other studies, including our own quantitative survey. Eight users out of twenty-four had owned several e-bikes and the date of purchase of the first e-bike ranged from 1996 to 2018, although only four users have owned an e-bike for longer than 10 years. In addition to an e-bike, eighteen users out of 24 (75%) indicated owning a conventional bicycle, a higher proportion than in the municipal population. Additionally, only half (n=12) had a car available in their household, which is slightly more than households in the urban municipality.

Table 4: Characteristics of e-bike users (N=24).

User No.	Name (fictional)	Age	Employment Status	E-bikes owned	Bicycles owned	Cars In household
1	Pascal	51	Employed full-time	2 or more	2 or more	1
2	Philippe	55	Employed full-time	1	1	None
3	Marie	36	Employed full-time	1	None	None
4	Sébastien	29	Employed full-time	1	2 or more	None
5	Nicole	42	Employed part-time	1	1	1
6	David	25	Student	1	2 or more	None
7	Hélène	36	Employed full-time	2 or more	None	1
8	Pierre	43	Employed full-time	1	2 or more	1
9	Denis	52	Employed full-time	1	2 or more	1
10	Laure	52	Employed full-time	1	1	None
11	Paul	30	Employed full-time	1	1	None
12	Claudine	50	Employed full-time	1	None	None
13	Sarah	33	Employed part-time	1	1	None
14	Daniel	34	Employed full-time	2 or more	None	None
15	Stéphanie	38	Employed part-time	2 or more	1	None
16	Lucas	40	Unemployed	1	None	None
17	Jacques	61	Employed full-time	2 or more	2 or more	2 or more
18	Christine	65	Retired	2 or more	1	1
19	Céline	69	Retired	1	None	1
20	Michèle	76	Retired	2 or more	1	2 or more
21	Robert	79	Retired	2 or more	1	None
22	Jean	69	Retired	1	1	2 or more
23	Hubert	80	Retired	1	1	1
24	Michel	70	Retired	1	1	1

Our qualitative sample covered diverse situations of e-bike use, but shows some differences compared to the survey of e-bike users we conducted in Lausanne, which included a small majority of women

(53%), fewer users over 60 years (19%), and a larger proportion of users between 40 and 59 years of age (45%). While our sample includes more experienced, long-time users who have owned several e-bikes, the survey indicates that two thirds of e-bike users in Lausanne are recent, having only made their purchase in the last two years.

3.7.3 Retrospective biographical interviews

We conducted retrospective biographical interviews of a duration of one hour, during which participants were asked to recall their long-term relationship to cycling over their life course, as well as the shorter period around the purchase of the e-bike.

This method has been judged to be the most adapted to understanding the complexity of influences which arise during biographical key events, and the decision process related to transport mode choices (Lanzendorf, 2003; Müggenburg et al., 2015). Mobility biography studies have also used quantitative data and life course calendars to study key events and variations in travel behaviour, but these studies have been criticized for focusing too much on the timing of events and assuming causality between events. By contrast, narrative approaches to mobility biographies, such as ours, use semi-structured interviews which allow a more inductive data collection and shift the focus away from a linear sequence of events, enabling a better understanding of changes in the meaning attributed to mobility practices over time (Sattlegger & Rau, 2016).

The use of retrospective data inherently implies a recall bias, where individuals may forget or mix up information over long periods of time. However, interviews force respondents to give more detailed information than quantitative surveys, and can thus help to provide a better recollection of events (Behrens & Mistro, 2010; Beige & Axhausen, 2008; Lanzendorf, 2010; Oakil et al., 2016). Moreover, focusing on the specific moment of the adoption of the e-bike proved to be helpful, as this event had taken place recently for most participants and was thus recalled well. Focusing on this point of reference (the adoption of the e-bike) was also useful as a way to activate participants' discourse on their mobility practices before and after the purchase of the e-bike. Nonetheless, some participants experienced more trouble when recalling the events before the purchase of their e-bike, especially those who had bought multiple e-bikes, and who were prone to mixing up motivations for their first, or second e-bike.

The interview guide (see appendix, section 12) we developed consisted of five parts: a description of the household and its mobility equipment (1), of the adoption of the e-bike (2), the long-term relationship to cycling and other transport modes (3), of travel behaviour before and after the purchase of the e-bike (4), and of the experience of using the e-bike in the city of Lausanne (5).

3.7.4 Analysis

After transcribing the interviews, individual transcripts were coded with the qualitative analysis software Atlas.Ti. After importing the interview transcripts into the program, we analysed them and assigned codes to specific quotes, which were representative of recurring themes (e.g. motivations, barriers, experiences, or key events) related to e-bike adoption. For each participant, an individual cycling trajectory was constructed, consisting in a textual timeline of periods of bicycle and e-bike use, as well as dates for key events.

A visual representation of each trajectory was also drawn. The trajectories were then regrouped into different prototypical categories based on the following criteria: (1) the presence of a significant period (at least one year) of interruption in cycling practice in the years before the purchase of the e-bike, (2) the perceived frequency of cycling at the time of purchase of the e-bike and its variation throughout the life course, (3) the type of cycling practised, with a distinction between transport or utilitarian trips taken in relation to other activities, and sports or leisure trips taken for their own sake. This categorization was loosely based on the work of H. Jones et al. (2015) who categorized trajectories depending on their evolution, "resilient" or stable, "restorative" or increasing, and "diminishing". Thus, we distinguished between two main types of cycling trajectories: resilient and restorative trajectories. These categories are the subject of the next chapter, which constitutes the first of our five articles.

4. From Conventional to Electrically-Assisted Cycling. A Biographical Approach to the Adoption of the E-Bike

4.1 Presentation of the article

The first article of the thesis aims to understand the link between e-bike use and conventional cycling at the individual level. It takes a biographical approach to mobility by viewing the e-bike within an individual's relationship to cycling over the life course. We reconstruct individual cycling trajectories by using retrospective biographical interviews with 24 e-bikers, with the aim to understand their relationship to cycling in the last years leading up to the adoption of the e-bike, the circumstances of the adoption of the e-bike, and its effects on mobility practices. We identify two main cycling trajectories and describe their specificities, using quotes to illustrate key points. On one hand, "restorative" trajectories where the e-bike serves to return to cycling after a significant interruption, or serve to begin cycling for transport, with the goal of rediscovering the pleasure of cycling. On the other hand, "resilient" trajectories where the e-bike is adopted as a continuation of an existing cycling practice, as a way to continue cycling despite a changing personal or spatial context. The article concludes that e-biking and cycling can indeed be viewed as part of the same cycling trajectory, and that e-bikes should be considered as an opportunity rather than a threat for cycling. Furthermore, the utility of biographical approaches for understanding modal choices is underlined, especially for cycling, which is often underestimated when analysed through a strictly cross-sectional lens.

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4.2 Abstract

Sales of electrically-assisted bicycles (e-bikes) have been rising in many European countries. Due to their electrical assistance, e-bikes could increase the number of people cycling and the potential uses of cycling. Existing research has not investigated the links between conventional cycling and e-bike use at the individual level. Using qualitative, retrospective data, this paper aims to determine how e-bike use fits into an existing cycling trajectory over the life course. E-bike users in the Swiss city of Lausanne (N=24) are interviewed to compare their cycling trajectories. They fall into two main trajectories: "restorative" and "resilient", which each represent different relationships to cycling and different reasons to adopt the e-bike over the life course. E-bikes might serve as both a way to restore an interrupted cycling practice, or to keep existing cyclists despite threats posed by changing personal and spatial contexts.

4.3 Introduction

Sales of electrically-assisted bicycles (hereafter: e-bikes) have been growing in the last ten years, with e-bikes representing more than a third of all bicycles sold in Switzerland in 2019 (Velosuisse, 2020) and up to half in the Netherlands (RAI//BOVAG/GfK, 2019). E-bikes are a new form of bicycle combining muscular power with an electrical assistance which activates when pedaling. In European countries and Switzerland, two categories of e-bikes are mainly present, namely those limited to an assistance of 25 km/h, or "pedelecs", as well as faster "speed-pedelecs" with an assistance up to 45 km/h[32].

E-bikes are part of a larger trend of the rebirth of cycling in cities in the last decade (Buehler & Pucher, 2012b). By reducing the amount of effort needed to operate a bicycle, they could broaden the appeal of cycling to a larger spectrum of users, notably older people or those with physical limitations (Rose, 2012; T. Jones, Chatterjee, et al., 2016). Moreover, e-bikes could facilitate cycling over longer distances and in hilly terrain (Lopez et al., 2017), as well as carrying heavier loads or children (Popovich et al., 2014). Due to their increased range, they could substitute short car trips, and conventional cycling trips alike. It has been argued that e-bikes are more sustainable if the mode of transport they replace is car use rather than conventional cycling (Rose, 2012).

Most existing research on e-bikes is cross-sectional and does not address the long-term relationship to cycling that e-bike users may already have. In this paper, we argue that a biographical view of e-bike users' past travel behavior is necessary to fully understand the e-bike's role in relation to cycling. To do so, we adapt the notion of a "cycling trajectory" (Chatterjee et al., 2012; H. Jones et al., 2015) to include both conventional cycling and e-bike use over the life course. We aim to answer the following question: How does the e-bike fit into an individual's cycling trajectory? Using qualitative, retrospective data from interviews with e-bike users (N=24) from the city of Lausanne, Switzerland, we reconstruct and classify the cycling trajectories of e-bike users.

In the following sections, we start by introducing biographical approaches to cycling and presenting our theoretical framework, before reviewing the available literature on e-bike users (section 2). Later, we introduce our methodology and data (section 3). Our results present two main cycling trajectories, as well as relevant subcategories (section 4). We then discuss our findings and the role of the e-bike in these cycling trajectories, as well as implications for future research (section 5). Lastly, we draw some conclusions (section 6).

4.4 Theoretical framework

4.4.1 Biographical approaches to mobility

Biographical approaches to mobility originated as a way of overcoming the limits of cross-sectional data which consider mobility at a specific moment rather than its evolution over time (Lanzendorf, 2003). These approaches have their roots in life course studies, which have been used in sociology, psychology, health and migration studies, and see current behavior as the cumulative outcome of a trajectory of past behavior across the life course (Elder Jr et al., 2003). As put forward by Giele and Elder (1998): "Any point in the life span must be viewed dynamically as the consequence of past experience and future expectation as well as the integration of individual motive with external constraint".

Building on this, the field of mobility biographies research (for a review, see Müggenburg et al., 2015) considers an individual's longitudinal trajectory in the mobility domain as embedded within other domains of life such as lifestyle and accessibility (Lanzendorf, 2003), or employment, household, and

[32] Although further types of e-bikes also exist which do not require pedalling, notably in China (Weinert et al., 2007), they are very rare in Switzerland and are not taken into account here.

residence (Scheiner, 2007). Mobility biographies research has mostly focused on the role of "key events", specific moments in the life course which trigger a reconsideration of habitual travel behavior (Klöckner, 2004, p. 2). Müggenburg et al. (2015) distinguish between "life events" which are strictly outside the scope of transport such as childbirth, "long-term mobility decisions" such as residential relocation or vehicle ownership, "exogenous interventions" including road closures or incentives, and "long-term processes in life" of socialization linked to age, cohort, or historical period.

However, some authors have contended that this focus on key events is too narrow, because it does not capture the full extent of mobility processes across the life course, particularly the social and cultural meanings of mobility practices (Sattlegger & Rau, 2016). As a result, a few studies, notably in the domain of cycling, have moved beyond key events to include the study of long-term trajectories of mobility (Chatterjee et al., 2013; H. Jones et al., 2014).

4.4.2 Biographical approaches to cycling

Research on cycling has mainly focused on the role of specific determinants in explaining the propensity to cycle (Handy et al., 2010; Heinen et al., 2010). Although most research on cycling is cross-sectional, a few studies have adopted a biographical perspective to study the variations in cycling over the life course.

Several studies have found changes in cycling to be triggered by key events in the life course (or external events according to Chatterjee et al. 2012), which can either force a reconsideration of travel behavior, change the social environment and norms around cycling, unleash a latent demand for cycling, or trigger new destinations and interest in cycling (Janke & Handy, 2019). Contextual changes in place of residence, workplace or education have especially been linked to changes in cycling (Chatterjee et al., 2013; Janke & Handy, 2019; Oakil et al., 2016). In particular, shortening the commute distance has a strong impact on switching to cycling (Oakil et al., 2016). Personal changes like friendships, meeting a new partner, and parenthood are also linked to changes in cycling, both increases in cycling as a social or familial activity, or decreases due to lack of time or interest (Bonham & Wilson, 2012; Janke & Handy, 2019).

Cycling is affected differently by events at specific life stages. A major interruption of cycling seems to occur at adolescence as the perception of cycling shifts negatively with the onset of driving in automobile-oriented societies (Bonham & Wilson, 2012; Underwood et al., 2014). In other countries where a decline in youth licensing is observed (Rérat, 2018), public transport seems to represent the main competitor to cycling. At adulthood, residential, workplace and relationship changes affect cycling most, with parenthood affecting women in particular (Bonham & Wilson, 2012; Janke & Handy, 2019). Later in life, health concerns are especially linked to changes in cycling, both as a leisure activity, but also because of interruptions due to injury or physical limitations (Bonham & Wilson, 2012).

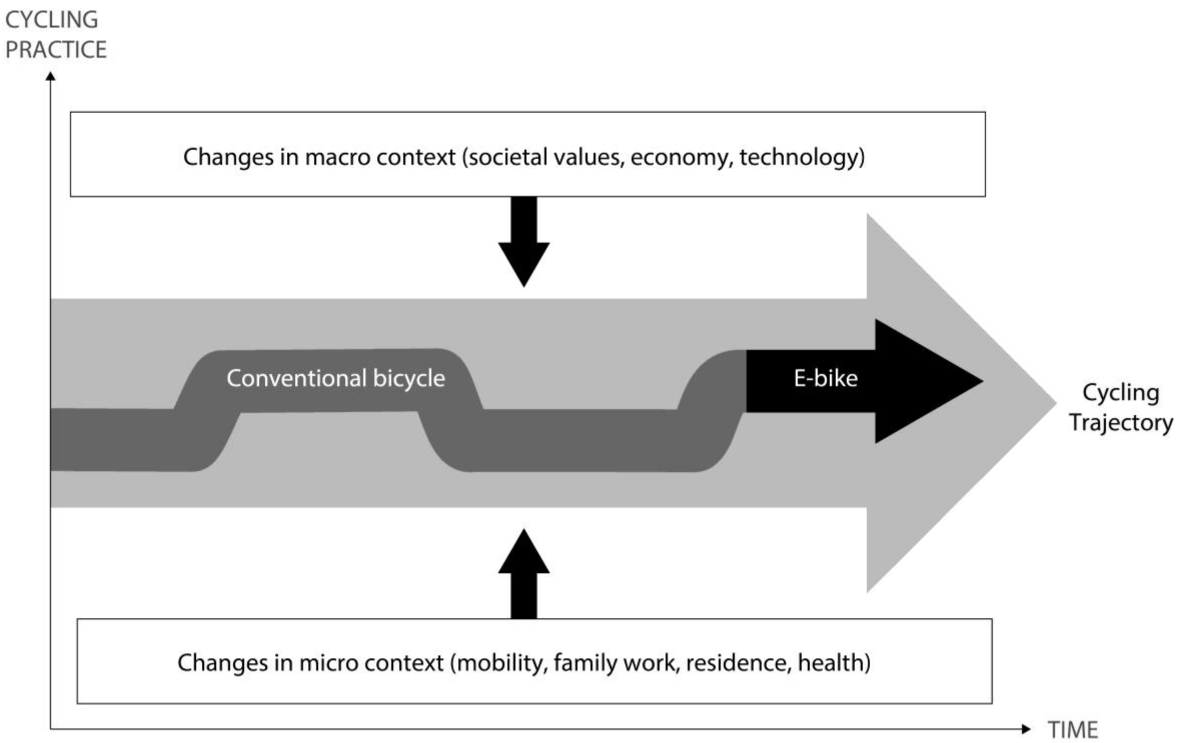
4.4.3 Conceptual framework: The cycling trajectory

Rather than focusing on specific events, analyzing individual variations in cycling over the whole life course leads to the consideration of cycling trajectories. Bonham & Wilson (2012) used women's "personal histories of cycling" to show multiple attempts to return to cycling over the life course, despite frequent interruptions.

The concept of cycling trajectory is the application of a life course approach to cycling. According to Chatterjee et al. (2012), it represents "A person's thoughts, feelings, capabilities and actions related to cycling […] developed over the course of their lives and shaped by transitions (or life-change events) that they have made and the contexts that they encounter" (Chatterjee et al., 2012 : 5).

Our conceptual framework in this paper is inspired by the one used by H. Jones and colleagues (H. Jones, 2013; H. Jones et al., 2014, 2015) and presented in Figure 38. The cycling trajectory is seen as influenced by a micro context which refers to key events in the domain of mobility, family, work, residence and health, as well as a macro context which includes societal, spatial, economic and technological developments in transport over time. It adapts H. Jones et al. (2015) by including both conventional cycling and e-bike use as part of the same cycling trajectory. The focus of this paper is specifically on the cycling trajectory itself, although some contextual elements for the setting of the study are briefly described in the methodology.

Figure 38. Cycling trajectory - adapted from H. Jones et al. (2015).



4.4.4 E-bikes and cycling

Research on e-bikes is recent but the context has changed much since the first studies on the topic (Cherry & Cervero, 2007; Weinert et al., 2007). We will not attempt a full review of the literature as this has already been undertaken (Fishman & Cherry, 2016). Instead, we focus on e-bike users, their mobility practices and their relationship to cycling.

Due to their electrical assistance, e-bikes may open up cycling to a larger spectrum of users compared to conventional bicycles, while also acting as an "equalizer" between the cycling levels of individuals (Popovich et al., 2014). Indeed, a defining trait of e-bike users seems to be their higher age, as individuals between 50 and 65 years old are overrepresented (Johnson & Rose, 2013; MacArthur et al., 2014; Simsekoglu & Klöckner, 2018; de Kruijf et al., 2019), although few studies report a majority of retired users (Wolf & Seebauer, 2014). E-bike users live in households mostly composed of families or couples, with income and education levels above average (Johnson & Rose, 2013; MacArthur et al., 2014; Wolf & Seebauer, 2014). Barriers of price and image may explain why younger adults under the age of 25 are rare. The gender makeup of e-bike users is more balanced than for cycling, particularly in cycle-friendly countries like Denmark or the Netherlands where women are a majority among e-bike users (Haustein and Møller, 2016), although this is not the case in countries such as the United States or Australia (Johnson & Rose, 2013; MacArthur et al., 2014).

Research on the health benefits of e-bikes shows that despite an electrical assistance, they still manage to provide a meaningful amount of physical activity (Bourne et al., 2018), especially when compared to non-active modes of travel such as car use. Crucially, they may contribute to better health and mobility for ageing users (Johnson & Rose, 2015; T. Jones, Chatterjee, et al., 2016; Van Cauwenberg et al., 2019), although the benefits of active mobility also extend to a broader spectrum of the population in the context of an increasingly sedentary lifestyle. In addition to physical activity, e-bikes have also been linked to healthy ageing as they improve cognitive functions and mental health through engagement with the outdoor environment, independence and mobility (Leyland et al., 2019; Spencer et al., 2019). However, their negative health effects include a higher risk of accident compared to conventional cycling, presumably due to the increased weight and speed of e-bikes (Schepers, Fishman, et al., 2014)

E-bikes may also allow for longer trips than conventional bicycles. According to the literature, switching to an e-bike mostly affects car use or conventional cycling (Fishman & Cherry, 2016), depending on the dominant forms of mobility in the setting of the study. In car-centered contexts like North America or Australia, the e-bike is considered as a way to reduce the use of the car (Dill & Rose, 2012; Edge et al., 2018; Johnson & Rose, 2013; MacArthur et al., 2014; Popovich et al., 2014), though this result has also been found in Norway (Simsekoglu & Klöckner, 2018) and Sweden (Hiselius & Svensson, 2017). Conversely, the e-bike mostly substitutes conventional cycling in countries where the population is already cycling at a high rate, such as in Denmark (Haustein & Møller, 2016a) or the Netherlands (Lee et al., 2015[33]), or for retired, leisure users, in Austria (Wolf & Seebauer, 2014). Although a switch from car use is more beneficial in environmental terms than one from conventional cycling (Rose, 2012), both are positive as studies show a reported increase in the volume and duration of trips with e-bikes compared to conventional bicycles (Fyhri & Fearnley, 2015; Kroesen, 2017; Ling et al., 2017).

Most studies consider e-bike use and conventional cycling as two separate practices. By doing so, they do not explicitly address the long-term cycling trajectory of e-bike users. Nonetheless, a few qualitative studies have investigated the previous experience that e-bike users have of conventional cycling. Almost all e-bike users seem to have practised conventional cycling at some point of their youth, or during their adult life, although many interrupted their practice (Le Bris, 2016; Leger et al., 2018). Le Bris (2016) finds the purchase of the e-bike to have either the objective of the conservation, reactivation or facilitation of an existing cycling practice. More generally, there seem to be two main types of e-bike users. Those who already cycled regularly before acquiring an e-bike and wish to maintain cycling or return to it, and those who did not cycle (T. Jones, Harms, et al., 2016).

We argue that there is a need for additional research on e-bike users' long-term relationship to conventional cycling. To do so, we will consider both conventional cycling and e-bike use as part of the same cycling trajectory over the life course.

[33] Another study in the Netherlands found that e-bikes substituted for car and public transport trips, but concerned a small sample of commuters living outside a city center (Plazier et al., 2017).

4.5 Methodology

4.5.1 Case study

The present study was conducted in Lausanne, the fourth-largest city in Switzerland with a population of 140'000 inhabitants (Canton of Vaud, 2018) and an urban area of about 415'000 inhabitants in 2017 (FSO, 2018). The city has the particularity of being notoriously hilly and has the lowest mode share of cycling among large cities in Switzerland, with only 1.6% of trips made by bicycle in 2015 (FSO & FOSD, 2017). It has been ranked the least safe city for cyclists among 24 cities in the country (Rérat et al., 2019)[34]. In the 2015 census, 3.1% of the households in the city owned an e-bike, compared to an average of 7% on the national level (FSO & FOSD, 2017). Similarly, only 41.7% of households owned a conventional bicycle, which is lower than the rate of 65% observed nationally (ibid.). Car ownership reached 53.7% of households compared to 78% nationally (ibid.). This difficult setting thus offers an interesting case study for e-bike adoption, which might be able to overcome some limitations of the city in terms of topography and bicycle infrastructure.

Table 5: Characteristics of e-bike users (N=24).

User No.	Name (fictional)	Age	Employment Status	E-bikes owned	Bicycles owned	Cars In household
1	Pascal	51	Employed full-time	2 or more	2 or more	1
2	Philippe	55	Employed full-time	1	1	None
3	Marie	36	Employed full-time	1	None	None
4	Sébastien	29	Employed full-time	1	2 or more	None
5	Nicole	42	Employed part-time	1	1	1
6	David	25	Student	1	2 or more	None
7	Hélène	36	Employed full-time	2 or more	None	1
8	Pierre	43	Employed full-time	1	2 or more	1
9	Denis	52	Employed full-time	1	2 or more	1
10	Laure	52	Employed full-time	1	1	None
11	Paul	30	Employed full-time	1	1	None
12	Claudine	50	Employed full-time	1	None	None
13	Sarah	33	Employed part-time	1	1	None
14	Daniel	34	Employed full-time	2 or more	None	None
15	Stéphanie	38	Employed part-time	2 or more	1	None
16	Lucas	40	Unemployed	1	None	None
17	Jacques	61	Employed full-time	2 or more	2 or more	2 or more
18	Christine	65	Retired	2 or more	1	1
19	Céline	69	Retired	1	None	1

[34] A national survey conducted in 2016 among 54'000 participants to a program called "Bike to work" found 34% of respondents in Lausanne reported they did not feel safe while cycling, compared to 14% on average nationally.

20	Michèle	76	Retired	2 or more	1	2 or more
21	Robert	79	Retired	2 or more	1	None
22	Jean	69	Retired	1	1	2 or more
23	Hubert	80	Retired	1	1	1
24	Michel	70	Retired	1	1	1

Our qualitative data comes from a sample of e-bike users (N=24), recruited among the beneficiaries of a municipal subsidy for the purchase of an e-bike from the city of Lausanne[35]. Twenty of them were selected among a broader set of participants to an online and postal survey of e-bike users[36]. Meanwhile, four additional users were recruited through staff and students on the campus of the University of Lausanne. The resulting sample was meant to illustrate the diversity of situations of e-bike users in terms of age and gender. Table 5 shows the age, employment status and mobility equipment of our respondents. They include 14 men and 10 women, with ages ranging from 25 to 81 years old at the time of the interview. A high proportion of users had a tertiary education, and most were professionally active, which reflects results from other studies, including our own quantitative survey. Eight users out of twenty-four had owned several e-bikes and the date of purchase of the first e-bike ranged from 1996 to 2018, although only four users have owned an e-bike for longer than 10 years. In addition to an e-bike, eighteen users out of 24 (75%) indicated owning a conventional bicycle, a higher proportion than in the municipal population. Additionally, only half (12 out of 24) had a car available in their household, which is slightly more than households in the urban municipality.

Our qualitative sample covered diverse situations of e-bike use, but shows some differences compared to the survey of e-bike users we conducted in Lausanne, which included a small majority of women (53%), fewer users over 60 years (19%), and a larger proportion of users between 40 and 59 years of age (45%). While our sample includes more experienced, long-time users who have owned several e-bikes, the survey indicates that two thirds of e-bike users in Lausanne are recent, having only made their purchase in the last two years. We discuss the further implications of this sample for the generalization of our results in section 5.

4.5.2 Interviews

Retrospective biographical interviews were conducted for approximately one hour and covered both the long-term relationship to cycling over the life course and the short-term period around the purchase of the e-bike. While quantitative data has been used to study the timing of biographical events and variations in travel behavior, some authors suggest the complexity of influences and decision processes during these events is more suited to qualitative analysis (Lanzendorf, 2003; Müggenburg et al., 2015). In line with so-called narrative approaches to mobility biographies, we chose to use semi-structured interviews rather than life course calendars, which allow a more inductive data collection and a focus on changes in meaning over time, rather than on linear sequences of events (Sattlegger & Rau, 2016).

[35] The subsidy has existed since the year 2000. At the time of survey, it covered 15% of the price of an e-bike, with a maximum of 500 swiss francs. Its conditions are widely known and promoted to customers by bicycle shops in the region, and as such it applies to all buyers of a new e-bike residing in the city. An additional subsidy is also available for the purchase of an e-bike battery (100 swiss francs).
[36] A quantitative survey targeted over 3,400 users in the city and yielded 1,466 responses. Among them, 717 users agreed to be contacted for interviews.

Although using a retrospective approach implies a recall bias, qualitative data forces respondents to give more detailed information and can provide a better recollection of events than quantitative data (Behrens & Mistro, 2010; Beige & Axhausen, 2008; Lanzendorf, 2010; Oakil et al., 2016). Additionally, our focus on the purchase of the e-bike was generally helpful as this moment was recalled well by most of our interviewees and had taken place only few years prior. Using the date of purchase of the first e-bike as a point of reference was found to be useful to activate discourse on mobility practices before and after the purchase of the e-bike. As can be expected, the recollection of events leading to the purchase of the first e-bike was easier for people who had recently purchased it than for more experienced users who had owned multiple e-bikes. The latter were also prone to mixing motivations for the first purchase with more specific technical requirements for later vehicles.

Our interview guide included five parts: a description of the household and its mobility equipment, of the adoption of the e-bike, the long-term relationship to cycling and other transport modes, of travel behavior before and after purchase of the e-bike, and of the experience of using the e-bike. The resulting interviews were transcribed and coded with the software Atlas.Ti. Individual cycling trajectories were constructed, which consisted in a timeline of periods of bicycle and e-bike use, as well as specific dates for biographical events. The trajectories were then classified on the basis of the following criteria: (1) the presence of a significant period (minimum one year) of interruption in cycling practice in the years before the purchase of the e-bike, (2) the perceived frequency of cycling at the time of purchase of the e-bike and its variation throughout the life course, (3) the type of cycling practised, with a distinction between transport or utilitarian trips taken in relation to other activities, and sports or leisure trips taken for their own sake.

Following H. Jones et al. (2015) who categorized trajectories depending on their evolution, "resilient" or stable, "restorative" or increasing, and "diminishing", we distinguish between two main types of cycling trajectories: resilient and restorative trajectories. Diminishing trajectories are not included as they are not found in the case of the e-bike users we interviewed, because the e-bike purchase always resulted in an increase in cycling[37]. The e-bike users who were not cycling regularly for transport at the time of the purchase of the e-bike, or had experienced an interruption in their cycling practice in the years before, were considered as having a restorative trajectory. Those who indicated that they had been regularly cycling for transport before buying an e-bike and did not experience an interruption in their cycling practice in the last years were considered to have a resilient trajectory.

4.6 The cycling trajectories of e-bike users

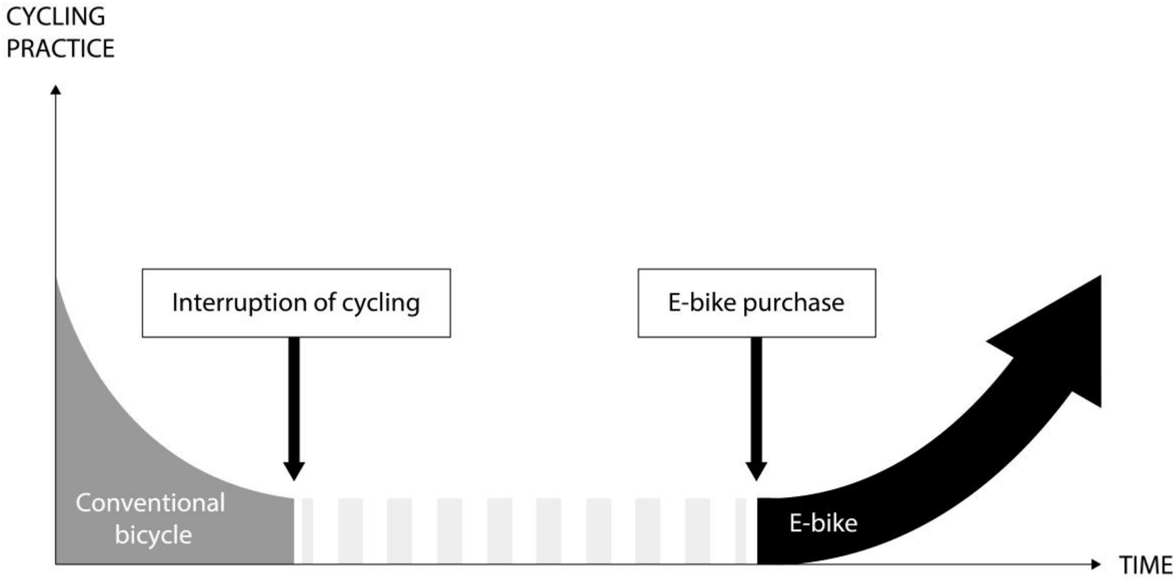
Our results are structured in two parts corresponding to the two cycling trajectories. For each cycling trajectory, we describe the general characteristics and subcategories and give examples of individual e-bike users.

4.6.1 Restorative trajectories: Using the e-bike to restart cycling

Restorative trajectories account for 14 users out of a total of 24 (58%). They correspond to e-bike users who, at the time of the purchase of the e-bike, were not cycling for transport anymore. The effect of purchasing an e-bike was to restore a regular cycling practice, as represented in Figure 39.

[37] The survey tends to confirm this as only 0.6% of respondents stated that they “never” use their e-bike. As former e-bike users may be less likely to respond, this share could be higher but still represents a small minority.

Figure 39. Restorative cycling trajectory. Source: Author.



Though they knew how to ride a bicycle, some e-bike users had never done so regularly, while others had cycled during youth before interrupting this practice. Interruptions to cycling mostly occurred in favor of other modes of transport, most often car use. They were linked to work obligations, and for women in particular, to parental duties while raising their children, confirming other studies (Bonham & Wilson, 2012). During this period of interruption, some users did not own a bicycle anymore, while others still cycled occasionally for recreation, as the dashed line in Figure 39 represents. This trajectory includes three subcategories, depending on the level of cycling practised before the adoption of the e-bike: returning to cycling (1), starting to cycle for transport (2), or continuing a return to cycling (3).

4.6.1.1 Returning to cycling

The first category of users (no. 01, 04, 09, 23, 24) had cycled regularly for transport at some point during their life course before interrupting this practice for a period of several years. The wish to practise physical activity and preserve one's health was often cited as an important motivation in adopting the e-bike, especially for middle-aged users. The adoption of the e-bike had the effect of restoring their cycling practice to a level similar or higher than previously. An example of this is Denis (52), who used to cycle to work when he was younger and living abroad. He had stopped cycling since moving to the city because the gradient made it too difficult to do so with a conventional bicycle. He adopted an e-bike as a way of doing some exercise and in order to bring his children to school without driving them by car:

> [Denis, 52] "Before, I always used to cycle. When I was in [another city], it was flat, and in [another city] as well. I went to school by bike as a kid. I always cycled to get around, never as a sport but as a way to move around. But in Lausanne, working downhill when you live uphill, some hills are really steep, like the road in front of our home. So, I hesitated for a long time, and then I thought an e-bike would not be bad and would help me avoid using the car "

4.6.1.2 Starting to cycle for transport

The second category of users (no. 02, 05, 14, 16, 18) considered themselves non-cyclists and had never cycled regularly. Their adoption of the e-bike was motivated in part by the practicality of the e-bike and a frustration with car use in an urban setting. An example of this is Daniel (34), who used to drive for work and rode a scooter (motorized two-wheeler). Coming from a rural region, he did not cycle at all before moving to the city. When he changed job to a location closer to the city center, using the car became too cumbersome because of traffic and parking restrictions. As he was simultaneously becoming a father, he took the opportunity to sell his car and bought an e-bike to go to work and carry his child. He also got rid of his scooter. Although his example of a switch to the e-bike goes with a larger transition in his lifestyle, he considers the e-bike as something different than conventional cycling.

> [Interviewer] " Did you cycle before [purchasing the e-bike]?"
>
> [Daniel, 34] "No, I didn't cycle at all before."
>
> [Interviewer] "How did the idea of cycling come to you?"
>
> [Daniel, 34] "It wasn't really cycling, in reality. I like the freedom that cycling gives you. I also have a scooter that I had more trouble giving up. I wanted to get rid of the car and keep the scooter. But after a few months, I also decided to sell my scooter. I've given it to a friend for now, because I don't use it anymore."

4.6.1.3 Continuing a return to cycling

After stopping cycling for several years, the third category of users (no. 07, 17, 19, 22) had attempted to return to cycling with a conventional bicycle, before switching to the e-bike. Their use of conventional cycling was generally limited and complemented by other modes such as public transport. Adopting the e-bike was seen from the viewpoint of the conventional bicycle as a way to make cycling easier. It had the effect of continuing a return to cycling that had already been started. An example of this trajectory is Jacques (61), who used to cycle for sport and as a commuter when he lived in another city, before interrupting cycling. Following a heart disease, he returned to conventional cycling as a less intensive form of exercise. He decided to switch to an e-bike due to his physical condition, as he felt he could not hold up anymore when cycling with his partner. This pushed him to cycle more regularly to work.

> [Jacques, 61] "We talked about it with my partner because we noticed in our [bicycle] tours that I was having more and more trouble. She also had knee problems, so she bought her [e-bike] first. We noticed that we were not performing as well as before and that's what decided us."

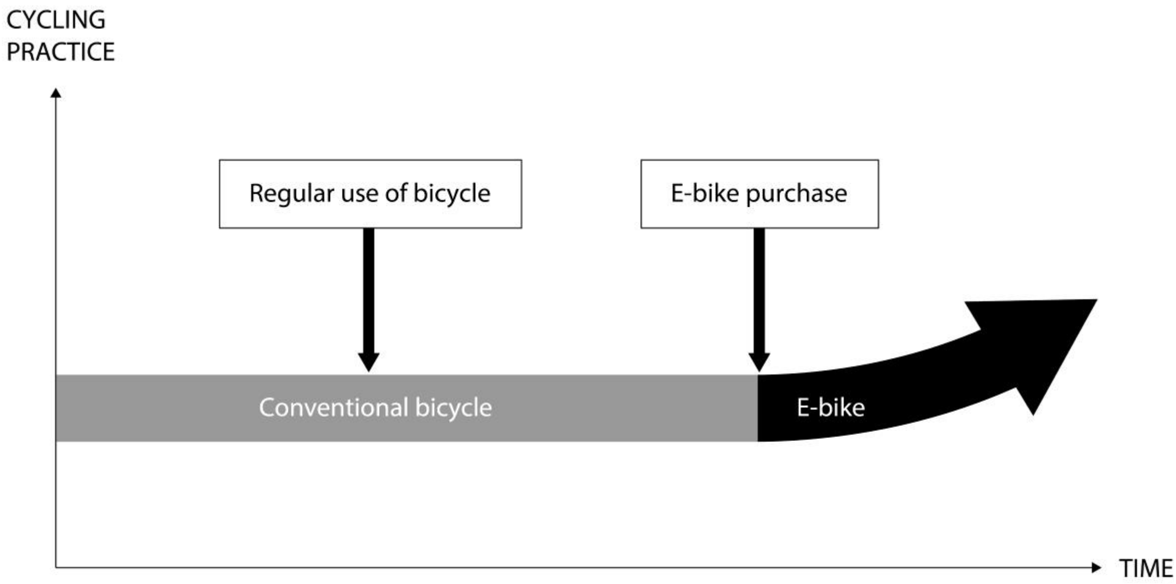
Restorative trajectories show that the e-bike constitutes, for many users, a return to a cycling practice that is less demanding than conventional cycling. In this sense, the e-bike has been called a "transitional step" towards cycling (Popovich et al., 2014). The subcategories of resilient trajectories reflect differences in the amount of conventional cycling practised before acquiring an e-bike. While some e-bike users are indeed new to cycling, most had already cycled regularly at some point of their life, even though they had stopped before purchasing an e-bike. The third sub-category also indicates that some attempts to return to cycling had been made after an interruption (similar to Bonham & Wilson, 2012), which were then continued with the e-bike.

4.6.2 Resilient trajectories: Maintaining cycling with the e-bike

Resilient trajectories are the second group of cycling trajectories linked to the e-bike. They include 10 users out of 24 (42%). In contrast to restorative trajectories, these people were already cycling regularly before purchasing an e-bike and maintained their practice over time (Figure 40). The e-bike was chosen specifically for its electrical assistance, as a way of maintaining a cycling practice despite contextual changes such as residential and work relocations, childbirth, and aging and diminishing physical capacities.

A common characteristic among resilient trajectories is that cycling was already their main mode of transport. A majority of users with resilient trajectories (8 out of 10) did not own a car, or had given it up. Living car-free can explain the continued importance of cycling as their main mode of transport. Cycling was seen as more than a physical activity, a mode of transport affording freedom of movement and autonomy to access the places of everyday life.

Figure 40. Resilient cycling trajectory. Source: Author.



Resilient trajectories can be distinguished according to whether conventional cycling remained practised alongside the e-bike. Depending on this, we find two subcategories of resilient trajectories: (1) Replacing conventional cycling by the e-bike and (2) Alternating conventional cycling and the e-bike.

4.6.2.1 Replacing conventional cycling by the e-bike

For the first category of users (no. 03, 10, 12, 15, 20, 21), purchasing an e-bike led to a complete replacement of their conventional bicycle. They saw the e-bike as essentially the same practice as conventional cycling, even referring to it as their "bicycle". Their switch to an e-bike was motivated by the difficulty of cycling because of the gradient, the need to carry children, or the increase of age. While some had given up or sold their conventional bicycle as a result, others had kept it but did not use it anymore. An example of this is Stéphanie (38), who used to cycle in another city and never owned a car. She moved to Lausanne and started using a conventional bicycle for work trips. When she was expecting her first child, she decided she would need an e-bike to keep cycling because of the additional weight, and bought an e-bike.

> [Stéphanie, 38] "The idea [of buying an e-bike] came with my pregnancy, I thought how am I going to carry my baby? […]. As soon as I saw the e-bike I thought it was what I needed to carry my child by bicycle, otherwise I wouldn't manage in Lausanne. In [another city] it would have been logical to use a child seat on a normal bicycle, but here it wasn't. So, I found a way to make it work."

4.6.2.2 Alternating conventional cycling and the e-bike

The second category of users (no. 06, 08, 11, 13) continued to use a conventional bicycle alongside an e-bike. Having a strong attachment to conventional cycling, they viewed the e-bike not as a replacement, but rather a complement to it. Although they justified its adoption by the topography of the city, they considered it a form of "cheating" compared to conventional cycling. Some users switched between an e-bike and a conventional bicycle depending on the type of trip (utility or sport), the level of fatigue or the weather, with the lighter, conventional bicycle more suited to warm summer months while the e-bike was preferred in winter. An example of this trajectory is Paul (30), who did not own a car and had been a regular cyclist for transport for many years. When he moved out of the city center to the suburbs, he decided to purchase an e-bike as a way of staying independent from public transport. He insisted on keeping his conventional bicycle to alternate with the e-bike in the summer months.

> [Paul, 30] "I wanted to keep my independence for longer during the year, because as soon as the weather gets cold, a regular bicycle is annoying because you sweat, it's unpleasant […]. E-bikes are well-built and comfortable with larger tires, so even when it rains, though maybe not if it's snowing, but almost all year I can cycle. That's the main reason why I bought an e-bike."

Resilient trajectories and their subcategories show that e-bike use and conventional cycling are both part of the same practice. For these users with a strong bond to cycling, adopting the e-bike is a way of maintaining cycling, even when circumstances would make conventional cycling difficult. This trajectory also shows that the e-bike does not necessarily replace conventional cycling, as both can be complementary to one another. However, despite their limitations and the effort they require, conventional bicycles retain specific advantages over e-bikes, for example as a form of exercise, as the following quote by Sarah (33) shows.

> [Sarah, 33] "It's special because with the e-bike I don't feel like I'm doing exercise. Since I'm used to a real bike and I also exercise in my free time, it's not…Yes, it makes me move a bit, it's certainly better than doing nothing but I don't consider it as exercise. This feeling of freedom and well-being, I have it more with a real bicycle, that's also why I keep using one as much as I can in the summer."

4.7 Discussion

The e-bike offers an insight into the adoption of a new mode of transport, but also into the long-term relationship people have to cycling. Existing literature on the e-bike tends to adopt a cross-sectional rather than biographical approach. Most studies do not specifically address e-bike users' past experience of cycling, although it may explain current e-bike use. In this paper, we have tried to fill this research gap, by applying the concept of cycling trajectory (Chatterjee et al., 2012; H. Jones et al., 2015) to include the practice of conventional cycling, and electrically-assisted cycling, over the life course. Our study aimed to question how the sub-practice of the e-bike fits into an existing conventional cycling practice.

Our results confirm that the purchase of an e-bike is part of a longer process that stretches throughout the life course and links with conventional cycling. E-bike users have different cycling trajectories, which we categorized following H. Jones et al. (2015) as either "restorative", where the e-bike constitutes a return to cycling, or "resilient", where it is a continuation of conventional cycling. Resilient and restorative cycling trajectories represent two different relationships to cycling.

For restorative trajectories, the e-bike constitutes a return to cycling after an interruption of several years, or a way to start cycling for transport. E-bike users with this trajectory either did not cycle or interrupted cycling for various reasons among which work obligations or child care, with cycling overshadowed by other mobility practices like car use and public transport. Their motivation to adopt the e-bike was often linked to the wish to take up a physical activity which was less demanding than conventional cycling. This relates to the findings of other studies that the e-bike minimizes stress on the body for people with injuries (Johnson & Rose, 2015; T. Jones, Harms, et al., 2016; Leger et al., 2018). Among restorative trajectories, the e-bike may be used as a return to cycling after an interruption, as a way to start cycling for transport, or as a continuation of a return to cycling that had already begun previously. This shows that different forms of returns to cycling may exist, as shown by Bonham & Wilson (2012).

For resilient trajectories, the e-bike was adopted as a continuation of an uninterrupted conventional cycling practice. For people who saw cycling as their main mode of transport, the e-bike represented a way of preserving this practice despite challenges posed by biographical changes like childbirth or the advance of age, and changes in spatial context which made it difficult to keep cycling. Our findings confirm that switching from a conventional bicycle to an e-bike can be an "adaptive" change in order to maintain cycling (H. Jones et al., 2015), or to avoid interrupting cycling due to a decline in health or physical ability (T. Jones, Harms, et al., 2016; Leger et al., 2018). Among resilient trajectories, there are users who entirely replaced their conventional bicycle by an e-bike, while others alternate between using both. These subcategories show how both e-biking and conventional cycling are closely related, and, in fact, part of the same practice.

Overall, cycling trajectories demonstrate the influence of biographical and contextual changes on the adoption of e-bikes. These changes can both act as opportunities for returning to cycling, or as threats to its continuation. This parallels the finding of Bonham and Wilson (2012), who noted the "circularity" of cycling and its tendency to return at various moments of life. By removing barriers to conventional cycling linked to distance, physical effort, or weight, the e-bike could play a role in reducing interruptions to cycling during the life course. However, e-bikes will not solve everything, and interruptions to cycling may also be due to an unsupportive cycling environment. Both maintaining and attracting e-bike users requires cycle friendly infrastructures which must satisfy criteria of cohesion, directness, attractiveness, safety and comfort (CROW, 2016).

The choice of a qualitative sample allowed us to gain an in-depth appreciation of the diversity of personal situations of e-bike users. However, this also means the proportions we found for restorative (58%) and resilient trajectories (42%) are not exactly representative. Our questionnaire survey among the population of e-bike users in Lausanne actually found restorative trajectories to account for about 3 e-bike users out of 4 (73%), whereas resilient trajectories represented 1 in 4 users (27%).

It is likely that the proportions of these two trajectories (restorative and resilient) may differ in other contexts. In Denmark, Haustein and Møller, (2016) found that close to half of e-bike users previously cycled several times a week, while 1 out of 4 did so less than once per month, suggesting a higher part of resilient trajectories. Similarly, in the Netherlands and Great Britain, T. Jones et al. (2016) found that half of the interviewed e-bikers previously used conventional cycling as their main mode of travel.

One possible explanation for the observed differences may be the particularly hilly setting of Lausanne, and its low modal share of cycling. Other studies may find different characteristics for e-bike users depending on the ease of practicing conventional cycling due to topography, cycling infrastructure or cycling culture. This was acknowledged by some e-bike users who maintained that they would go back to conventional cycling if they lived in a flatter city. For example, younger individuals who would not need to use an e-bike elsewhere might be overrepresented in Lausanne, while difficult cycling conditions might lead to underrepresenting older e-bike users.

Future research should strive for a better understanding of the diversity of e-bike users. This implies studying the cycling trajectories of e-bike users in different spatial or topographical settings, as well as different cycling environments. One area that presents much potential for e-bike research is in suburban and rural settings, where the development of e-bikes has been higher than in urban areas (for Switzerland, see Ravalet et al. 2019).

4.8 Conclusion

With increasing sales and availability of data on e-bike users, the future development of e-bikes presents an interesting avenue for research. Ongoing trends in cycling might change the proportions of cycling trajectories. E-bikes have been increasingly diffusing, attracting women and younger users, and moving away from their initial audience of elderly cyclists (Peine et al., 2017; Ravalet et al., 2018). Meanwhile, an increase in overall levels of cycling (Buehler & Pucher, 2012b) coupled with receding car ownership among young adults (Rérat, 2018) can be expected to increase the number of resilient cyclists, who are at present a minority, over time.

Moving beyond conventional, cross-sectional approaches of individual modal choice, biographical approaches to mobility have forced us to rethink the way mobility changes over time through key events and the influence of social, familial and historical contexts. The study of mobility trajectories may be a useful tool to visualize and analyze how past experiences can influence mobility behavior over time. Cycling trajectories offer the possibility to view cycling as a long-term practice over the life course rather than just a daily decision. This may offer a more realistic view of cycling, which has been systematically underestimated because of its short trips, and the difficulty of categorizing leisure and utility trips. By extending the possibilities of cycling in terms of distance, physical effort, age, and carrying capacity, but also, by maintaining cycling over time, the emergence of e-bikes may fit the needs of a larger spectrum of people who would otherwise not cycle. Rather than opposing conventional and electrically-assisted cycling, and the sustainability of a switch from one to the other, e-bikes should therefore be seen as an opportunity to enlarge the potential of cycling.

5. The Cycling Trajectories of E-Bike Users: A Biographical Approach

5.1 Presentation of the article

The second article of the thesis complements the findings of the first article by estimating the share of e-bike users' cycling trajectories within a larger quantitative sample. It uses a mixed-method approach combining 24 biographical interviews with quantitative data from a large-scale survey (N=1466). E-bike users with restorative trajectories (i.e. who have returned to cycling after an interruption) are found to account for 73% of the sample, while the remaining 27% have resilient trajectories (i.e. they continue cycling). A binary logistic regression identifies the factors associated with having a resilient rather than restorative trajectory. Resilient e-bike users are more likely to be aged over 60 or 40-59, and to be male rather than women, while restorative users are more likely to be female and younger. Compared to restorative users, resilient users are unlikely to own a car nor a motorized two-wheeler, but more likely to own a conventional bike and car-sharing pass, suggesting their mobility revolves around cycling for transport. In terms of e-bike use, resilient trajectories show a more intensive use both for weekly frequency and for winter use, suggesting that unlike restorative trajectories, they are more resilient cyclists. The trips for which the e-bike is used suggest that resilient users cycle more for leisure (recreation), while restorative users have a more mixed use combining utilitarian trips (work, shopping, going to activities) and leisure, although this difference may be explained by the former's higher age or to sample size and composition. The article concludes by proposing that e-bikes may help to engage with cycling over the whole life course, avoiding interruptions to cycling. The growth of e-bike sales could mean a growing part of resilient trajectories. Finally, mixed methods combining biographical approaches with quantitative give important insights for the increasing complexity of travel patterns, which traditional cross-sectional quantitative approaches are unable to match.

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5.2 Abstract

This chapter uses the concept of a cycling trajectory to study the past mobility practices of users of electrically assisted bicycles (e-bikes) and the relationship between conventional cycling and e-bike use. A mixed method approach combines interviews and a quantitative survey of e-bike users in Lausanne, Switzerland. We identify two types of cycling trajectory: restorative trajectories, where the e-bike helps the user to return to cycling after an interruption of several years, and resilient trajectories, where the e-bike is used to maintain a continued cycling practice. Within these trajectories, users differ in terms of socio-demographic profile, mobility equipment and type of use of the e-bike. Our results highlight the need to consider both the continuity of and interruptions to cycling over the life course.

5.3 Introduction

The use of electrically assisted bicycles, or e-bikes, also known as pedelecs, has spread rapidly in recent years. E-bikes currently represent 32% of bicycles sold in Switzerland (Velosuisse, 2019), 40% in the Netherlands (RAI, 2019) and 45% in Belgium (Bike Europe, 2017). They have an electrical motor, providing assistance with pedalling[38], and may enlarge the appeal of cycling to a broader population (Behrendt, 2018). They share many similarities with conventional bicycles and can be considered as a sub-category within *velomobility*, or the practices, systems and technologies of cycling (Watson, 2013). Along with shared bicycle systems, foldable bicycles and cargo bikes, the rise of the e-bike can be situated within a general resurgence of cycling in cities (Buehler & Pucher, 2012b).

Little is known about the past mobility practices of e-bike users. Until recently, cycling has mainly been approached from a cross-sectional viewpoint (Handy et al., 2014); however, in line with a growing literature on biographical approaches to mobility, we argue that a longitudinal approach is necessary to understand the adoption of the e-bike. Using the concept of a cycling trajectory, which represents an individual's changing relationship to cycling over their life course (see Driller et al., 2020; Rau et al., 2020), we consider both the use of the e-bike and conventional cycling as part of the same, life-long practice.

We adopt a mixed method approach, using data from interviews (N=24) and a survey (N=1,466) with e-bike users in Lausanne, Switzerland[39]. This chapter is structured as follows: we first present the theoretical framework (drawing on the literature on the e-bike and on biographical approaches to cycling) and the methodology used. We then present our results, highlighting two main types of trajectory for e-bike users, before concluding with a few final remarks.

5.4 Theoretical framework

5.4.1 Research on the e-bike

Literature on the e-bike shows contradictory results for user profiles, depending on the national context in which the study was conducted. Indeed, as has been observed for conventional cycling (Buehler & Pucher, 2012b), cycle-friendly countries have more diversity between users in terms of age or gender than less cycle-friendly ones. The majority of e-bike users in studies in Denmark are women (Haustein & Møller, 2016a), whereas more men have been found among e-bike users in the United States (MacArthur et al., 2014) and Australia (Johnson & Rose, 2013), and among older users in Austria (Wolf & Seebauer, 2014). With regard to age, users younger than 25 and older than 75 years old are generally strongly underrepresented because of barriers due to the price of e-bikes and physical limitations, while mature age categories between 40 and 65 years old are overrepresented in many studies on e-bike users (e.g. Johnson and Rose, 2013; MacArthur et al., 2014), with the exception of an Austrian study in which the majority of users were retired people over 65 (Wolf and Seebauer, 2014). People with high income and education levels are overrepresented among e-bike users (Johnson & Rose, 2013; MacArthur et al.,

[38] In this study, we only include e-bikes or "pedelecs" which are pedal-assisted. In Switzerland, this refers to two categories of vehicle depending on the speed enabled by the assistance and the power output, namely regular e-bikes with an assistance until 25 km/h (also known as pedelecs in other contexts), and "fast" e-bikes with an assistance until 45 km/h (also known as s-pedelecs). Although there exist forms of e-bikes where no pedaling is required and a trigger activates an electric electric motor, they are uncommon in Switzerland and fall outside these legal categories.

[39] The authors are thankful to the Industrial Services of the City of Lausanne (Services industriels de Lausanne – SiL) for supporting this research through their energy efficiency fund.

2014; Wolf & Seebauer, 2014); with regard to residential location, Wolf and Seebauer (2014) show that most e-bike owning households live in suburban or rural settings and not in the inner city. In another study, we have found that e-bike ownership in Switzerland increases with household size and income and with possession of a conventional bicycle, which is more common in rural and suburban areas (Ravalet, Marincek, and Rérat, 2019), while the intensity of use is higher in urban areas.

Why do people purchase an e-bike? The most frequent motivation, compared to the conventional bicycle, seems to be the ability to cycle further without being too tired (Johnson and Rose, 2013; MacArthur et al., 2014; Popovich et al., 2014; Haustein and Møller, 2016; T. Jones et al., 2016), or the ability to cycle despite a steep uphill (Ahrens et al., 2013; Dill and Rose, 2012). The increased fun the e-bike delivers while cycling is also important (Haustein and Moller 2016). For people who would currently not use a conventional bicycle, one of the main motivations is the ability to continue cycling despite a decline in physical capacity due to age or health problems (MacArthur et al., 2014; Popovich et al., 2014; T. Jones, Harms, et al., 2016). The desire to start cycling again and the health benefits from this activity can also be a motivation (Johnson & Rose, 2013; Popovich et al., 2014). Lastly, environmental concerns, such as wanting to reduce car use, are also mentioned, especially in the United States or Australia (Dill & Rose, 2012; Johnson & Rose, 2013; MacArthur et al., 2014).

The study of the effects of the e-bike on other modes has focused mainly on car use and conventional cycling. Indeed, e-bikes can reduce the overall number of trips made by car, as found in the Netherlands (Kroesen, 2017) and by a study in Denmark, which found that the e-bike was seen as a replacement for one of the cars in the household (Haustein & Møller, 2016a). In some cases, the e-bike also seems to replace the conventional bicycle, particularly in cycle-friendly countries where people are often already cyclists (Lee et al., 2015; Wolf and Seebauer, 2014; Kroesen, 2017). In Norway, a trial study found that cyclists who switched to an e-bike increased the distances and the total number of trips travelled by bike (Fyhri & Fearnley, 2015), a result which was also confirmed in other studies (Kroesen, 2017).

Little is known about how the practices of conventional cycling and the e-bike are linked at the individual level. To fill this gap, a broader, longitudinal view of mobility over time is needed, rather than a cross-sectional approach at a specific moment. The following section elaborates on this by presenting the literature on biographical approaches to cycling.

5.4.2 Biographical approaches to cycling and the cycling trajectory

Cycling research has been mostly cross-sectional in its nature, as noted by Handy et al. (2014). However, it seems particularly suited to a biographical approach as a life-long practice, learned as a child by most people in western countries. At the same time, cycling is often interrupted and is practised more irregularly than other modes of transport, as well as being generally underestimated in the field of transport. Building on this, a series of studies have provided interesting insights on how the practice of cycling varies for people across the life course.

In a qualitative study of female cyclists in Australia, Bonham and Wilson (2012) showed that cycling was interrupted almost systematically throughout the life course in an automobile-oriented society. However, they also indicated that women were more likely to return to cycling due to their changing life circumstances (familial roles and childbirth), with many trying at some point in their life to reinstate this practice.

Chatterjee et al. (2012; 2013) developed the notion of “cycling trajectory” as the application of a life course approach to cycling: *"People arrive at their current cycling behaviour within trajectories that* *are developed over the course of their lives and shaped by transitions (or life-change events) that they have made and the contexts that they encounter"* (Chatterjee et al., 2012, p. 5). Changes in cycling practice were seen as the result of a deliberation process triggered by life events (e.g. having children) and/or changes to the external environment (e.g. residential moves), which led to a reconsideration of mobility practices. During this deliberation, the individual's personal history of cycling, along with their motivations (e.g. keeping fit) and "facilitating conditions" (e.g. parking facilities), played the role of mediating factors. In a subsequent study, Chatterjee et al. (2013) found that some life events were more likely to affect younger people (e.g. residential relocation or childbirth), while others were more likely to inhibit older cyclists (e.g. health issues).

By studying long-term trajectories using life history calendars, Jones et al. (2014) found that cycling was affected by periods of uncertainty around the time of entering adulthood and during the transition to retirement, in contrast to longer periods of stability during middle age. Eight types of cycling trajectory were identified, depending on the life course and the purpose of cycling (recreational, transportation or mixed): "no cycling beyond childhood", "cycling in early adulthood", "one-off experiences in adulthood", "unsuccessful return as adult", "twenties dabblers", "leisure purists", "revolving returners" and "committed commuters". These trajectories were also categorised as either resilient (stable), restorative (increasing) or diminishing (decreasing) in the long term. Although these studies focused on conventional cycling, the e-bike was mentioned for older users as constituting either an "adaptive change", to maintain cycling, or a "restorative change", as a way of taking up cycling again.

While cycling research has used biographical approaches, most research on the e-bike has not taken advantage of this possibility. An exception to this is a German-language doctoral thesis by Le Bris (2016). Focusing on the adoption of the e-bike, she found that its users already had a positive orientation towards cycling and had already engaged with this practice during their life course. She saw the e-bike as enabling the conservation, reactivation or facilitation of cycling, as well as increasing the overall amount of cycling.

These qualitative findings offer interesting insights, which have yet to be confirmed on a larger scale. Our contribution to emerging research in this field uses a mixed method approach which includes a qualitative and quantitative sample of e-bike users. We thus aim to answer the following question: *How does e-bike use fit into an individual's life-long cycling practice?*

5.5 Methodology

The present study was conducted in Lausanne, the fourth-largest city in Switzerland, which has a population of 140,000 inhabitants and is at the core of an urban area of 420,000 inhabitants (SFSO, 2019). Located on the shores of Lake Geneva, the city is built on hilly terrain, which makes cycling difficult. This, in addition to a lack of cycling infrastructure, means that bicycle share in Lausanne is the lowest for large cities in Switzerland, with only 1.6% of trips made by bicycle in 2015 compared to an average of 7% on the national level (Rérat, 2019).

Quantitative data was taken from a questionnaire survey specifically targeting e-bike users (N=1,466) who had benefitted from a grant for the purchase of an e-bike by the City of Lausanne[40] as part of its policy to promote an energy transition. Only respondents who said that they owned an e-bike were considered. An online survey was sent to those for whom E-mail addresses were available, and a postal survey sent to the rest of the participants; the global response rate was 45%. The results from both the online and postal surveys were combined. The survey included questions regarding the profile of e-bike owners and their mobility practices, as well as motivations, barriers and experiences related to the use of the e-bike.

Qualitative data was obtained through in-depth interviews (N=24) conducted with a sample of e-bike users recruited among participants to the quantitative survey and reflecting a variety of socio-economic and demographic profiles. In line with narrative approaches to mobility biographies described above (Sattlegger & Rau, 2016) we chose not to use a life history calendar but rather conducted open-ended interviews with a biographical focus on cycling practices across the life course. We concentrated on the period before and after the acquisition of the e-bike, including major life course events in order to reconstruct cycling trajectories.

The e-bike users we interviewed were aged from 25 to 80 years old, with eight being aged under 40, eight between 40 and 59, and eight over the age of 60. Most of them worked full time (12) or part time (3), while a smaller proportion was retired (7), unemployed (1) or studying (1). They were found to have a high level of education, with 67% having accomplished some form of tertiary education.

5.6 A qualitative account of the cycling trajectories of e-bike users

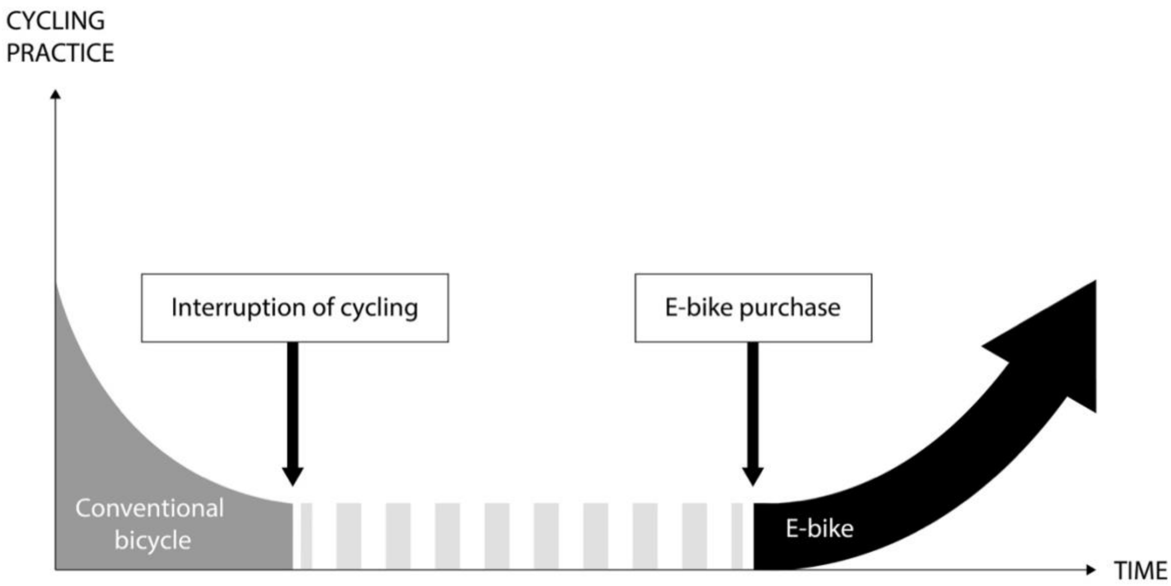
Our cycling trajectories of e-bike users reference the categorisation adopted by Jones et al. (2015) of resilient, restorative and diminishing trajectories. We adapted this categorisation, however, because none of the e-bike users we interviewed could be said to have a diminishing trajectory, which can be explained by the fact that all had recently purchased an e-bike. Moreover, as we consider specifically the role of the e-bike with relation to the existing cycling trajectory, we focus on the period of purchase of the e-bike.

5.6.1 Restorative trajectories: using an e-bike to (re)start cycling

The first family of cycling trajectories is "restorative" and applies to individuals who had stopped cycling regularly as a means of transport several years before adopting the e-bike. This interruption of cycling is represented as a dotted line in Figure 41, as some people may continue to cycle for leisure or on holiday. Purchasing an e-bike enabled these people to take up cycling again, thereby restoring their cycling practice. We use the term "restorative" because all users had learned to cycle during childhood or youth and were not absolute beginners when purchasing their e-bike. The motivation of doing more physical activity, or going on leisure trips with a partner, often played an important role in their choice of an e-bike, especially among mature people (aged 50+) or those approaching retirement.

[40] The grant was available specifically to residents of Lausanne, but also to businesses based in the city. More than 4000 grants have been given out since its introduction in the year 2000. The value of the grant is now 15% of the price of a new e-bike.

Figure 41: Restorative cycling trajectory



Although they knew how to cycle, some e-bike users were not used to cycling regularly for transport in an urban setting, although they cycled occasionally for leisure (e.g. mountain biking). For others, the e-bike was a way of rediscovering cycling after an interruption lasting at least a few years. Having cycled regularly for transport at some point in their lifetime, they had stopped some years ago for various reasons including a lack of time due to children, or because their workplace or residential location was considered too far away for cycling. A few other users had already returned to cycling a few years previously with a conventional bicycle, before purchasing an e-bike, as evidenced in the quote below. In this case, conventional cycling was quite limited in its scope and complemented by the use of walking and public transport.

> Céline, woman, 69 y.o.: "I had a period, when the kids were little, when I was completely by car, I worked as a teacher in the upper part of the city. After that […] when I was only going to work [in the lower part] I started using the bicycle. […] There was a colleague going by bike, and I was influenced [by him] from about 2002-2003, I was 52-53 years old. […] I changed my bike, I had one that I used for leisure, and bought a new one. […] I also went a lot by foot. It was 25 minutes walking, and I often went back up by bus."

A common theme heard among users with a restorative trajectory was the perceived impossibility of cycling with a conventional bicycle due to the steep hills in the city. On purchasing an e-bike, they rediscovered the pleasures of cycling without the associated physical effort, which made cycling "fun" again.

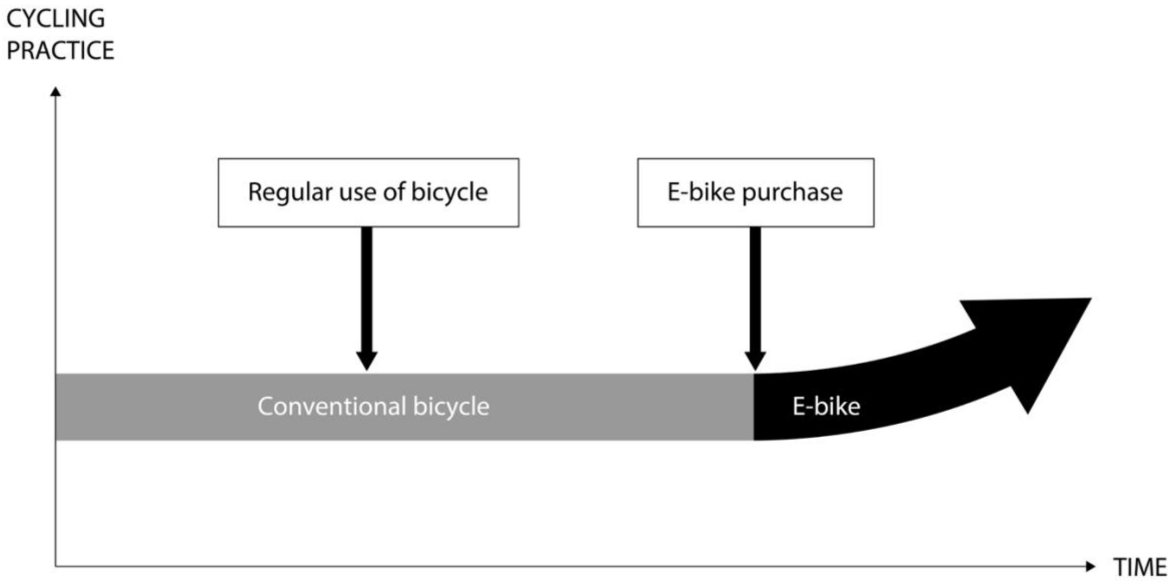
> Nicole, woman, 42 y.o.: "It didn't occur to me to go from [the lowest point in the city] to [an upper street] by bicycle, I think I wouldn't have made it with my daughter in the back, physically. That's why I chose an electric assistance [bicycle]"

> Denis, man, 52 y.o.: "No, [I haven't had a bicycle] since I arrived in Lausanne. Because it goes up and down, and I'm not very athletic, at least not for cycling. I often told myself, hey, I could buy a bicycle, but I didn't have the courage to do it actually."

5.6.2 Resilient trajectories: using an e-bike to continue cycling

Resilient cycling trajectories refer to e-bike users who moved around by bicycle for most of their life before owning an e-bike, as represented by the continuous line in Figure 42. For these users, the e-bike had the effect of maintaining an existing cycling practice, despite contextual changes or physical difficulties.

Figure 42: Resilient cycling trajectory



A common characteristic among resilient trajectories was the importance of cycling as a means of transportation throughout the life course. This continuous use of cycling goes hand in hand with the choice to live without a private car, which relates to the notion of *"altermobility"* (Vincent, 2008), or the search for alternative modes of transport to the car. It also implies, for many users, living in a central location and working within the city boundaries. In this urban context, some users said they had resorted to purchasing an e-bike when moving to a new residential area or changing jobs. The e-bike was seen as a way of continuing cycling more easily or with less effort despite changing biographical circumstances.

> Paul, man, 30 y.o.: "I recently moved to [a village outside Lausanne] and that was when I bought an e-bike, to be able to keep that independence of movement, so I don't need to look at public transport timetables and I can move around when I want to, during the day or the night, by myself."

One of the differences among resilient trajectories concerns the status of the conventional bicycle. While for some users, the e-bike replaced their conventional bicycle as essentially the same vehicle, others users continued to use both a conventional bicycle and an e-bike alongside each other. In particular, younger users often wished to differentiate their utilitarian e-bike practice from a sporting cycling practice, for which the e-bike was considered unfit. Switching between a conventional bicycle in summer, when temperatures are higher and clothing lighter, to an e-bike in winter, was one of the strategies employed in this regard.

> Sarah, woman, 33 y.o.: "It's different because with the e-bike I don't have the impression that I'm doing exercise. Since I'm used to a real bike and I also do some sport, […] this sensation of

freedom or well-being, I have it more with a real bicycle, that's why I keep using it as much as I can in summer.

5.6.3 Differences between restorative and resilient trajectories

The restorative and resilient cycling trajectories of e-bike users differ in terms of the triggers and motivations for using an e-bike, as well as the individual's life-long relationship to cycling.

First, restorative cyclists who turn to the e-bike as a means of getting back into cycling tend to be middle-aged or mature people. Their motivations relate to physical activity and the desire to restart cycling, rather than to a single life event. Resilient cyclists, on the other hand, usually choose an e-bike as a way to carry on cycling despite changing contextual circumstances, such as residential relocation or having children.

Second, the relationship to cycling of e-bike users with resilient trajectories appears to be much stronger than that of users with a restorative trajectory. The strength of cycling in the first case also seems to be linked with the choice to live in deliberately car-free households, making cycling the main mode of transport. For restorative trajectories, where cycling has not been practised for a number of years, other mobility habits have since been put into place, including car use.

The next section pursues the analysis of the two cycling trajectories identified in the interviews by using the questionnaire survey (N=1,466). It aims to quantify the restorative and resilient cycling trajectories among e-bike users in Lausanne, to identify their characteristics and to analyse the impacts of the purchase of an e-bike on their mobility practices.

5.7 A quantitative assessment of cycling trajectories

5.7.1 Frequency and profile

To identify trajectory type, we used the multiple-choice question *"How did you formerly travel for trips which you now take by e-bike?"*[41]. Users who chose "conventional bicycle"[42] are considered as having a resilient trajectory where the person was already cycling for the trips now done by e-bike. Users with other answers imply a restorative trajectory where cycling was not previously practised for trips now done by e-bike. We estimate the proportions of these trajectories in our sample to be 72.9% for restorative trajectories, while resilient cyclists are estimated to account for 27.1% of respondents.

We use a binary logistic regression to identify the differences between the cycling trajectories in terms of the socio-demographic characteristics of respondents, equipment (ownership of vehicles and access to mobility services), and their use of the e-bike (Table 6). A logistic regression allows us to show the influence of each variable on the propensity to belong to the resilient trajectory; this is described in terms of odds ratios, where an odds ratio [Exp(B)] represents the ratio of odds of an event (here, of belonging to the 'resilient trajectory' category) occurring in one group compared to another. A value higher than one implies that the group is more likely to follow a resilient trajectory, while an odds ratio below one implies the opposite. A table of frequencies for each category can be found in the appendix (Table 7).

[41] Such a question has two limitations. First, it might not be clear which period in the life course "formerly" refers to. Second, this formulation may not account for trips which are different to those currently made by e-bike.
[42] Other answers also included walking, car, public transport, motorcycle/scooter, or "I didn't take these trips".

*Table 6: Binary logistic regression for resilient rather than restorative cycling trajectory. N=1,102[43]. Model sig. p<0.01; R2= 0.098 (Cox and Snell), 0.143 (Nagelkerke). *p < 0.1 ,** p < 0.05, *** p < 0.01.*

		B	S.E. (Standard Error)	Exp(B) (Odds ratio)
Age	Under 40 (ref)			
	40 to 59	0.349	0.169	1.418**
	60 and over	1.091	0.222	2.978***
Gender	Woman (ref)			
	Man	0.383	0.150	1.466**
Car in the household	No car (ref)			
	At least 1 car	-0.381	0.212	0.683*
Motorised two-wheelers in the household	No two-wheeler (ref)			
	At least 1 two-wheeler	-0.377	0.179	0.686**
Bicycles in the household	No conventional bicycle (ref)			
	At least 1 conventional bicycle	1.183	0.202	3.264***
E-bikes in the household	1 e-bike (ref)			
	2 or more e-bikes	0.052	0.163	1.053
Public transport pass	No (ref)			
	Yes	0.015	0.149	1.015
Carsharing subscription	No (ref)			
	Yes	0.420	0.204	1.522**
E-bike frequency of use	Every day or almost	0.090	0.232	1.095
	Several times per week	-0.443	0.226	0.642**
	Less often (ref)			
E-bike winter use	No winter use (ref)			
	Used in winter	0.389	0.200	1.475**
E-bike trip purposes	Utilitarian	-0.359	0.167	0.699**
	Mixed (ref)			
	Leisure	0.615	0.274	1.849**
Constant		-2.394	0.352	0.091***

Resilient users are more likely to be over 60 or in the 40–59 age bracket than restorative users[44]. This may be because older cyclists switch from a conventional bicycle to the e-bike because of physical issues. Cyclists with a resilient trajectory are also more likely to be male, while those with a restorative trajectory are more likely to be female. Possible explanations may include the fact that women might

[43] In this model, the sample is composed of 1,102 respondents because of non-responses in some of the questions considered.
[44] Users over 60 years old account for 26.5% of resilient trajectories, but only 16.3% of restorative trajectories.

have to stop cycling more often than men over their life course due to childbirth or the gendered division of work (Bonham & Wilson, 2012), or it may be that they are usually underrepresented among conventional cyclists in cities – such as Lausanne – with a low level of cycling (Garrard et al., 2008)[45].

5.7.2 Equipment in transportation modes

Individuals with resilient trajectories are likely to be from less motorized households than those with restorative trajectories. Cyclists characterised by a resilient trajectory have a greater chance of owning neither a car nor a motorized two-wheeler (motorcycle or scooter). They are therefore more likely to rely on cycling for part of their mobility needs, and the electric assistance helps them to do so. Subscription to a carsharing scheme is logically higher among resilient trajectories, as it compensates for the absence of a private car, while in the case of restorative trajectories, the e-bike may be seen as a way of reducing car use without giving up ownership of a car.

The likelihood of owning a conventional bicycle is, as expected, much higher in the case of resilient trajectories. Such cyclists give greater importance to cycling and are more likely to keep their conventional bike after purchasing an e-bike. In the case of a restorative trajectory, however, an e-bike user is much more likely not to have a conventional bicycle in the household.

Finally, there is no difference between the trajectories if other members of the household also own an e-bike and if the person has a (regional or national) public transport pass.

5.7.3 Use of the e-bike and conventional cycling

We now question whether the use of the e-bike varies in terms of frequency, seasonality and trip purposes (utilitarian, mixed and leisure) according to the two cycling trajectories.

Cyclists following a resilient trajectory have a slightly higher probability of using the e-bike daily than their counterparts, though the odds are not statistically significant; they also have a lower probability of having a lower frequency of use (several times per week). Differences are also found in terms of seasonality. Respondents with a resilient trajectory are more likely to continue using their e-bike in winter than those with a restorative trajectory; this may be explained by their greater experience acquired while cycling with a conventional bicycle (e.g. knowing which equipment to use in winter). They may also be more resilient to harsh weather, or they may simply have reduced access to motorized vehicles. These results show that the intensity of e-bike use is stronger both in terms of frequency and winter use among cyclists with a resilient trajectory. E-bike users who already cycled before seem to be more assiduous than those who bought an e-bike in order to return to cycling.

Journeys are often differentiated depending on whether they are for utilitarian or leisure purposes, as these may indicate very different practices. Based on the stated purposes for which the e-bike was used, we created a variable with three categories of e-bike use: *Utilitarian* (commuting, shopping, and trips to reach leisure activities), *Leisure* (cycling for its own sake or as a sports activity), and *Mixed* (both utilitarian and leisure trips). Compared to restorative trajectories, individuals with resilient trajectories are less likely to have a utilitarian use of the e-bike and more likely to use the e-bike for leisure purposes. This result is surprising at first glance, as we might have expected experienced cyclists to have a more utilitarian practice of the e-bike, and returning cyclists to favour leisure. However, leisure users only

[45] It is worth noting that the e-bike could change this trend as women are overrepresented in our sample (53% vs 47%) and this trend has intensified over time.

account for a small proportion of the sample, namely 8% of resilient trajectories and 12% of restorative trajectories in comparison to utilitarian and mixed users[46] (see Table 7 in the appendix). Moreover, the over-representation of older age groups among resilient trajectories may explain why there are fewer utilitarian users in this trajectory, as older people tend to travel less often for utilitarian trips than other age groups. An additional explanation could be that the stronger cycling habit of those with resilient trajectories is linked to a larger range of activities, including more leisure trips with the e-bike, while newer cyclists would be expected to use it for a more limited range of trips. Finally, as previously noted, trajectories were defined based on whether the trips now travelled by e-bike were previously done by conventional bicycle. Resilient trajectories could therefore include people who only had a strictly leisure-oriented cycling practice.

5.8 Conclusion

Our study aimed to better understand e-bike users by analysing their cycling trajectories, referring both to their past and current cycling practice. The e-bike lends itself well to a biographical approach, as it is simultaneously a new sub-practice within cycling and the continuation of an existing cycling practice. We adopted a mixed method approach based on in-depth interviews and a large questionnaire survey among e-bike users in the city of Lausanne.

Our results identified two main cycling trajectories of e-bike users: restorative and resilient. In restorative trajectories the e-bike helps to restart a practice of cycling that had been interrupted for several years; in resilient trajectories the e-bike is used to continue the practice of cycling. Overall, a number of key differences emerged among the two cycling trajectories, with each corresponding to users with different socio-demographic profiles, mobility characteristics and use of the e-bike. E-bike users who already cycled regularly before buying an e-bike (resilient trajectories) have mobility practices centred around cycling (both conventional and electrically assisted), with less reliance on the car. Conversely, e-bike users who (re)started cycling after purchasing an e-bike (restorative trajectories) have mobility practices more reliant on motorized vehicles, with a higher ownership of cars and motorized two-wheelers.

The use of the e-bike also differs according to cycling trajectory. In resilient trajectories, the use of the e-bike is more often combined with conventional cycling, a high frequency of use and a lower rate of winter interruption. Interestingly, users belonging to this trajectory tend to use the e-bike for leisure more often than users with restorative trajectories, who tend to have a mixed use combining utility and leisure, although this difference could be due to sample size or composition.

Distinguishing different types of cycling trajectory provides a useful addition to existing knowledge about e-bike users and cyclists. Seeing cycling not only as a daily choice but as a life-long practice, as proposed by Bonham and Wilson (2012), can help build a better understanding of differences in mobility practices. Looking forward, more research is needed on interruptions to cycling, their extent and causes, and including retrospective questions about this subject in mobility surveys could give a more realistic appreciation of the variations of cycling throughout time than standard, cross-sectional approaches.

E-bikes can encourage a life-long engagement with cycling by lowering the effort required to cycle, increasing cycling among younger people, and enabling a manageable level of physical activity for

[46] Mixed users are the largest group, as they account for 58.2% of restorative users and 60.2% of resilient users. Utilitarian users account for 33.7% of restorative users and 27.8% of resilient users.

older users. This might outweigh the benefits of conventional cycling in the long term (Johnson and Rose, 2015). With the rapid growth of e-bike sales and a general increase in cycling, the relative proportions of users with each cycling trajectory described here are likely to change. As the social norm of seeing cycling as incompatible with adult life is slowly changing, interruptions to cycling could become rarer, and thus life-long cyclists with resilient cycling trajectories should increase.

Nonetheless, it remains important, especially for novices or returning cyclists, to avoid negative experiences and to make cycling easy on a daily basis. Some interruptions to cycling could be avoided with safer, direct, continuous and attractive cycling infrastructure, as seen in cities or countries with a "mature" cycling culture (Rérat, 2019). In the context of a competition between transport modes, this means accepting the legitimacy of cycling, and the e-bike, as a fully-fledged means of transportation.

To conclude, increasingly multimodal and complex mobility practices call for a fine-grained analysis that goes beyond the traditional, binary approach of modal shift (defined as the replacement of one mode by another). As we have shown, it is important to view cycling in particular over time rather than only at one particular moment, and to acknowledge the evolving relationship people have to their mobility practices, which goes beyond just transport. Second, the adoption of the e-bike may have an impact on both the use and ownership of other modes such as the car or public transport, while also changing the types of journeys by redefining activity spaces. Yet travel patterns may still vary depending on the day or the season. Methodologically, accounting for this complexity poses a challenge. While quantitative data such as that used in this survey remains necessary in order to quantify trends and test hypotheses, we feel that qualitative data, gathered through in-depth interviews, for example, is essential to take things further. As our understanding of mobility continues to grow, it is reasonable to think that mixed-method approaches will become ever more relevant.

5.1 Appendix

Table 7: Frequency table for the logistic regression

		Restorative cycling trajectory	Resilient cycling trajectory	Total
Age	Under 40	38.1%	29.8%	35.9%
	40 to 59	45.5%	43.6%	45.0%
	60 and over	16.3%	26.5%	19.1%
Gender	Woman	56.0%	44.7%	52.9%
	Man	44.0%	55.3%	47.1%
Cars in the household	No car	21.0%	28.8%	23.1%
	At least 1 car	79.0%	71.2%	76.9%
Motorised two-wheelers in the household	1 e-bike	74.8%	80.4%	76.3%
	2 or more e-bikes	25.2%	19.6%	23.7%
Bicycles in the household	No bicycles	33.0%	13.9%	27.8%
	At least 1 bicycle	67.0%	86.1%	72.2%
E-bikes in the household	1 e-bike	75.0%	68.4%	73.2%
	2 or more e-bikes	25.0%	31.6%	26.8%

Public transport pass in % of e-bike owners	Yes	48.6%	56.0%	50.6%
	No	51.4%	44.0%	49.4%
Carsharing subscription in % of e-bike owners	Yes	15.1%	25.4%	17.8%
	No	84.9%	74.6%	82.2%
E-bike frequency of use	Every day or almost	39.9%	48.1%	42.1%
	Several times per week	38.6%	27.8%	35.7%
	Less often	21.5%	24.1%	22.2%
E-bike winter use	No winter use	29.2%	22.0%	27.3%
	Used in winter	70.8%	78.0%	72.7%
E-bike motive of use	Utilitarian	33.7%	27.8%	32.1%
	Mixed	58.2%	60.2%	58.7%
	Leisure	8.1%	12.0%	9.1%

Table 8: Frequency table for the interviews

		Counts	Percentage
Age	Under 40	8	33%
	40 to 59	8	33%
	60 and over	8	33%
Gender	Woman	10	42%
	Man	14	58%
Cars in the household	No car	12	50%
	At least 1 car	12	50%
Bicycles in the household	No bicycles	6	25%
	At least 1 bicycle	18	75%
Date of E-bike purchase	Before 2015	12	50%
	2015	2	8%
	2016	4	17%
	2017	4	17%
	2018	2	8%

6. Key Events, Motivations, and Past Experiences in the Adoption of the E-Bike

6.1 Presentation of the article

The third article, like the first two, takes a biographical approach to e-bike adoption, in line with the mobility biographies approach. It is also based on the same qualitative data from retrospective interviews. However, it focuses on the role of key events and the process by which they may trigger the adoption of the e-bike, as well as the influence of motivations and past experiences. We find that over half of all e-bike users (14 of 24) adopted their e-bike following a key event or a combination of events, either workplace changes, residential changes, childbirth, daycare or schooling changes, health events, or partner-related events. These events can be categorized as (1) contextual changes (workplace, residential, or daycare changes), which change the spatial and also the social context for cycling; (2) biographical changes (childbirth, health events), which alter the conditions for cycling and in the individual's physical capacity; (3) or partner-related events (a partner buying an e-bike), which influence the individual's decision to adopt the e-bike. The main difference between the role of key events for e-bikes compared to conventional bicycles is that many events which traditionally have been found to reduce cycling, such as longer distances, childbirth, or health events, were a trigger for adopting an e-bike. Thus, e-bikes may help to avoid interruptions to cycling. As for the role of motivations and past experiences, we found that specific motivations were related to contextual changes (adopting the e-bike to avoid the car or public transport, being able to cycle uphill), while others were related to more long-term processes of aging (physical exercise, pleasure of cycling). The results of this study had originally been presented at the "Becoming urban cyclists" conference held in Lyon (France) in 2020. The chapter has now been published as part of a book by the organizers of the conference.

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6.2 Abstract

The continued success of e-bikes may encourage more people to take up or return to cycling. However, not much is known about e-bike users themselves. In this paper, we take a biographical approach to explore the role of individual circumstances in the adoption of e-bikes through retrospective interviews in Lausanne, Switzerland (N=24). We investigate the influence of key events in the life course, motivations, and past experiences of cycling on the decision to adopt an e-bike. We find that contextual, biographical, and partner-related events can be linked to e-bike adoption. Focusing the promotion of the e-bike on these events may be useful in order to both retain existing cyclists and recruit new or returning cyclists. Understanding e-bike users' different backgrounds may help target policies to serve their needs better.

Keywords: e-bike, cycling, key events, motivations, past experiences

6.3 Introduction: e-bikes and urban cycling

Urban cycling has much potential as a sustainable mode of transport to replace journeys by car and public transport and increase population health. Electrically assisted bicycles (e-bikes) provide assistance while pedaling, which makes cycling less physically challenging, and may enable a broader spectrum of people to cycle in a wider range of conditions, such as trips that involve carrying loads, or long or hilly journeys (Behrendt, 2018; Rose, 2012). E-bike users include people who had stopped cycling and wish to return to it, as well as existing cyclists who would otherwise have stopped cycling (Marincek & Rérat, 2020). In recent years, e-bike sales have grown significantly and now represent a third of bicycles sold annually in Switzerland (Velosuisse, 2020)[47]. Understanding why and when people adopt e-bikes may be helpful for cycling policies.

Traditional research on cycling considers the effect of determinants in the decision to cycle: the built environment (density), the natural environment (topography, weather), socio-economic variables (age, gender, income, and education level), psychological factors (attitudes), and aspects related to cost, time, effort, and safety (Heinen et al., 2010; Handy et al., 2014; Rérat, 2019). However, cross-sectional data collected at a specific time point may only show a correlation between factors, but cannot establish causality for why people cycle (Janke & Handy, 2019). To gain a deeper understanding of how travel behavior changes across time, mobility biographies research (MBR) adopts a longitudinal view of mobility, which sees current behavior as the result of a life course trajectory (or "mobility biography") influenced over time by "key events" such as residential relocations or childbirth (Lanzendorf, 2003; Scheiner, 2007). Recently, cycling research has started to take advantage of a biographical approach to understand how cycling varies over the course of a person's life, and why and when people start or stop cycling (Bonham & Wilson, 2012; Chatterjee et al., 2013).

Contributors to this book give various clues as to how people become or stay urban cyclists throughout their lives. Sometimes, the impetus for getting into cycling can come from unexpected events, such as the Covid-19 pandemic, which acted as a trigger for cycling in many cities (Cox, 2021). Planned interventions such cycling promotion campaigns (Rérat, 2021b) may also provide an opportunity to try out new habits. Maintaining and developing cycling over time also requires learning certain skills, such as know-how of a given spatial context and its "bikeability" (Adam et al., 2021), or bicycle repair and maintenance skills (Abord de Chatillon, 2021). However, cycling habits can also be fragile, especially for adult beginner cyclists who are vulnerable to interrupting cycling (Buhler, 2021) and weakened by social pressure, as for young women in low-cycling contexts (Sayagh et al., 2021) or second-generation immigrants (Welsch, 2021).

This chapter aims to explore the adoption of e-bikes as one way of "becoming urban cyclists". We argue that e-bike adoption offers an interesting case study for understanding the processes and key events involved in taking up or continuing to cycle. Our research question is simple: What makes people adopt an e-bike? To answer it, we first offer a theoretical framework for biographical approaches to cycling and e-bike use. We then present our method, case study, and data, which is based on retrospective, biographical interviews with e-bike users in Lausanne, Switzerland (N=24). Later, we present and discuss our results in relation to existing literature, before suggesting implications for future research and policy.

[47] There are two categories of e-bike in Switzerland. E-bikes which offer assistance up to 25 km/h (known as "pedelecs") made up 86% of sales in 2018, while those providing assistance up to 45 km/h ("speed-pedelecs") represented 14%.

6.4 Theoretical framework: biographical approaches to cycling

6.4.1 Mobility biographies research and key events as turning points

Mobility biographies research has its roots in life course studies (Elder Jr et al., 2003). The mobility biography refers to an individual's life course trajectory in the domain of mobility (Lanzendorf, 2003), where present behavior is seen as the cumulative outcome of past behavior. It assumes that mobility is influenced by events happening in other domains of life—lifestyle, accessibility for Lanzendorf (2003), employment, household and residence for Scheiner (2007).

Most travel behavior research has focused specifically on the role of key events (also called life events or turning points) as triggers for changing behavior. As most travel behavior is seen as habitual, it is hypothesized that key events break routines and act as a "window of opportunity" for reconsidering travel behavior (Klöckner, 2004; Verplanken et al., 2008). In their review of papers on the subject, Müggenburg, Busch-Geertsema, and Lanzendorf (2015) make a distinction between "life events" that fall outside of transport, such as relationships or childbirth; "long-term mobility decisions" including vehicle ownership and use as well as residential relocations; "exogenous interventions" such as road closures (Marsden & Docherty, 2013); and "long-term processes" of socialization (Döring et al., 2014; Tully & Baier, 2011). Life events can be private or professional. An example of a private life event is the birth of a child, which affects professional activity and leads to changes in travel, especially for women (Lanzendorf, 2010). An example of a professional event is a change in employment, such as a move from full- to part-time work, which is most likely to occur between the ages of 20 and 35 years (Beige & Axhausen, 2008); another example is retirement. Long-term mobility decisions such as residential relocations and changes in vehicle ownership (Clark et al., 2016) imply a substantial cost and long-lasting implications. We choose to consider them as key events, although they may also be considered as adaptations to life events (Müggenburg et al., 2015).

Research on key events has been criticized by some authors for its narrow focus on specific events, leaving out long-term changes in the cultural meanings of transport (Sattlegger & Rau, 2016). While some key events have a limited effect on travel behavior, others, such as getting a driver's license, have been called "mobility milestones" (Rau & Manton, 2016) because they act as rites of passage and have lasting effects over the life course. In some cases, it may be difficult to distinguish between specific key events and longer-term processes, such as retirement or entry into adult working life (Müggenburg et al., 2015). Scheiner (2017) also argues that the social aspects of mobility biographies have been under-researched. Notably, the influence of peers and family (also called "linked lives" in life course research - Elder Jr, 1994) plays an important role in travel socialization among children and youth for the development of individual travel behavior (Baslington, 2008; Döring et al., 2014; Tully & Baier, 2011). Lastly, on a larger scale, individuals should be considered as evolving within a specific social and spatial context or "mobility culture", which influences generations of individuals over time (Deffner et al., 2006; Klinger et al., 2013).

6.4.2 Key events and cycling trajectories

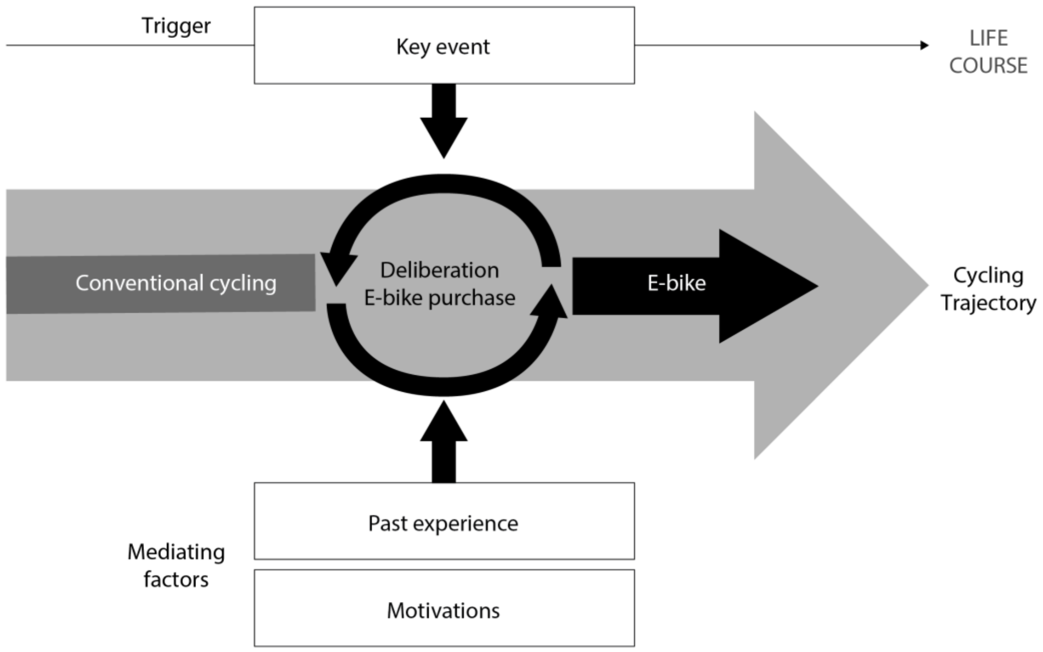
Although most research on cycling is still cross-sectional (Handy et al., 2014), a few studies have adopted a biographical perspective on the variation of cycling throughout the life course. According to a British study (Chatterjee et al., 2013), changes in the frequency of cycling are mostly triggered by one or more life events in the domain of education and employment, relationships, residential location, children's development, physical health, or leisure and fitness interests, while transport-related events (linked to car and bicycle availability) or changes to the cycling environment are less likely to have an effect. In the Netherlands, Oakil et al. (2016) identified residential relocations and job changes as the key events most frequently linked to taking up bicycle commuting, particularly when those changes resulted in shorter commuting distances. Meanwhile, in the United States, Janke and Handy (2019) found changes in cycling at various stages of life to be triggered in particular by residential relocation and meeting a partner, while women mentioned parenthood as both a reason to decrease or increase cycling. Another contribution to this book by Sayagh, Dusong and Papon (Sayagh et al., 2021) found women in France to reduce cycling due to social pressure during their teenage years, and later in life, due to pregnancy and child-care duties.

Going beyond key events, a few studies have used retrospective qualitative data to analyze whole life course trajectories of cycling, or "cycling trajectories". In Australia, Bonham and Wilson (2012) showed that women often returned to cycling despite frequent interruptions due to their changing life circumstances and family roles, challenging linear visions of mobility as a progression from cycling to car use. A series of studies by H. Jones (H. Jones, 2013; H. Jones et al., 2014, 2015) analyzed individual walking and cycling trajectories over the whole life course, and categorized them as either "restorative" (increasing), "diminishing" (decreasing), or "resilient" (stable).

Few studies have sought to understand the theoretical role of key events in cycling. Chatterjee et al. (2012) put forward a conceptual model which sees changes (or "turning points") in cycling as the result of a deliberation triggered by a life course event, a change to the external environment, or a transport-related event, with mediating factors such as personal motivations, facilitating conditions, and personal history (Chatterjee et al., 2012, 2013). This model sees an individual's current cycling practice as the result of a cycling trajectory over their life course which includes "a person's thoughts, feelings, capabilities and actions related to cycling [. . .] developed over the course of their lives and shaped by transitions (or life-change events) that they have made and the contexts that they encounter" (Chatterjee et al. 2012:5). More recently, Janke & Handy (2019) theorized the influence of key events on cycling through four processes, namely (1) forcing a reconsideration of travel behavior, (2) involving changes to the social environment and the norms around cycling, (3) unleashing a latent demand for cycling, or (4) triggering new destinations and interest in cycling (Janke & Handy, 2019).

Our conceptual framework draws from Chatterjee et al. (2012) and is presented in Figure 43. We consider the e-bike within a lifelong cycling trajectory which also includes conventional cycling. Although the adoption of the e-bike constitutes by itself a "transport-related event" in the cycling trajectory (Chatterjee et al., 2013), we assume that it is also influenced by key events which may happen in other spheres of life. We view the deliberation process leading to the adoption of an e-bike as influenced by mediating factors such as intrinsic motivations and past experiences related to conventional cycling (the cycling trajectory).

Figure 43: Conceptual model of the adoption of the e-bike—adapted from Chatterjee et al. (2012), Jones et al. (2015)



6.4.3 E-bike adoption

Research on the e-bike is still quite recent (Bourne et al., 2020; Fishman & Cherry, 2016). Since the first studies in 2006 (Weinert et al., 2006), e-bikes have evolved and become widespread, yet consistent data on e-bike users remains scarce, as there are large differences between studies in terms of geographical origin, sample size and method of recruitment. In this section, we will present existing research on the profile of e-bike users and their motivations for adopting the e-bike.

E-bikes offer an electric assistance which reduces physical effort when pedaling. This means that they may broaden cycling to people who would not consider conventional bicycles, and for trips which may have been considered too difficult (Behrendt, 2018; Rose, 2012). E-bikes have long been marketed to mature and near-retired people between the ages of 50 to 65 years old, who are overrepresented among e-bike users in most studies (see Fishman and Cherry, 2016). The gender makeup of e-bike users follows that of conventional cyclists: women are more represented in cycle-friendly contexts like Denmark (Haustein & Møller, 2016a), but not in the United States or Australia (Johnson & Rose, 2013; MacArthur et al., 2014).

The main motivation for acquiring an e-bike is the reduced effort it requires compared to a conventional bicycle, which presents an advantage over longer distances or hilly terrain. The reduced effort required may also motivate people with reduced strength or physical disabilities (due to age or illness) to continue to cycle (MacArthur et al., 2014; Popovich et al., 2014; T. Jones, Harms, et al., 2016). E-bikes have health benefits because they provide a low-intensity physical activity which meets recommended health guidelines (Bourne et al., 2018; Gojanovic et al., 2011; Van Cauwenberg, de Geus, et al., 2018). A further motivation is the replacement of car trips, for practicality as well as environmental concerns, which has been reported in car-centered contexts in North America or Australia (Dill & Rose, 2012; Johnson & Rose, 2013; MacArthur et al., 2014; Popovich et al., 2014).

Few studies have explicitly considered the role of key events in the adoption of the e-bike. In terms of cycling experience, e-bike users seem to fall into two main categories: existing cyclists, on the one hand, and non-cyclists (or interrupted cyclists) on the other. Le Bris (2016) finds e-bike users to have a pre-existing cycling practice, with the e-bike having the objective of either conserving, reactivating, or facilitating cycling. In terms of trip purpose, Haustein and Møller (2016) distinguish "enthusiastic" users wishing to increase their cycling, "utilitarian" users already cycling, and "recreational" users cycling less regularly for leisure.

Existing research gives some clues as to which key events may trigger e-bike adoption. Among older users, these include health problems or loss of strength which make cycling more difficult (Leger et al., 2018), or "a personal sense of decline in health" (T. Jones, Harms, et al., 2016). For parents, the need to carry young children can also be a trigger for adopting the e-bike, as the additional weight makes conventional cycling difficult (Le Bris, 2016). Another category of triggers are changes in the physical environment, such as the shortening of distances to work or residence, which may lead to switching from the car or public transport to the e-bike (Plazier et al., 2017). Moving to a new city or neighborhood and the resulting change in social and cycling environment may also trigger the adoption of the e-bike, by forcing a reconsideration of existing travel patterns or environmental beliefs (Le Bris, 2016). Lastly, external interventions such as subsidies or the opportunity to do a test-ride (Rérat, 2021b) may also encourage individuals to purchase an e-bike (Le Bris, 2016).

In order to analyze the effects of key events on the adoption of the e-bike, and to develop a deeper understanding of this process, this study employs a qualitative approach. We now describe the setting of our study and our methodology.

6.5 Methodology: a biographical approach to cycling

6.5.1 E-bike users in Lausanne, Switzerland

The setting of this study is the city of Lausanne, the fourth largest in the country with a population of 140,000 inhabitants (Canton of Vaud, 2018) and 415,000 in the urban area in 2017 (FSO, 2018). The city has the particularity of being notoriously hilly and has the lowest modal share of cycling among large cities in Switzerland, with only 1.6% of trips made by bicycle in 2015 (FSO & FOSD, 2017). Switzerland is one of the foremost countries in the world in terms of e-bike adoption. In the 2015 Swiss micro-census, 7% of households owned an e-bike, of which 5.9% owned a pedelec (assistance up to 25 km/h) and 1.2% owned an s-pedelec (assistance up to 45 km/h). In cities such as Lausanne, where only 2.4% of households owned an e-bike in 2015 (Ibid., 2017), e-bike ownership is generally lower than in suburban or rural areas due to smaller household sizes.

Since the year 2000, the municipality of Lausanne has offered a subsidy for the purchase of an e-bike[48]. With the city's approval, we sent out an online and postal survey to beneficiaries of the e-bike subsidy and received 1466 responses. Out of those who had agreed to be contacted for interviews (N=717), 20 users were chosen randomly. Additional users were recruited through exploratory interviews organized with staff and students of the University of Lausanne (n=4), for a total of 24 in-depth interviews.

Due to our small sample size, we aimed to include a diversity of users in terms of age, gender, and e-bike use, rather than being representative of the general population of e-bike users. Our sample of

[48] At the time of the study, the subsidy for an e-bike purchase had a value of 15% of the price, to a maximum of 500 Swiss francs. A smaller subsidy was also available for the purchase of an e-bike battery (100 Swiss francs).

respondents (see Table 9 in the Appendix) is slightly skewed, with 14 men and 10 women, as men were more willing to participate in the interviews. This contrasts with the quantitative survey, where 53% of respondents were women. Ages ranged from 20 to 81 years at the time of the interview, with respondents evenly spread between age groups under 40 years old, 40–59, and over 60. A high proportion of users (16 out of 24) had a university degree, and the same proportion was professionally active, which reflects results from our quantitative survey. Only half of the users interviewed (12) had access to a car in their household, slightly less than the 53.7% of households who own a car in the municipality of Lausanne (FSO & FOSD, 2017). Compared to e-bike users in Lausanne, our interviewees included more long-time users who had bought their e-bike more than four years previously (12 out of 24), whereas most e-bike users responding to the survey had bought an e-bike in the previous two years.

6.5.2 Retrospective biographical interviews

It has been argued that the complexity of influences arising as a result of key events is more suited to qualitative than quantitative analysis (Lanzendorf, 2003; Müggenburg et al., 2015). We chose a qualitative retrospective approach, using semi-structured interviews rather than life course calendars, in line with narrative approaches to mobility biographies (Sattlegger & Rau, 2016); this enabled a more inductive data collection. Retrospective data has been shown to be effective for recalling travel changes associated with key events (Behrens & Mistro, 2010; Beige & Axhausen, 2008; Lanzendorf, 2003; Oakil et al., 2016). The time of purchase of the e-bike was generally recalled well by most of our interviewees, as it had taken place only a few years prior. However, experienced users who had owned multiple e-bikes had more difficulty in recollecting events leading to the purchase of the e-bike, as they were prone to confusing memories of initial adoption of the e-bike with their most recent e-bike purchase.

Each in-depth interview lasted about one hour and covered both the individual's long-term relationship with cycling over their life course, and the short-term period around the purchase of the e-bike. The resulting transcripts were coded with the software "Atlas.Ti." and used to build individual cycling trajectories. These consisted of a timeline of periods of bicycle and e-bike use, as well as dates of specific biographical events. The trajectories were then classified on the basis of the presence of a significant period of interruption in cycling practice in the years before the purchase of the e-bike, the perceived frequency of cycling, and the type of cycling (utilitarian or leisure), both before the purchase of the e-bike and throughout the life course.

The next section presents our results, starting with the influence of key events on e-bike adoption, and then looking at the role of motivations and past experiences of cycling.

6.6 Results: understanding the adoption of the e-bike

6.6.1 Key events as triggers for adoption

As this paper aims to study the influence of key events on the adoption of the e-bike, we have limited our focus to the first purchase of an e-bike, even though there may be a second or third e-bike whose purchase may have been influenced by other occurrences (e.g. crashes, theft, mechanical issues). In line with mobility biographies research, we chose to focus on larger key events in the life course, excluding smaller triggers like the municipal subsidy (which concerned all users), discounted prices, or test rides, although they may have played a role in precipitating the purchase of an e-bike (Le Bris, 2016).

For 14 e-bike users out of 24, a key event played a role in the purchase of their first e-bike. We found six types of key events to trigger the adoption of the e-bike: residential changes (n=4), workplace changes (n=4), daycare/schooling changes (n=2), childbirth (n=3), health events (n=3), partner-related events (n=3). Ten users did not mention any key event whatsoever linked to the adoption of the e-bike, while three users mentioned more than one. We will now describe each of these types of events in detail.

Workplace changes lead to a change in spatial context. This can trigger a reconsideration of existing travel habits, which in turn may lead to the purchase of an e-bike. On the one hand, the e-bike can be adopted in order to cope with a location that is difficult to reach, for example because of a steep gradient which would have made conventional cycling difficult, as in the case of Laure (52). On the other hand, starting a job in a location closer to one's residence or to the city center can also be used as an opportunity to change commuting habits. Daniel (34) mentions how a restriction on car parking at his new job and a discount on public transport passes acted as triggers to sell his car and switch to an e-bike.

> **Laure, 52:** *I used to work in another city and left my bike at the train station. I moved around Lausanne by bike. Then two years ago I changed job and started working in the upper part of the city. The problem is that it's uphill and I carry a heavy bag, so I was sweating when I arrived. So I thought I should buy an e-bike [...] I wanted to wait for Christmas [to buy it] but couldn't because with my old bike there was just too much of a gradient.*

> **Daniel, 34:** *After I left my previous job […] I was living in the city center and working in the urban area, I had a stable job, so no need for my car. I added up the price of the car and the time lost in traffic, and realized that […] the best mode of transport for me was an e-bike, combined with public transport. So I sold my car and bought two e-bikes, one for my wife and one for myself.*

Like workplace changes, ***residential changes*** have an impact on the spatial context and often go together with another event, like a new job, the birth of a child, or moving in with a partner, and these events act together to change travel condition. In the case of Paul (30), deciding to move to a suburban neighborhood served as a trigger to buy an e-bike in anticipation, in order to keep cycling and to compensate for the increase in distance and lack of public transport at his new location. Residential moves also change the social context and norms around cycling. For Hélène (36), moving to the city triggered a change in her travel behavior and she started travelling by bicycle instead of by car (using a conventional bike at first, and then an e-bike a few months later).

> **Paul, 30:** *I recently moved to [a suburban neighborhood] and left Lausanne. That's when I bought the e-bike, to keep my freedom of movement. I don't have to check the public transport schedule and can travel on my own when I want to, by day or night.*

> **Hélène, 36:** *I arrived in Lausanne in August 2015. My partner used to live in [a central neighborhood] and I had a normal bicycle which I had begun to use. [...] Since we live in the city center, we don't want to use the car as our daily mode of transport, and we didn't want the bicycle to be just for exercise but for transport. [...] That's why we switched to the e-bike.*

Planning for ***childbirth*** leads future parents to start thinking about how to travel with their children. For some users, the e-bike was a solution to carry children more easily than a conventional bicycle, thanks to its electrical assistance, and was often bought together with a trailer or child seat. For Stéphanie (38), who wanted to keep cycling, it was also a way of avoiding having to use a car transport children, groceries, or other things.

Stéphanie, 38: *Since I became pregnant, I knew I wouldn't be able to carry a child seat on a non-electric bicycle, [...] my body wouldn't have held up [with the effort required].*

Daniel, 34: *At around the same time [as I changed my job], I became a father […] and my son was born. That made us ask ourselves how we should carry him, how we should travel with him.*

Daycare and schooling changes can affect the space-time constraints imposed upon young, working parents. Faced with car traffic in the city, the e-bike can provide a simple way to carry children without a car. For Denis (52), buying an e-bike with a trailer was intended as a way to transport his two children to school and avoid using the car in the city, while also getting some exercise. Meanwhile, for Nicole (42), the e-bike appeared as the only way to bring her child to a daycare center before work hours.

Denis, 52: *I bought [my e-bike] in 2013. I used to go down to the school and continue on to the daycare center, where I left my daughter. But doing the school run by car was complicated with traffic, going to the daycare and not knowing where to park, and then taking my son to the school [...] I'm convinced that if I hadn't had children, I wouldn't have bought an e-bike.*

Nicole, 42: *Two years ago, my daughter changed daycare. Before, she came with me and I could drop her off before work. Once she was older, she wasn't allowed to go there anymore so we put her in [another daycare center]. Since I had to be [at work] either at 6:45 or 7:15 and the daycare opened at 6:45, it was impossible to get to work on time. It was really difficult because the daycare center is 20 minutes away from home and 20 minutes from the metro. [...] The only solution I found was an e-bike. By carrying her by e-bike and then taking the metro, I saved a huge amount of time.*

Experiencing a serious ***health event*** like a heart disease or an injury can also lead to the adoption of the e-bike. When regular cycling becomes too difficult, turning to an e-bike can be a way to avoid giving up cycling and to keep exercising. For Pascal (51), who had experienced an injury, the e-bike offered a form of rehabilitation by enabling a moderate effort, when a conventional bicycle would have been too intense.

Pascal, 51: *I went from a [gasoline-powered] scooter to the electric bicycle during my rehabilitation following a knee accident. [...] With a broken knee, it was a bit too hard to cycle. The e-bike was the right solution.*

The interrelation between people in the same household or social circle is called "linked lives" in mobility biographies research (Holz-Rau & Scheiner, 2015). These ***partner-related events*** (Lanzendorf, 2010) can also have an indirect effect on the decision to adopt an e-bike. Often, the purchase of an e-bike is discussed among couples, and some of them purchase two e-bikes at the same time. An example of this is Jacques (61), for whom the decision to buy an e-bike was made to be able to keep up with his partner, who had already bought one previously.

Jacques, 61: *I talked about it with my partner because during our bike trips I was having trouble. She also had some knee pain, so she bought hers first. We noticed we were not performing the same, and that's what decided us. After that we visited a trade fair, and she bought her e-bike, and I followed soon after, because I saw her so at ease that I was becoming jealous.*

The above examples show that key events can act as triggers for the decision to adopt an e-bike. These events can be summed up in three main categories. First are contextual changes (workplace, residence, daycare), which change the spatial context of everyday mobility through the location and schedule of activities, as well as changing the social context and social norms associated with cycling (i.e., a positive image of cycling), prompting users to consider the e-bike as an alternative to the car and public transport. Second are biographical changes (childbirth and health events), which lead to a change in the conditions for cycling and the individual's physical capacity, or trigger a reconsideration of travel behavior, leading to the adoption of the e-bike as a way to keep cycling or return to cycling. Third, partner-related events—which may include their purchase of an e-bike—influence the individual indirectly through socialization effects, such as the desire not to be left behind when cycling together for leisure.

However, for 10 users out of 24, the adoption of the e-bike was not found to be linked to a specific key event. This is probably because most users who did not mention a key event were near or past retirement age, and the majority of key events tend to happen before the age of 40 (Beige & Axhausen, 2012). In these cases, longer processes that fall outside the scope of key events, such as aging or the transition to retirement, may be related to the adoption of the e-bike, although they do not trigger it directly. Indeed, we found many older users had bought their e-bike while they were still working in order to get back in shape or keep cycling despite reduced physical capacities. After retirement, reducing their daily trips had given them more free time and the opportunity to take up cycling as a regular form of leisure, often practised as a couple.

6.6.2 Motivations and past experiences of cycling as mediating factors

In addition to key events, both motivations for adopting an e-bike and past experiences of cycling can play a mediating role in the decision to adopt an e-bike. We identified six main motivations for buying an e-bike, namely (1) avoiding to use the car or public transport, (2) taking up a physical exercise, (3) cycling for leisure, (4) cycling in hilly terrain, (5) continuing to cycle in winter, and (6) carrying children or heavy goods. These can be classified into two main groups. A first group of motivations is often linked to biographical changes such as the birth of a child, or daycare changes, which may lead to the purchase of an e-bike in order to be able to transport children. Adopting an e-bike to avoid using the car or public transport, or to cycle in hilly terrain, is often linked to spatial changes in workplace or residential location. A second group of motivations is more associated with long-term processes such as aging. This is often the case when physical exercise is the motivation for adopting an e-bike, as a way of preserving one's physical capacities and mobility.

The degree of past experiences of conventional cycling, or the individual's "cycling trajectory" (H. Jones, 2013), is an important factor in the adoption of the e-bike, but greatly varies between e-bike users. Inspired by the categorization of H. Jones, Chatterjee, and Gray (2015), we identify two main categories, depending on whether or not cycling was practised before adopting the e-bike: (1) restorative trajectories and (2) resilient[49] trajectories. The restorative trajectory (Figure 44) includes people who either did not cycle previously, or had stopped cycling for multiple years before adopting the e-bike. For e-bike users with a restorative trajectory, the e-bike had the effect of either beginning to cycle, or restoring their cycling practice to its former level (for those who had previously been regular cyclists). The resilient trajectory (Figure 45) includes people for whom conventional cycling was a regular activity which had not been interrupted by key events, and often constituted their main mode of

[49] H. Jones, Chatterjee, and Gray (2015) included resilient, restorative and diminishing trajectories. We consider that there are no diminishing trajectories because no users claimed to be cycling less than they had done before they got an e-bike.

transport, as many did not own a car. For them, the adoption of the e-bike was a way to maintain this continuous or "resilient" cycling practice.

Figure 44: Restorative cycling trajectory

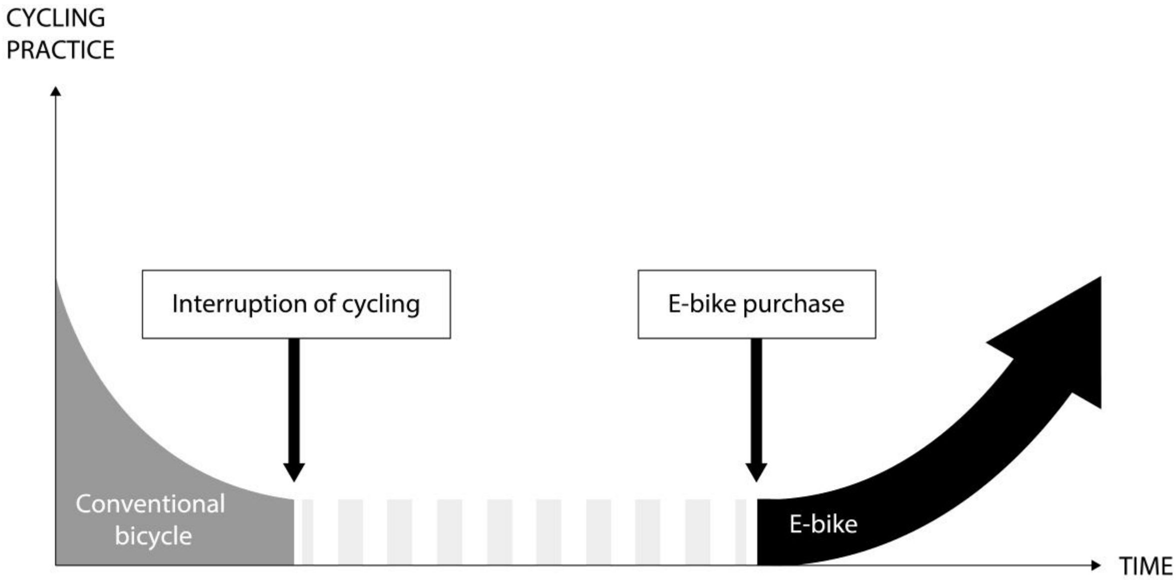
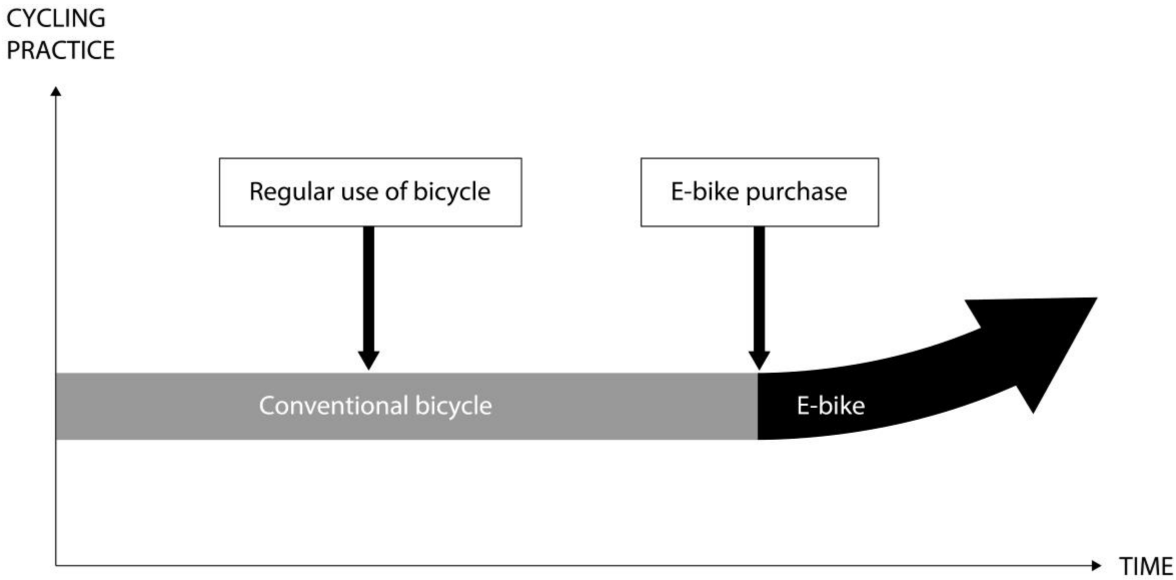


Figure 45: Resilient cycling trajectory



Cycling trajectories change the role that key events can play in the adoption of the e-bike. For restorative trajectories (new or returning cyclists), key events such as health issues or contextual changes serve as opportunities to start cycling or get back into cycling. This rediscovery of cycling is motivated by the wish to engage in physical exercise or leisure, or to switch to a different mode of transport in the city. For resilient trajectories (regular cyclists), switching from conventional cycling to the e-bike is mostly linked to either a contextual change (in the workplace or place of residence) or a biographical change (e.g., childbirth) which poses a threat to conventional cycling and prompts the adoption of an e-bike. An increase in distance or declivity, the need to transport children, or the effect of age, were all mentioned as making the use of a conventional bicycle too difficult. This desire to maintain cycling despite difficult circumstances can be explained by the high value this practice has within these individuals' lifestyle, and the freedom and independence associated with cycling.

6.7 Discussion

The goal of the present chapter was to investigate the adoption of the e-bike. We conducted retrospective biographical interviews to consider the role of key events, motivations, and past experiences of cycling in this process.

Just over half of all interviewed e-bike users (14 out of 24) adopted an e-bike following a key event or a combination of events, either a workplace change, residential change, the birth of a child, a daycare or schooling change, a health event, or a partner-related event. These events can be broadly categorized as either contextual changes (workplace, residential, or daycare changes), which change the spatial and also the social context for cycling; biographical changes (childbirth, health events), which lead to changes in the conditions for cycling and in the individual's physical capacity; or partner-related events, which influence the individual's decision to adopt the e-bike.

We found that residential and workplace relocations linked to shorter distances triggered a shift towards the e-bike, confirming results for conventional cycling (Bonham & Wilson, 2012; Oakil et al., 2016). Moving to a new spatial and social context in the city also acted as a trigger for starting to use an e-bike, confirming findings on residential relocation to a bike-friendly city (Janke & Handy, 2019). However, while research on conventional cycling links an increase in commuting distance to a shift away from cycling, we found that increased distances were, in this case mentioned as a reason for switching from conventional cycling to the e-bike. Thus, adopting the e-bike may be a way to adjust to a new cycling environment, steeper gradients, or longer distances, while avoiding giving up cycling.

Childbirth was mentioned as a trigger for adopting an e-bike in order to be able to maintain cycling despite the additional weight of carrying children (on a bicycle seat) and despite an increased number of trips. This contrasts with conventional cycling literature, which shows that the birth of a child tends to interrupt cycling (Oakil et al., 2016), suggesting that e-bikes could help maintain a person's cycling practice throughout the phase of children's development. We also found that the birth of a child could trigger a reconsideration of travel behavior, which led to restarting cycling with an e-bike. This confirms findings on the importance of parenthood as a potential opportunity to restart an interrupted cycling practice (Bonham & Wilson, 2012; Janke & Handy, 2019).

Our results show that health events may act as triggers for adopting the e-bike as a form of moderate exercise or as a way of continuing cycling despite reduced physical capacity. Conversely, in cycling literature, health events are generally linked with a decrease in conventional cycling, although the desire to stay healthy has also been found to be a reason for restarting cycling (Chatterjee et al., 2013). This confirms studies which have shown that e-bikes can act as a mobility aid for people with limited abilities or of older age (T. Jones, Harms, et al., 2016).

As for partner-related events, we found that the e-bike was a topic of discussion within couples, with the purchase of a first e-bike often followed by a second one. This shows the importance of considering cycling not only as an individual choice but as a social activity, and the role partners may play in the decision to restart cycling (Bonham & Wilson, 2012; Janke & Handy, 2019). E-bikes may be especially useful as an "equalizer" (Popovich et al., 2014) between different levels of physical ability, also helping to extend cycling as a social activity into later life.

In addition to key events, we found that motivations and past experiences of conventional cycling played a mediating role in adopting the e-bike. Adopting the e-bike to avoid car or public transport use, and being able to cycle uphill, was often related to contextual changes (changes in residence or workplace), while adopting the e-bike to take up physical exercise and cycle for leisure was related to aging and health preoccupations.

Based on H. Jones, Chatterjee, and Gray (2015), we distinguished two different kinds of cycling trajectories depending on an individual's past experience of cycling. First, restorative trajectories (new or returning cyclists) adopted the e-bike as an opportunity to get into (or return to) cycling, for leisure or physical exercise, or to reduce car use. In this trajectory, motivations for returning to cycling play an important role, while key events act as opportunities to put these plans into action by "unleashing a latent demand" for cycling" (Janke and Handy, 2019). Meanwhile, resilient trajectories (continuing cyclists) adopted the e-bike in order to maintain cycling despite a contextual change or health event. For these users, childbirth, aging, or moving to a new home or job act as threats to their cycling practice, leading to a switch to an e-bike as a way to maintain cycling. This confirms findings on the role of the e-bike as a form of "adaptive" change for cyclists (H. Jones et al., 2015).

Nonetheless, our results are not without a few limitations. Compared to other studies, a smaller proportion of users than expected (14 out of 24) mentioned a key event as a trigger for adopting an e-bike. Firstly, this may be because our study only considers what Chatterjee, Sherwin, and Jain (2013) call "life events", and not transport-related events (such as changes in car possession) or changes to the external environment (such as a new cycling infrastructure). Secondly, another explanation may be related to the limited time frame we considered, which included just the period of adoption of the first e-bike, and not the subsequent use of it, and the fact that we did not count as key events the purchase of the e-bike itself, nor the subsidy received for it, in contrast with other studies (Janke & Handy, 2019; Plazier et al., 2017). Thirdly, a further reason may be that the use of qualitative rather than quantitative data limits the number of key events to those voluntarily reported by users, although we argue that it presents a more realistic account of the causality of these events on e-bike adoption. In fact, the actual number of key events mentioned by e-bike users as linked to their e-bike adoption was quite restricted.

Future research could go further than the adoption of the e-bike by investigating the effects of key events on e-bike use over time. This includes the purchase of other vehicles (whether additional e-bikes, different e-bike types, or other modes of transport), and variations in the frequency of e-bike use. More generally, with increasing numbers of e-bikes and data on e-bike users, more opportunities for the field of e-bike research should become available.

6.8 Conclusion

E-bikes hold much potential for increasing urban cycling. By removing physical barriers to cycling, they may give some people the confidence to become urban cyclists or the means to maintain cycling despite challenging circumstances. This includes categories which are less represented among cyclists, such as mature or retired people, those with limited physical abilities, and parents of young children. Our research has shown that the adoption of the e-bike can be triggered by key events—contextual changes, biographical events, or partner-related events—happening over the life course. Because conventional cycling is vulnerable to changing spatial and biographical circumstances which make it more difficult, e-bikes may be a solution to help recruit new cyclists, but also re-engage lapsed cyclists and retain regular cyclists over time. It follows that to promote urban cycling, e-bikes should be targeted not just to non-cyclists, but also to conventional cyclists who could benefit from switching to electrically assisted cycling. Public policies could also address existing and returning cyclists differently. New or returning cyclists may respond to interventions limiting car use such as mobility schemes (e.g., restricting car parking) and to e-bike trials at the workplace, while existing cyclists could be attracted to switch from conventional bicycles to e-bikes after residential relocation or childbirth through encouragements such as financial subsidies for e-bikes or cargo bicycles. In conclusion, a biographical approach to cycling has helped us to better understand the adoption of the e-bike. A further understanding of the role of cycling over the life course could help develop policies to better serve the diversity of cyclists, both present and future.

6.9 Appendix

Table 9: Characteristics of interviewed e-bike users (N=24)

User no.	Name (fictional)	Age	Employment status	E-bikes owned	Bicycles owned	Cars in household
1	Pascal	51	Employed full-time	2 or more	2 or more	1
2	Philippe	55	Employed full-time	1	1	None
3	Marie	36	Employed full-time	1	None	None
4	Sébastien	29	Employed full-time	1	2 or more	None
5	Nicole	42	Employed part-time	1	1	1
6	David	25	Student	1	2 or more	None
7	Hélène	36	Employed full-time	2 or more	None	1
8	Pierre	43	Employed full-time	1	2 or more	1
9	Denis	52	Employed full-time	1	2 or more	1
10	Laure	52	Employed full-time	1	1	None
11	Paul	30	Employed full-time	1	1	None
12	Claudine	50	Employed full-time	1	None	None
13	Sarah	33	Employed part-time	1	1	None
14	Daniel	34	Employed full-time	2 or more	None	None
15	Stéphanie	38	Employed part-time	2 or more	1	None
16	Lucas	40	Unemployed	1	None	None
17	Jacques	61	Employed full-time	2 or more	2 or more	2 or more
18	Christine	65	Retired	2 or more	1	1
19	Céline	69	Retired	1	None	1
20	Michèle	76	Retired	2 or more	1	2 or more
21	Robert	79	Retired	2 or more	1	None
22	Jean	69	Retired	1	1	2 or more
23	Hubert	80	Retired	1	1	1
24	Michel	70	Retired	1	1	1

7. A systemic approach to understanding the frequency of e-bike use in a low-cycling city

7.1 Presentation of the article

The fourth article of this thesis focuses on e-bike use and the factors associated with different frequencies of e-bike use. Few studies on e-bikes have attempted to understand which factors affect their use at the individual level, but also, at the environmental level. To fill this gap, we take a systemic approach to e-bike uses by situating them within a system of vélomobility as the result from the meeting between individual's potential for mobility and the possibilities offered by a territory's hosting potential. To test the influence of individual and environmental characteristics on frequency of e-bike use, we use quantitative data from the survey of e-bike users, as well as geospatial (GIS) data by georeferencing 1005 e-bikers' residential addresses. Lastly, we develop a multinomial regression model which identifies the factors associated with e-biking regularly (daily and pluri-weekly) rather than occasionally.

We find e-bikes to be used frequently, with 44% of participants e-cycling every day or almost (i.e. "daily" users), 38% several times per week (i.e. "pluri-weekly" users) and 18% a few times per month or less (i.e. "occasional" users). The strongest influence on frequency of e-bike use is the use of the e-bike for utilitarian trip purposes (e-biking to work, shopping, or going to leisure activities), and previous use of non-motorized travel modes. Within the territorial hosting potential, greater proximity to work increases the frequency of e-bike use, but not density, or cycling infrastructure around the home. The individual's mobility potential increases the frequency of e-bike use through a lack of transport alternatives (not owning a public transport pass), a recent e-bike purchase (<2 years), higher cycling skills (comfort for cycling in different infrastructures), utilitarian motivations (e.g. having an alternative to the car), and a lower sensibility to barriers. This study provides a first example of the multiple individual and environmental factors affecting the frequency of e-bike use, and the application of a systemic theoretical framework of vélomobility to e-bike use.

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7.1 Abstract

E-bikes have the potential to widen the appeal of cycling and increase the number and reach of cycling trips. However, the individual and environmental factors associated with the frequency of e-bike use have not been addressed. This paper views e-bike use within a systemic approach, as the meeting between individuals' cycling potential, and the opportunities offered by the spatial context. We compare daily, pluri-weekly and occasional e-bike users' individual and environmental characteristics, before using a multinomial logistic regression to identify the factors associated with regular e-bike use. Our data comes from a survey of 1005 existing e-bike users in Lausanne, Switzerland, as well as spatial (GIS) measures of density and cycle infrastructure around the residence. Frequency of e-bike use is found to be associated with five groups of factors: (1) uses (e-biking for shopping and leisure trips, non-automobile travel habits); (2) motivations and barriers (utilitarian motivations, low sensibility to barriers); (3) skills (comfort for cycling in different infrastructures); (4) access to vehicles (recent e-

bike purchase, lack of public transport pass); (5) spatial context (proximity to the workplace). These results offer a first example of the multiple factors affecting e-bike use in a hilly, low-cycling city.

Keywords: e-bike, cycling, frequency, bikeability, vélomobility

7.2 Introduction

In the last decade, e-bikes have become an integral part of the mobility landscape in countries of the Global North. These bicycles offer an electrical assistance which activates only when pedalling, and until speeds of 25 km/h[50] for "pedelecs" or 45 km/h for "speed-pedelecs". Sales of e-bikes represent four out of ten bicycles sold in Switzerland (Velosuisse, 2022), and half in the Netherlands and Belgium (Bike Europe, 2019). Given their success, e-bikes have attracted increasing attention from researchers (see reviews by Fishman & Cherry, 2016; Bourne et al., 2020). E-bikes have the potential to expand the boundaries of cycling as a practice by allowing "more people to cycle more" (Behrendt, 2017). They enable people of all ages to restart or continue cycling (Marincek & Rérat, 2020). They facilitate cycling in hilly environments or when carrying children and heavy goods. By maintaining speed with less effort, they increase the spatial range of cycling. They provide low-intensity exercise and significant health benefits (Bourne et al., 2018).

This paper aims to understand the factors affecting the frequency of e-bike use. With increasing data about e-bike users, some studies have begun to consider the factors affecting e-bike ownership and use at the individual level (Haustein & Møller, 2016a; Kroesen, 2017; Melia & Bartle, 2021). However, no studies have simultaneously examined "the individual, social and physical factors directly associated with e-bike use and travel behaviour through quantitative estimates" (Bourne et al., 2020, p. 11).

Within cycling literature, behavioural frameworks have focused on the effects of personal attitudes on cycling (see Willis et al., 2015) or the influence of social and environmental contexts (e.g., Sallis et al., 2013). However, these approaches view cycling as an individual decision and have been criticized for failing to explain why few people cycle, and putting the blame on individual rather than structural factors (Spotswood et al., 2015). Meanwhile, researchers from the social sciences have used the term "vélomobility" to consider a system of practices around the bicycle, by analogy with the dominant system of automobility (Urry, 2004). Vélomobility, or e-vélomobility for e-bikes (Behrendt, 2018), has been used with different meanings, from the sensory experiences of cycling to the planning context around cycling (Watson, 2013; Koglin, 2018). Here, we draw on Rérat (2021b) to define vélomobility as the system within which cycling takes place.

The remainder of this paper is structured as follows. In our theoretical framework, we review the individual and environmental determinants of e-bike use within the system of vélomobility. Thereafter, we present our methods and data. The results section includes a descriptive analysis of the factors affecting frequency of e-bike use, and a multinomial logistic regression model which shows their combined effect. The discussion compares our results with the literature and offers some conclusions for future research.

[50] 20 mph or 32 km/h in North America.

7.3 Conceptual framework

7.3.1 A system of vélomobility

Vélomobility as defined by Rérat (2021b) is an adaptation to cycling of two concepts developed by the sociologist Vincent Kaufmann (2016): "motility" as an individual potential for mobility, and the "territorial hosting potential" as the opportunities for movement provided by an environment. The ***individual mobility potential*** is composed of three dimensions. *Access* refers to the availability of vehicles and transport passes. *Skills* or competences refer to the abilities required to cycle, both physical and learned. *Appropriation* relates to agency and how a person makes use of their potential to cycle. It includes the motivations for e-cycling, and the barriers which deter from it. The ***territorial hosting potential*** refers to how suitable an environment is for cycling, similar to the concept of bikeability (Lowry et al., 2012). This potential includes the *spatial context* (built and natural environment), the *cycling infrastructure*, and the *norms and rules* related to e-cycling. Within this framework, e-bike uses correspond to the trips made by e-bike (in terms of frequency, purpose, duration and length), which result from the meeting between individual and territorial potentials.

Figure 46: System of vélomobility. Adapted from Rérat (2021).

7.3.2 E-bike uses

E-bikes are used more frequently than conventional (unassisted) bicycles (Melia & Bartle, 2021; Rérat, 2021c; Van Cauwenberg et al., 2021), for longer distances – between 3 and 11.5 km depending on the study (Bourne et al., 2020) - and for longer durations (Fyhri & Beate Sundfør, 2020). In terms of trip purposes, they are used more often for utilitarian trips such as commuting or shopping (Bourne et al., 2020; MacArthur et al., 2018), although recreational uses are common among older users (Wolf & Seebauer, 2014). Like conventional cycling, e-bike uses vary depending on the local context or "cycling culture" (Haustein et al., 2019). In regions with a strong cycling culture like the Netherlands or Flanders, e-biking "optimizes" pre-existing cycling trips (Kroesen, 2017; Van Cauwenberg et al., 2021). However, e-bikes do not entirely replace conventional cycling, as both forms of cycling may coexist (Marincek & Rérat, 2020). In regions with weaker cycling cultures such as North America or Australia, e-biking mainly replaces trips made by car or bike (MacArthur et al., 2018; Washington et al., 2020). In medium-cycling European countries, e-bikes tend to substitute trips by public transport, cars and cycling (Hiselius & Svensson, 2017; Melia & Bartle, 2021). Previous use of conventional cycling is associated with e-biking more often (de Kruijf et al., 2018; Melia & Bartle, 2021). We now present the environmental and individual factors associated with e-bike use.

7.3.3 Territorial hosting potential

The ***built environment*** favours cycling through dense, mixed-use neighbourhoods with connected streets and a diversity of urban functions which reduce trip distances to destinations (Yang et al., 2019). Propensity to cycle decreases on longer distances but also for short trips where walking is preferred (e.g., Goodman et al., 2019). In Switzerland and the Netherlands, e-bike owners are overrepresented in suburban or rural areas rather than dense urban cores (Kroesen, 2017; de Kruijf et al., 2018; Rérat, 2021c). In the Chinese context[51] e-bike ownership is negatively associated with residential density and access to public transport (Zhang et al., 2013), but positively associated with job density at the workplace (Hu et al., 2021). Moreover, Ding et al. (2019) find that distance, density and land-use mix have non-linear effects, with e-bike ownership highest at 8km from the city centre. Contrary to e-bike ownership, the distance travelled by e-bike increases with density in the Netherlands (Kroesen, 2017). In Sweden, urban e-bike users cycle more frequently and make more utilitarian trips (work/school, groceries, visiting friends) than rural users (Hiselius & Svensson, 2017).

Natural environment factors such as topography and steep inclines over 5% negatively affect cycling (Heinen et al., 2010). E-bikes' assistance facilitates cycling in hilly locations and opens up routes which would not have been considered possible (MacArthur et al., 2018; Behrendt et al., 2021). An attractive cycling landscape (greenness, urbanisation) also increases satisfaction with e-bike use (de Kruijf et al., 2018). However, the quantitative effect these variables on e-bike use has not been assessed.

Cycling infrastructure encourages cycling through the presence of a continuous network of cycling lanes or paths offering separation from traffic (Buehler & Dill, 2016). Few studies have investigated the effect of infrastructure on e-bike use. In China, Hu et al. (2021) found the presence of bike paths near the workplace to increase e-bike use for commuting. When cycling without dedicated infrastructure, e-bikes are more confidence-inducing than conventional bicycles due to their ability to maintain a constant speed with the flow of traffic and accelerate from a stop (MacArthur et al., 2018; Popovich et al., 2014). Some have argued e-bikes' higher speed makes them less suitable for mixed-use paths with pedestrians (Kazemzadeh & Ronchi, 2021). However, e-bike users themselves prefer using separated lanes or paths (Rérat, 2021c). The presence of traffic-calmed roads (30 km/h) has also been associated with increased cycling (Mertens et al., 2017), but its effect on e-bikes is unknown. Providing bicycle parking at workplaces, transport stations and home also encourages cycling (Heinen & Buehler, 2019). Due to their higher price and risk of theft, e-bikes require secure storage (Bourne et al., 2020). Lacking bicycle parking in inner-city households may explain the lower share of e-bike owners in cities (Rérat, 2021c).

Norms and rules include e-bike legislation. In Switzerland, pedelecs (25 km/h) can be used from 14-16 years with a moped license, and from 16 years onward without any license. They are considered as bicycles and generally permitted on cycling infrastructure (OFROU, 2021). Speed-pedelecs (45 km/h) are considered as mopeds and require a license, helmet, insurance, and a registration plate. Contrary to other European countries, they are allowed to use cycle infrastructure and represent a significant share of e-bike sales - 12% in 2021 (Velosuisse, 2022). The social norms surrounding e-bikes may also affect their use. E-bikes may suffer from a negative perception of as a form of cheating, or a mode of recreation reserved for older people, rather than a legitimate form of transport (Popovich et al., 2014; Behrendt,

[51] E-bikes in China also include "scooter-style" e-bikes which do not require pedalling and fall outside of the focus of this paper.

2018). However, this perception appears to have changed as e-bikes now attract younger users (Peine et al., 2017).

7.3.4 Individual mobility potential

Access to other vehicles in the household, particularly cars, has a negative effect on cycling frequency by competing for cyclists' time (Pucher & Buehler, 2006; Stinson & Bhat, 2004). Because e-bike owners tend to be suburban or rural household who rely on motorized modes (Rérat, 2021c), car ownership is associated with e-bike ownership (Kroesen, 2017). However, owning a car (or several cars) decreases e-bike use (Kroesen, 2017; de Kruijf et al., 2018; Melia & Bartle, 2021). Because of their household profile, e-bike users tend to own fewer public transport passes than the general population (Rérat, 2021c). Ownership of conventional bicycles is associated with increased e-bike use, likely reflecting a pro-cycling attitude or existing habits (Kroesen, 2017).

Cycling requires physical ***skills*** for maintaining balance and pedalling (Wierda & Brookhuis, 1991), but also practical knowledge for cycling in urban environments (Cox, 2019). Compared to conventional bikes, e-bikes reduce the importance of physical ability for cycling. Some e-bike users have pre-existing cycling habits - a "resilient" cycling trajectory - while other restart or resume cycling after an interruption - a "restorative" trajectory (Marincek & Rérat, 2020). The majority of e-bike users have some experience of regular cycling in their life (MacArthur et al., 2014; Haustein & Møller, 2016b). Although e-bikes are still diffusing, many users have owned them for several years (Hiselius & Svensson, 2017).

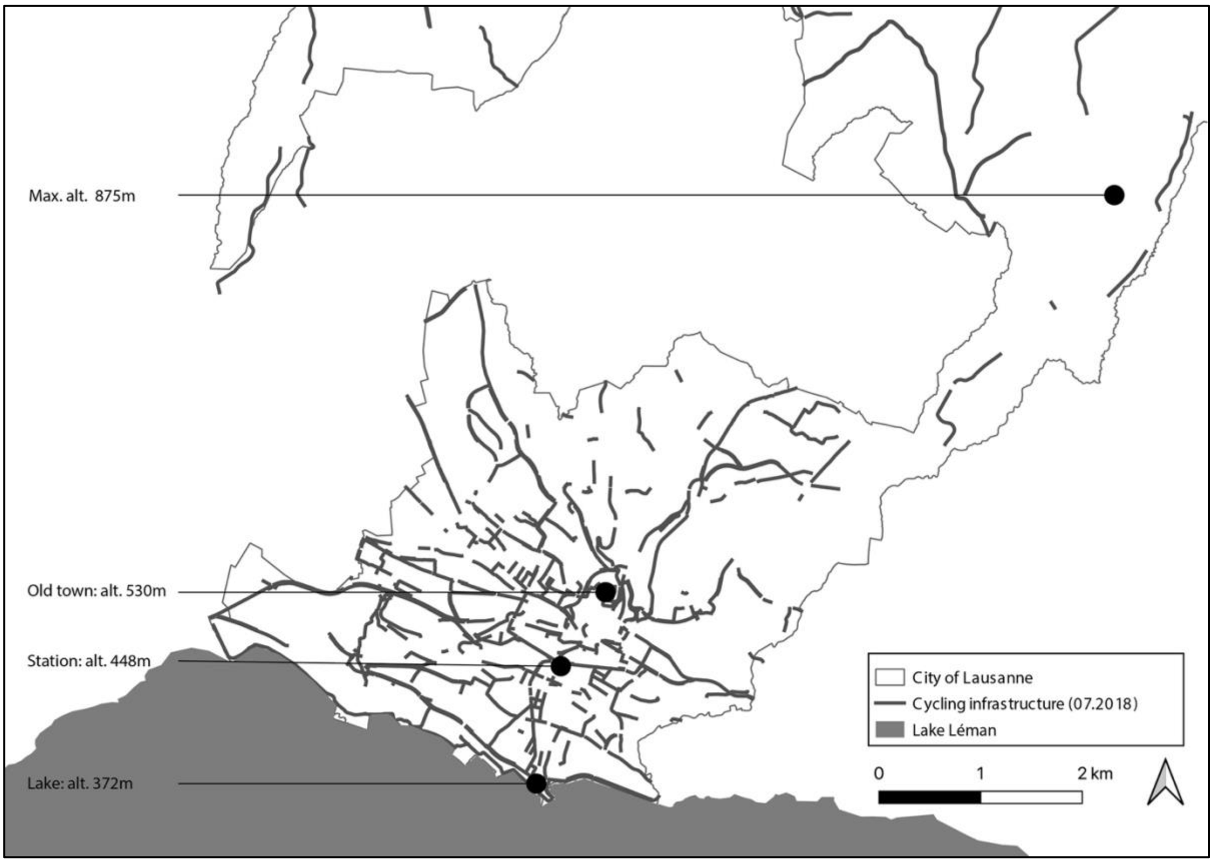
Appropriation, or the personal motivations and barriers related to cycling, are considered to have more impact than environmental factors on cycling (De Geus et al., 2007; Willis et al., 2015). Strong motivations increase the likelihood of e-bike use (Simsekoglu & Klöckner, 2018). Motivations for using an e-bike include individual benefits (fun, reduced effort, exercise, confidence), physical benefits (riding longer distances, faster journeys, carrying heavier loads) and riding with friends and family (Bourne et al., 2020). Compared to cyclists, e-bikers' motivations are similar to driving, with an emphasis on pleasure and disconnecting from work, rather than saving time or social activism (Rérat, 2021b). Sensibility to barriers is negatively associated with frequent cycling (De Geus et al., 2007; Willis et al., 2015). Barriers affecting e-bike use are similar to cycling, such as weather and lacking safety (Haustein & Møller, 2016b; Popovich et al., 2014). Specific barriers include weight, cost, risk of theft, battery range, and social stigma related to the image of e-cycling (see above) (Bourne et al., 2020). E-bikers may be sensitive to safety given to their older age, and because of worse cycling conditions in suburban territories (Rérat, 2021b).

In addition to these dimensions, socio-demographic characteristics including age, gender, ethnic background and socio-economic status have a complex relationship with cycling (Heinen et al., 2010). On one hand, they are outcome of the quality of cycling conditions, with greater representativeness as cycling levels increase (Buehler & Pucher, 2012b), and on the other hand, they have an effect of their own on cycling, for example through lower perceived safety among women and older adults (Aldred et al., 2017). While e-bikes help to engage women into cycling by reducing barriers (Wild et al., 2021), they remain underrepresented among e-bikers in low-cycling contexts (MacArthur et al., 2014, 2018; Washington et al., 2020). In high-cycling contexts, being a woman increases the chance of being an e-bike owner, but still decreases the likelihood of using an e-bike (de Kruijf et al., 2018; Kroesen, 2017). E-bikes reduce the effect of age on cycling by helping to maintaining cycling longer in life. E-bike owners are mostly mature (40-65 years) people in low-cycling countries (Fishman & Cherry, 2016), while in the Netherlands or Denmark they are often retired (Haustein & Møller, 2016a; Kroesen, 2017). Although the probability of owning an e-bike increases with age, frequency of use is negatively related to age, due to fewer trips (Kroesen, 2017).

This literature review suggests that the system of vélomobility affects e-bike use at both the individual and environmental level, although several factors have yet to be considered for e-bikes. The remainder of this paper will attempt to understand how these factors affect the frequency of e-bike use. We now present the methods and data used for this purpose.

7.4 Method

Figure 47: Map of Lausanne with cycling infrastructure in 2018. Note: northern boundaries are cropped.



7.4.1 Study context

Lausanne is the 4th largest city of Switzerland, with 140,000 inhabitants and 415,000 people in its urban area (FSO, 2018). Located on the shore of Lake Geneva, it has a hilly topography. The city extends from 372 to 530 metres in the centre and up to nearly 900 metres in the highest neighbourhoods. Lausanne is a starter cycling city (Silva, Teixeira, Proença, et al., 2019) with a low modal share of cycling (1.6% of trips vs. 7% nationally) and few bicycle-owning households (41.7% vs. 65% nationally) (FSO & FOSD, 2017). Its cycling infrastructure is recent, and at the time of the study in 2018, the network had many gaps. Between 2000 and 2019[52] the length of cycle lanes or paths grew from 9.8 km to 71.5 km (Ville de Lausanne, 2020b). Cycling safety is low compared to other cities in

[52] No data is available for 2018.

the country. In a nationwide cycling survey, 34% of respondents did not feel safe, compared to 14% nationally, while 55% did not feel respected by other road users, compared to 32% nationally (Rérat, 2021a).

7.4.2 Data

Data for this paper was collected through a survey among recipients of an e-bike subsidy. Since the year 2000, the Industrial Services of the City of Lausanne offer a subsidy for e-bikes[53] which represents 15% of the purchase price[54] or a maximum of 500 Swiss Francs. The subsidy applies to all residents and is systematically offered in bicycle shops. In June and July 2018, 3400 subsidy recipients (excluding invalid addresses) were contacted through a postal and web-based survey, which 1466 respondents completed (45% response rate). The survey did not include residential addresses. For the purpose of this study, we anonymized respondents[55] and matched them with the database of subsidy recipients, yielding 1119 valid addresses (76% of initial addresses[56]). Residential addresses were then georeferenced using QGIS plugin OpenStreetMap Nominatim, which resulted in a final sample of 1005 e-bike users.

7.4.3 Variables

The dependent variable, frequency of e-bike use, was recoded from five categories into three: "daily" (every day or almost), "pluri-weekly" (several times per week), and "occasional" (a few times per month or a few times per year). Eight participants who "never" used their e-bike were removed. Consistent with our theoretical framework, we consider three main groups of independent variables: uses (1), territorial characteristics (2), and individual characteristics (3).

Use variables include e-bike use (yes/no) for the following trip purposes: work/studying, shopping/grocery/service, trips to leisure activities, and recreation and exercise. Participants were asked which travel modes they previously used for the trips now done by e-bike (car, bicycle, public transport, motor two-wheeler).

Territorial characteristics include residential neighbourhood (postcode), workplace location, and satisfaction with available bicycle parking at the workplace/destination (rather agree, rather disagree). Population density within a 300-meter buffer around the residence was calculated using data from the Swiss Federal Territorial Office and street network from OpenStreetMap (OSM). Using geodata from the city of Lausanne, we calculated the length of cycle paths or lanes within a 300m service area from the residence, as well as the length of traffic-calmed streets (30 km/h, 20 km/h, pedestrian areas) within a 200-meter service area. These buffers and service area sizes showed the most variation among e-bike users.

Individual characteristics include socio-demographic variables (age, gender, education, employment status). Access to vehicles includes e-bike category, date of purchase, other vehicles in the household (bicycle, car, motor two-wheeler) and transport passes. Skills were assessed using participants' comfort in eight different situations on a four-point Likert scale ("disagree", "rather disagree", "rather agree",

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[53] A further subsidy of 100 Swiss Francs was proposed for an e-bike battery, as well as a separate subsidy for e-scooters.

[54] The average price of an e-bike is around 3000 Swiss Francs in Lausanne, according to the survey.

[55] All names and personal identifiers were anonymized.

[56] Some people had moved to another locality since asking for the subsidy, and others could not be matches due to insufficient information in the database.

"agree"). Lastly, motivations and barriers were evaluated through 11 statements to which participants were asked to state their agreement using a four-point Likert scale.

7.4.4 Analysis

Statistical analyses were conducted in IBM SPSS Statistics version 26. Firstly, significant differences between daily, pluri-weekly and occasional e-bikers were identified for each independent variable by using Pearson's Chi-square tests for categorical variables, and ANOVA for continuous variables. At this stage, Likert scales were considered as continuous. Principal component analysis (PCA) was then used to reduce the number of variables and identify underlying dimensions. Secondly, a multinomial logistic regression model was developed in order to consider the combined effect of all independent variables on a categorical outcome, in this case frequency of e-bike use (Field, 2013). The variables were retained in the final model based on their AIC values (Akaike's information criteria). To test for multicollinearity, linear regressions were conducted, confirming that all variables had a tolerance statistic lower than 0.1 and variance inflation factors (VIF) below 10 (Field, 2013).

7.4.5 Respondent characteristics

Table 10: Respondent characteristics.

Variable	Categories	Daily	Pluri-weekly	Occasional	Total	City population	Pearson's Chi2 test
Gender	Female	59%	50%	53%	55%	52%	p<.05
	Male	41%	50%	47%	45%	48%	
Age	20-39	51%	41%	36%	44%	45%[57]	p<.001
	40-59	43%	44%	45%	44%	32%	
	>60	6%	16%	20%	12%	23%	
University degree	No	27%	35%	39%	32%	58%	p<.01
	Yes	74%	65%	62%	68%	42%[58]	
Household type	Alone	16%	17%	25%	18%	48%[59]	p<.01
	Alone with children	7%	6%	6%	6%	8%	
	Couple without children	27%	26%	37%	28%	19%	
	Couple with children	43%	47%	30%	42%	21%	
	Flatshare or other	7%	4%	3%	5%	3%	
Employment	Work full-time	59%	49%	53%	54%	41%[60]	p<.001
	Work part-time	31%	34%	28%	31%	17%	
	Unemployed	3%	2%	3%	3%	6%	
	Not working/retired/student	7%	15%	17%	12%	35%	

[57] Population aged 20 and over. Source: City of Lausanne, data from Federal Statistical Office, 2018. STATPOP.
[58] Population aged 25 and over. Source: City of Lausanne. data from Federal statistical Office, 2018. Structural annual census.
[59] Household data. Source: City of Lausanne. data from Federal Statistical Office, 2018. Structural annual census.
[60] Population aged 15 and over. Source: City of Lausanne. data from Federal Statistical Office, 2018. Structural annual census.

Due to barriers of price, license requirements and likely the image of e-bikes, there are no participants under 20 years. However, e-bike users surveyed in Lausanne remain significantly younger than in other studies (mean age: 43.7 years). Compared to the city's population over the age of 20, people aged 40-59 and 20-39 are overrepresented, while people over 60 are underrepresented. This may be explained by the city's hilly topography and difficult cycling conditions, which detract older adults and encourage younger cyclists to use an e-bike. In terms of gender, 55% of e-bikers are women compared to 45% of men. Female e-bike users tend to be younger than men (mean age: 42.6 vs. 45.2).

E-bike users are overrepresented in households composed of families with children and couples. This household structure is due to the underrepresentation of younger and older age categories. Most e-bike users are employed, working full-time or part-time. Few e-bikers are professionally inactive, retired or unemployed (12%), compared to 35% of the population of Lausanne aged over 15. Consequently, education levels are higher than in the general population, with 68% of participants users holding a university degree, compared to just 42% of people over 25 in the city.

44% of e-bikers (n=410) use their e-bike daily, 38% (n=354) pluri-weekly and 18% (n=170) occasionally (a few times per month or year). Daily e-bike users are more likely to be female ($p<.05$) and aged under 40 years ($p<.001$), working full-time ($p<.001$) and university graduates ($p<.01$). Pluri-weekly users include more part-time employees and couples with children. Occasional users are more likely to be over 60 years, retired or not working, and to live in single-person households.

7.5 Results

7.5.1 E-bike trip motives

Compared to occasional users, more daily and pluri-weekly e-bike to work ($p<.001$), for shopping/grocery trips ($p<.001$) and to reach leisure activities ($p<.001$). No difference is found for recreational or sports-related trips.

Table 11: E-bike use for selected trip purposes (% of yes).

Variable	Daily	Pluri-weekly	Occasional	Total	Pearson's Chi2 test
Work/study trips	96%	76%	38%	80%	p<.001
Shopping/grocery trips	81%	59%	32%	64%	p<.001
Trips to leisure activities	82%	64%	37%	67%	p<.001
Recreational trips	69%	70%	69%	69%	n.s.

7.5.2 Previous travel modes

E-bikers previously conducted their trips by public transport (69%), walking (52%), or car (47%), but only 26% were previously cycling. This reflects the low share of cycling in the city. Before adopting an e-bike, daily users were more reliant on public transport ($p<.001$), cycling ($p<.01$), and walking ($p<.1$), while pluri-weekly users relied more on cars ($p<.01$) and motorized two-wheelers ($p<0.05$). Occasional users are more likely to newly conduct trips since adopting an e-bike ($p<.001$), suggesting they e-bike for recreation.

Table 12: Travel modes previously used for trips now made by e-bike (% of yes).

Variable	Daily	Pluri-weekly	Occasional	Total	Pearson's Chi2 test
Public transport	81%	62%	52%	69%	p<.001
Walking	56%	51%	46%	52%	p<.1
Car	42%	55%	44%	47%	p<.01
Conventional bicycle	30%	20%	28%	26%	p<.01
Motor two-wheeler	12%	18%	11%	14%	p<.05
Did not do these trips	4%	5%	15%	7%	p<.001

7.5.3 Spatial context

E-bike users are evenly distributed among neighbourhoods in the city[61]. Altitude levels at the residence range from 374 to 875 metres. Although occasional users live on average slightly higher in the city, the differences are not significant. Population density within a 300-meter buffer around the residence ranges from 600 to 21'206 inhabitants/km^2, with daily users living in significantly denser neighbourhoods than occasional and pluri-weekly users (p<.001). 58% of e-bikers' work in the city, but significantly more daily and pluri-weekly users than occasional users (p<.001). Eight in ten e-bike users live within 10 km from their workplace, with significantly more daily users living between 2 and 5 km (p<.001). Interestingly, a higher share of occasional users live under 2 km as well as over 10 km away from work. This suggests occasional users may live too far, but also too close to use their e-bike.

Table 13: Spatial context variables.

Variable	Categories	Daily	Pluri-weekly	Occasional	Total	Pearson's Chi2 test
Residential Neighbourhood	South	23%	25%	24%	24%	n.s.
	Centre, East, West	42%	36%	39%	40%	
	North	34%	39%	37%	36%	
Workplace location	Lausanne	64%	58%	43%	58%	p<.001
	Urban area or region	23%	22%	24%	23%	
	Other or not working	13%	21%	33%	20%	
Distance to workplace	< 2 km	13%	14%	22%	15%	p<.001
	2-5 km	50%	40%	25%	42%	
	5-10 km	25%	22%	22%	23%	
	>10km	12%	25%	32%	20%	
Variable		**Daily Mean (SD)**	**Pluri-weekly Mean (SD)**	**Occasional Mean (SD)**	**Total Mean (SD)**	**ANOVA**
Altitude at point of residence		527.2 (84.1)	532.5 (97.9)	543.9 (100.6)	532.3 (92.7)	n.s.

[61] Compared to the population weight of each neighborhood.

Population density per km2 within 300m buffer	11045 (4486)	9761 (4349)	10379 (4256)	10437 (4426)	p<.001

7.5.4 Cycling infrastructure

The length of bicycle lanes or paths within a 300m service area around the residence ranges from 0 to 3931 metres but shows no significant differences depending on frequency of e-bike use. Similarly, the length of traffic-calmed roads (20 km/h, 30 km/h and pedestrian zones) within a 200-meter service area ranges from 0 to 1921 metres but also shows no significant differences. Two thirds of e-bike users have good bicycle parking at their workplace or destination, but significantly more daily than pluri-weekly and occasional users (p<.05).

Table 14: Cycling infrastructure variables.

Variable		Daily Mean (SD)	Pluri-weekly Mean (SD)	Occasional Mean (SD)	Total Mean (SD)	ANOVA
Length of cycle lanes and paths within 300m SA		693 (615)	718 (626)	661 (598)	697 (616)	n.s.
Length of traffic-calmed roads within 200m SA		465 (457)	481 (493)	488 (474)	475 (474)	n.s.
Variable	**Categories**	**Daily**	**Pluri-weekly**	**Occasional**	**Total**	**Pearson's Chi2 test**
Availability of bicycle parking at work/destination	Disagree or rather disagree	29%	36%	39%	33%	p<.05
	Agree or rather agree	72%	64%	61%	67%	

7.5.5 Access to vehicles and transport passes

Despite the subsidy running since 2000, 53% of participants bought their e-bike in the two years before the survey (2017, 2018). This reflects a strong increase in sales, but also a lack of reliable data before 2014[62]. Occasional users are more likely be long-time owners, while daily and pluri-weekly users are recent adopters (p<.001). 86% of participants own regular “pedelecs” while faster “s-pedelecs” are rarer (14%), with no significant difference related to frequency of e-bike use. In terms of access to other vehicles, 73% of e-bikers have access to a car in their household (54% in Lausanne), 71% a conventional bicycle (42% in Lausanne) 21% a motorized two-wheeler (9% in Lausanne), 46% a public transport pass (67% in Lausanne), and 20% a carsharing pass[63] (FSO & FOSD, 2017). Pluri-weekly and occasional users have access to significantly more motorized modes - cars and two-wheelers - (p<.001 and p<.01) and public transport passes (p<.05). Meanwhile, daily users own more carsharing passes (p<.05) and slightly more conventional bicycles (non-significant).

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62 The information in the subsidy database before 2014 is incomplete.

63 The most popular service is Mobility carsharing: https://www.mobility.ch/. This share is likely much higher than in the population.

Table 15: Vehicles and transport passes.

Variable	Categories	Daily	Pluri-weekly	Occasional	Total	Pearson's Chi2 test
Date of e-bike purchase	Before 2017	46%	41%	61%	47%	p<.001
	2017 - 2018	54%	59%	40%	53%	
E-bike category	S-pedelec 45 km/h	15%	15%	13%	15%	n.s.
	Pedelec 25 km/h	85%	85%	88%	85%	
Car ownership	1 car	54%	63%	55%	58%	p<.001
	2 or more	11%	18%	22%	16%	
Bicycle ownership	1 or more	74%	72%	68%	72%	n.s.
Motor two-wheeler ownership	1 or more	17%	26%	24%	22%	p<.01
Carsharing pass	Yes	24%	17%	14%	20%	p<.05
Public transport pass	Yes	41%	49%	53%	46%	p<.05

7.5.6 Skills

E-bike users' level of comfort varies strongly depending on the separation from motor traffic (Table 16). Daily users are significantly more comfortable than pluri-weekly and occasional users when cycling in traffic with cars (p<.001), in an intersection or a roundabout (p<.001), on a contra-flow lane (p<.001), or on a bus lane (p<.001). Differences remain significant (but are less substantial) on dedicated cycle lanes or paths, or mixed-use paths. Fewer differences are observed for battery management (p<.05), mechanical maintenance (p<.1), or repairing a flat tyre (non-significant). Using principal component analysis, skills were reduced to two components (Table 19). Cycling skills (Cronbach's Alpha: 0.767), and mechanical skills (Cronbach's Alpha: 0.871). Battery management did not load onto the dimensions and was excluded.

Table 16: Level of comfort. Mean scores (1=uncomfortable 2= rather uncomfortable, 3=rather at ease 4= at ease).

	Daily	Pluri-weekly	Occasional	ANOVA
Cycling in traffic with cars	2.77	2.53	2.31	p<.001
Cycling on a cycle lane or path with bicycles	3.48	3.37	3.27	p<.01
Cycling on sidewalk or mixed-use path with pedestrians	3.01	2.99	2.72	p<.01
Cycling on bus lane	3.25	3.1	2.83	p<.001
Cycling on contra-flow lane (against traffic)	2.66	2.58	2.29	p<.001
Cycling through an intersection or roundabout	2.66	2.41	2.3	p<.001
*Managing the battery of my e-bike**	*3.39*	*3.39*	*3.24*	*p<.05*
Repairing a flat tyre	2.05	2.09	2.05	n.s.
Doing mechanical maintenance on my e-bike	1.93	2.07	2.07	p<.1

**Not included in principal component analysis*

7.5.7 Motivations and barriers

Motivations for e-cycling vary strongly among participants (Table 17). Regular e-bike users (daily and pluri-weekly) are significantly more motivated than occasional users by transport-related motivations like having an alternative travel mode (p<.001), carrying children or goods (p<.001), adopting an innovative form of mobility (p<.001), and by the advantages of e-bikes over conventional bikes, like cycling faster or further than a conventional bike (p<.05) or being able cycle despite the slope (p<.001). Meanwhile, occasional e-bike users are more motivated by exercise and pleasure, though the differences are non-significant.

Daily users are less sensitive to barriers than less frequent users (pluri-weekly and occasional users). Interestingly, pluri-weekly users are more affected than occasional users by having to use roads with heavy traffic (p<.001), carrying children or goods (p<.001), or unfavourable weather (p<.001), suggesting certain barriers are related to utilitarian trips. Meanwhile, occasional users are more deterred by other kinds of barriers such as cycling at night (p<.001), sweating (p<.001), and the risk of theft (p<.001). Daily users, on the other hand, are deterred by a long or tiring trip (non-significant). Other barriers including the difficulty of carrying the e-bike in the train or metro, or insufficient battery, show no differences.

Table 17: Motivations and barriers for e-bike use. Mean scores. (1=disagree 2= rather disagree, 3=rather agree 4= agree).

	Daily	Pluri-weekly	Occasional	ANOVA
Ability to cycle despite slope	3.82	3.69	3.62	p<.001
Alternative to public transport or car use	3.79	3.56	2.87	p<.001
Exercise while travelling	3.29	3.27	3.3	n.s.
Cycle more or continue to cycle	3.32	3.23	3.24	n.s.
Pleasure of e-cycling	3.14	3.05	3.18	n.s.
Innovative travel mode	3.14	3.08	2.81	p<.001
*Go faster or further than conventional bike**	*3.13*	*3.03*	*2.91*	*p<.05*
*Ability to carry children or goods**	*2.42*	*2.16*	*1.68*	*p<.001*
Unfavourable weather	2.87	3.22	3.12	p<.001
*Difficulty taking e-bike in train or metro**	*2.85*	*2.91*	*2.86*	*n.s.*
Have to use a road with heavy traffic	2.53	2.96	2.85	p<.001
A long or tiring trip	2.44	2.56	2.54	n.s.
*Difficulty of carrying children or goods**	*2.35*	*2.67*	*2.43*	*p<.001*
Risk of theft or vandalism*	2.15	2.38	2.48	p<.001
Not wanting to cycle at night	1.79	2.36	2.49	p<.001
*Insufficient range (or uncharged battery)**	*2.11*	*2.1*	*1.97*	*n.s.*
Not wanting to sweat	1.66	1.92	2.07	p<.001

**Not included in principal component analysis.*

For further analyses, motivations and barriers were reduced to three dimensions using principal component analysis (Table 20): (1) hedonistic motivations (Cronbach's Alpha: 0.659) including pleasure, exercise, ability to continue cycling; (2) utilitarian motivations (Cronbach's Alpha: 0.479) including having an alternative to car or public transport, adopting an innovative mobility form; (3)

barriers (Cronbach's Alpha: 0.627) including traffic, night, weather, fatigue, sweating. Several variables did not load onto the dimensions and were excluded.

7.5.8 Determinants of the frequency of e-bike use

This section presents the result of the multinomial logistic regression, which shows the odds of e-biking daily, and pluri-weekly, compared to occasionally (reference category). The variables included in the model showed significant inter-group differences and were significant in bivariate logistic regressions. Several variables which did not contribute to the model were dropped[64]. We also excluded distance to work, which showed collinearity with workplace location. Lastly, e-bike use for work trips was dropped as it concentrated too much of the variance in the model and had an obvious relationship to e-biking frequency.

The final model indicates that the frequency of e-bike is affected, in order of importance, by e-bike trip motives, motivations, sensitivity to barriers, date of e-bike purchase, workplace location, previous travel modes, cycling skills, and ownership of public transport passes. Using the e-bike for utilitarian trips strongly increases the likelihood of e-cycling every day or several times per week, whether for groceries/shopping (odds ratio: 3.38), to reach leisure activities (odds ratio: 2.30). Previously driving a car is negatively associated with e-biking daily (odds ratio: 0.54), while previously using public transport has a positive effect (odds ratio: 2.30). Previously cycling showed an effect in bivariate analyses but has no effect in the final model.

Among territorial variables, proximity to the workplace increases e-bike use. Working in Lausanne increases the likelihood of e-cycling daily (odds ratio: 5.27) and pluri-weekly (odds ratio: 3.72). Population density showed an effect in bivariate analyses but is no longer significant once other variables are considered.

At the individual level, having purchased an e-bike less than two years ago increases the likelihood of e-cycling pluri-weekly (odds ratio: 2.85), and daily (odds ratio: 2.66). Cycling skills are positively associated with using the e-bike everyday (odds ratio: 1.3) but are not significant for pluri-weekly use. Utilitarian motivations (having an alternative to car or public transport, adopting an innovative travel mode) increase the likelihood of e-cycling daily (odds ratio: 3.0), and of e-cycling several times per week (odds ratio: 2.0). Sensitivity to barriers decreases the odds of cycling daily (odds ratio: 0.56) but has no effect on pluri-weekly use. Vehicle ownership has a low effect, except for a negative effect of owning a public transport pass on e-cycling daily (10% significance level). Working full-time has a negative effect on pluri-weekly use (odds ratio: 0.28), which might explain a slightly lower frequency of use. Lastly, male gender is modestly associated with pluri-weekly use ($p<.1$), likely due to the over-representation of women in the sample.

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64 Availability of bicycle parking, carsharing pass ownership, education level, household structure, car ownership, motor two-wheeler ownership, previous use of a motor two-wheeler, and previous conventional cycling

Table 18: Multinomial logistic regression. Dependent variable: Frequency of e-bike use.

	Daily (Every day or almost)		Pluri-weekly (A few times per week)	
	Exp(B)	Sig.	Exp(B)	Sig.
Population density within 300m buffer	0.955	n.s.	0.843	n.s.
Cycling skills	**1.325**	**p<.05**	1.187	n.s.
Barriers	**0.566**	**p<.001**	0.972	n.s.
Utilitarian motivations	**3.018**	**p<.001**	**2.042**	**p<.001**
Age: <40 years	0.885	n.s.	0.9	n.s.
Age: 40-59	1.43	n.s.	1.274	n.s.
Age: >60 (REF)	.	.	.	.
Male	0.871	n.s.	**1.674**	**p<.1**
Female (REF)	.	.	.	.
Employed full-time	0.703	n.s.	**0.282**	**p<.05**
Employed part-time	0.467	n.s.	0.42	n.s.
Retired or not employed (REF)	.	.	.	.
Shopping by e-bike: yes	**4.755**	**p<.001**	**2.41**	**p<.01**
Shopping by e-bike: no (REF)	.	.	.	.
Leisure by e-bike: yes	**3.381**	**p<.001**	**2.166**	**p<.01**
Leisure by e-bike: no (REF)	.	.	.	.
Previously public transport: yes	**2.305**	**p<.01**	1.236	n.s.
Previously public transport: no (REF)	.	.	.	.
Previously cycling: yes	1.469	n.s.	0.871	n.s.
Previously cycling: no (REF)	.	.	.	.
Previously driving: yes	**0.542**	**p<.05**	0.917	n.s.
Previously driving: no (REF)	.	.	.	.
Purchase: < 2 years	**2.662**	**p<.001**	**2.851**	**p<.001**
Purchase: >2 years (REF)	.	.	.	.
Public transport pass: yes	**0.576**	**p<.1**	0.952	n.s.
Public transport pass: no (REF)	.	.	.	.
Workplace: Lausanne	**5.273**	**p<.01**	**3.727**	**p<.01**
Workplace: Urban area or region	2.364	n.s.	1.953	n.s.
Workplace: other or not working (REF)	.	.	.	.
Pseudo R square: 0.374 (Cox and Snell)				
N=764				
Reference category: a few times per month or less (occasional)				

7.6 Discussion and conclusion

E-bike use is growing at a rapid pace, diffusing across population groups and spatial contexts. This paper fills a gap in the literature by quantitatively assessing the individual and environmental factors related to the frequency of e-bike use, based on a sample of 1005 e-bike users in Lausanne, Switzerland. Using the conceptual framework of a system of vélomobility, we consider e-bike use as a result of the meeting between individuals' potential for mobility, and the territorial hosting potential or "bikeability". We now discuss our results within this framework.

In terms of uses, 82% of participants e-bike several times per week, a high frequency similar to other studies (MacArthur et al., 2018; Melia & Bartle, 2021). This confirms that e-bikes make people cycle more (Fyhri & Beate Sundfør, 2020). Use-related variables are the strongest determinants of frequent e-bike use. As expected, e-biking for utilitarian trip motives, especially commuting to work, but also shopping and going to leisure activities, is the strongest determinant of e-biking frequency. Thus, it makes sense to categorize e-bikers as either enthusiastic, utilitarian, and recreational (Haustein & Møller, 2016a). Previous travel habits also influence frequency of e-bike use. Having previously used public transport and not driven a car for trips which are now done by e-bike is associated with e-biking daily. This relates to the negative effect of motorization on distance travelled by e-bike (Kroesen, 2017), with previous commuting by car being associated with less frequent e-bike use (Melia & Bartle, 2021). However, previously cycling is not significant for e-bike use, likely because it only concerns 28% of participants. By comparison, other studies in low-cycling contexts found between half (MacArthur et al., 2018) and one third (Melia & Bartle, 2021) of e-bikers were cycling before e-bike adoption. This lower cycling experience might be explained by the topography and young cycling culture of the city, which results in more non-cyclists taking up the e-bike.

We found the effect of the territorial hosting potential to be rather low on e-biking frequency. Proximity to the workplace (i.e. working in Lausanne) has the strongest effect, significantly increasing daily e-cycling. As expected, longer distances reduce commuting by e-bike, which is the biggest driver of cycling frequency, due to the competition with other travel modes. Residential density is significantly higher for daily than pluri-weekly and occasional users, but its effect disappears when considering other factors. The effect of density is likely smaller in an urban centre than at a regional or national scale. Compared to rural areas, living in dense urban areas has been found to increase frequency of e-biking and utilitarian trips (Hiselius & Svensson, 2017), as well as distance travelled by e-bike (Kroesen, 2017). The effect of bikeability, both for cycling infrastructure and traffic-calmed zones in the neighbourhood, is not significant. Only availability of bicycle parking at the workplace was higher for daily users, although it was not significant in the final model. This result may be due to few streets having cycle infrastructure which provides physical separation (and greater safety) from traffic in Lausanne at the time of the study. It also suggests that bikeability should be considered beyond the residential neighbourhood, especially given e-bikes' increased range. However, this would require origin-destination data, which was not available. Considering cycling infrastructure around the workplace may also be of interest (Hu et al., 2021). Combining several measures including cycle path availability, traffic-calmed zones, traffic volumes, or bicycle parking might also be more representative of e-bike users' experience of bikeability.

Individuals' mobility potential has a strong effect on frequency of e-bike use. Access to other modes of transport in the household decreases the likelihood of daily e-biking, confirming that travel modes compete for users' time. Daily users own significantly fewer cars, motor two-wheelers and public transport passes compared to pluri-weekly or occasional users. In the regression model, owning of a public transport pass decreases the likelihood of e-biking daily. This confirms other European studies which found that e-bikes compete with public transport and cars (Haustein & Møller, 2016b; Kroesen, 2017). Interestingly, having recently purchased an e-bike (< 2 years) increases daily or pluri-weekly use, suggesting long-term users e-bike less often. This could signal a waning interest in e-bike use over time linked to increasing age, or a generational shift towards younger, more utilitarian users (Peine et al., 2017; de Haas et al., 2021).

Cycling skills, or e-bikers' level of comfort, are significantly higher among daily users in situations without separation from traffic (mixed traffic, intersections or roundabouts, contra-flow lanes, bus lanes). This indicates that the territorial and individual cycling potentials and are strongly interrelated. In the regression model, cycling skills increase the likelihood of e-biking daily, but not pluri-weekly. Thus, despite electrical assistance compensating physical capacities, e-bikers have different cycling abilities. While studies suggest older adults (>60), women, and less experienced e-bike users have lower levels of comfort (Haustein & Møller, 2016b; MacArthur et al., 2018), we found daily e-bike users (with the highest comfort) included the most women and recent e-bike users. However, daily users' higher comfort may be explained by their relatively young age (see below).

Motivations for using an e-bike have a strong effect on frequency of e-bike use. Daily and pluri-weekly users tend to be motivated by utilitarian reasons (having an alternative to the car or public transport, using an innovative travel mode), whereas occasional users are motivated by hedonistic reasons (exercise, pleasure). In the regression model, having utilitarian motivations triples the odds of e-cycling every day, and doubles those of e-cycling several times per week. This confirms Simsekoglu & Klöckner (2019) who found that mobility benefits (i.e., practicality, accessibility) had a stronger effect than health or symbolic benefits for buying an e-bike. Rérat (2021b) also found that e-bikers' motivations were related to transportation benefits compared to the car, and less to environmental convictions, compared to conventional cyclists. Conversely, low sensibility to barriers is associated with daily e-bike use. The causal relationship between barriers and frequency is likely bidirectional: e-cycling regularly makes people less sensitive through habit, but low sensibility is a requirement to e-cycle daily. Moreover, while pluri-weekly users are sensitive to "practical" barriers including traffic, unfavourable weather, or carrying goods or children, occasional users are deterred by cycling at night, sweating, or the risk of theft, suggesting different purposes of use. The importance of traffic-related barriers indicates that bikeability in Lausanne remains insufficient, especially for pluri-weekly users who might cycle more often without them. This also confirms that e-bikers' electrical assistance does not make them immune to safety conditions (Bourne et al., 2020; Rérat, 2021c).

While socio-demographic characteristics (age, gender and employment) differ significantly between daily, pluri-weekly and occasional e-bikers, they have a low effect in the regression model. This confirms Melia et al. (2021), who also found no socio-demographic effect on frequency of e-bike use, but contradicts Kroesen (2017) who found a negative effect of female gender and older age on distance travelled by e-bike (but not frequency). Despite a low-cycling context, there is a high share of women in our sample (52%) compared to studies in Great Britain or Sweden where the majority of e-bikers are men (Hiselius & Svensson, 2017; Melia & Bartle, 2021), confirming that e-bikes can be an "enabler" for women (Wild et al., 2021). Meanwhile, the underrepresentation of people over 60 may be due to the city's hilly topography and cycling conditions discouraging older users, and leading younger people than elsewhere to use an e-bike.

Future research should aim to deepen our understanding of e-bike use through the relationship between the individual and the territorial context. At the individual level, by studying e-bikers' experiences and strategies for coping with their environment, through qualitative methods (e.g. ride-alongs, video) or biographical interviews. At the territorial level, by comparing "e-bike geographies" within different environments (large and small cities, suburban or rural areas), cycling cultures, or topographical settings. Lastly, as we have shown, a coherent theoretical framework is needed to analyse the system of e-bike use, such as the one provided by vélomobility.

Looking forward, e-bikes hold great potential for increasing the modal share of cycling in the context of a transition towards sustainable mobility. The role of e-bikes is expanding with their diffusion to younger populations (de Haas et al., 2021; Peine et al., 2017), the arrival of cargo bikes, and the blurring of boundaries with conventional bikes. To accompany this development in the coming years, increasing our understanding of the relationship between individuals and their cycling environments will be essential.

7.7 Acknowledgements

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7.8 Appendix

Table 19: Skills for e-bike use. Component loadings.

	1 (Cycling skills)	2 (Mechanical skills)
Cycling in traffic with cars	**0.683**	0.303
Cycling on a cycle lane or path with bicycles	**0.606**	0.014
Cycling on sidewalk or mixed-use path with pedestrians	**0.643**	-0.18
Cycling on bus lane	**0.763**	0.045
Cycling on contra-flow lane (against traffic)	**0.685**	0.039
Cycling through an intersection or roundabout	**0.674**	0.248
Repairing a flat tyre	0.078	**0.923**
Doing mechanical maintenance on my e-bike	0.038	**0.918**

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

A Rotation converged in 3 iterations.

Table 20: Dimensions of motivations and barriers. Component loadings.

	1 (hedonistic motivation)	2 (barriers)	3 (utilitarian motivation)
Cycling more or continuing to cycle	**0.737**	-0.038	-0.089
Able to cycle despite slope	**0.462**	0.169	0.21
Having an alternative to public transport or car use	0.065	-0.035	**0.894**
Pleasure of using an e-bike	**0.714**	0.079	0.038
Adopting an innovative form of mobility	0.514	-0.008	**0.537**
Doing exercise while travelling	**0.752**	0.09	0.128
Cycling on a road with strong traffic	0.197	**0.515**	-0.103
Not wanting to cycle at night	0.197	**0.698**	-0.242
Unfavourable weather	0.033	**0.713**	0.087
A long or tiring trip	0.003	**0.665**	0.169
Not wanting to sweat	-0.052	**0.545**	-0.008

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

A Rotation converged in 5 iterations.

8. Comparing e-bike users' perceptions of safety: the case of Lausanne, Switzerland

8.1 Presentation of the article

The fifth article of this thesis focuses on cycling safety among e-bike users. It focuses on perceived safety, as a subjective feeling resulting from e-bikers' representations and everyday experiences, rather than actual crashes, which happen less frequently and may not concern all e-cyclists. Perceived safety is conceptualized as a dimension resulting from the meeting of individuals with given characteristics and uses of the e-bike, and an environment with a certain bikeability. Using quantitative data from the survey of e-bike users, we use 13 items to define perceived safety, which are reduced to three components: comfort for cycling in different situations (1), satisfaction with cycling conditions (2), and barriers to cycling (3). We find e-bike users to have low levels of perceived safety overall, varying levels of comfort depending on the separation from motorized traffic, and to be very affected by barriers related to traffic conditions. We identify four groups of e-bike users: Confident all-rounders (1) are male, regular cyclists who are comfortable in any condition and unaffected by barriers, although critical of cycling conditions; Recreational on-roaders (2) are satisfied with present conditions and relatively comfortable, but mostly cycle for recreational trips; Worried traffic-avoiders (3) are older, mostly female cyclists uncomfortable without separation from traffic and likely to avoid cycling in strong traffic; Unconfident path users (4) are mostly female cyclists who are uncomfortable in all situations except dedicated cycle paths, and very unsatisfied with current conditions. This article's findings, although specific to a low-cycling city (Lausanne), show that lacking safety remains a challenge for e-bike users and will have to be improved in order to keep e-bikers cycling in the future.

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8.2 Abstract

Electrically-assisted bicycles (E-bikes) may broaden cycling to a wider spectrum of users, territories, and trips. But what are e-bike users' experiences of safety in a low-cycling city, and how do they vary among different users? This paper conceptualizes perceived safety based on vélomobility as the meeting point between users with specific characteristics (age, gender, etc.) and an environment more or less amenable to cycling. It is based on data from a survey of 1466 e-bike users who received a subsidy in Lausanne, Switzerland. We use 13 variables to measure perceived safety, finding 3 components: comfort for cycling in different situations, satisfaction with cycling conditions, and barriers to e-bike use. Based on these components, we identify four groups of e-bike users: (1) confident all-rounders, (2) recreational on-roaders, (3) worried traffic-avoiders and (4) unconfident path-users. We find gender and age to be the main factors associated with being a member of a group with lower perceived safety. Low weekly frequency of e-bike use, reduced winter e-bike use, and cycling for recreational trips exclusively also reduce perceived safety. Despite the benefits of electrical assistance compared to conventional bicycles, low safety due to unwelcoming road conditions remains a major concern for many e-bike users.

8.3 Introduction

In recent years the definition of cycling has been challenged by the arrival of new forms of vehicles, among them shared bicycles, cargo bicycles, and – the focus of this article – electrically assisted bicycles or e-bikes (also known as pedelecs)[65]. E-bike sales have grown tremendously in the last decade (Fishman & Cherry, 2016). They now represent one in three bicycles sold in Switzerland (Velosuisse, 2020)[66], and half in the Netherlands (RAI//BOVAG/GfK, 2019) and Belgium (Sutton, 2020). In the near future, they could exceed conventional bicycle sales.

The potential of e-bikes lies in their ability to expand the boundaries of cycling as a practice, allowing a larger subset of people to cycle, increasing the intensity of cycling trips, and changing the shapes and functions bicycles serve (Behrendt, 2018; Watson, 2012). Thanks to their pedal assistance, e-bikes have changed the way people think about bicycles. E-bikes have attracted population categories underrepresented among conventional cyclists in low-cycling contexts, such as women and mature or older adults, providing these groups that need it the most with outdoor physical activity (Van Cauwenberg, de Geus, et al., 2018). They have allowed people who no longer cycled to resume cycling, and others to maintain cycling despite health limitations, old age, or personal circumstances which restricted conventional cycling such as childbirth or residential relocations (Marincek & Rérat, 2020). E-bikes have also changed the spatial reach of cycling, by enabling trips on longer distances and hilly terrain (Bourne et al., 2020). With the right cycling infrastructure, e-bikes help to expand utilitarian cycling to suburban or rural areas (Rérat, 2021c). Lastly, e-bikes could play a role in a transition towards sustainable mobility by replacing cars for many trips where driving had previously been the default option, reducing car-related negative externalities (Kroesen, 2017).

Given this potential, what are the experiences of e-bike users themselves in the daily reality of a low-cycling city? How do e-bikes fit into an existing traffic landscape, where cars are still dominant and cycling infrastructure is incomplete? How have individuals with different cycling trajectories, some of whom have recently returned to cycling, adapted to city cycling with an e-bike? To answer these questions, this paper aims to understand the experiences of e-bike users by focusing on their perceived safety.

Low perceived safety remains one of the main barriers preventing people from cycling (Winters et al., 2011), causing occasional or potential cyclists to avoid cycling altogether, in what has been called "fear-based exclusion" (Chataway et al., 2014). Perceived safety affects cyclists' actions on multiple levels, from the decision to cycle to their route choice, their on-road behavior and positioning (Manton et al., 2016). Previous research indicates there are important differences in how people experience depending on their personal characteristics – their gender, age, or level of cycling experience – and depending on the type of infrastructure on which they cycle – whether separated from traffic or not (Aldred et al., 2017).

Most research on safety for e-bikes has focused on crashes rather than perceived safety, a recurring topic being the higher crash rates of e-bikes compared to conventional bicycles (Schepers, Fishman, et al., 2014). The lack of studies on e-bike users' perceived safety may be explained by their recent diffusion, but also, by the assumption that e-bike users' experiences are largely similarly to those of

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[65] We refer strictly to pedal-assisted bicycles. Other types of e-bikes can be ridden without pedaling but are rare in European contexts.

[66] There are two main categories of e-bikes in Switzerland. Regular e-bikes (pedelecs) with an assistance until 25 km/h account for 85% of sales, while faster e-bikes with an assistance until 45 km/h (speed-pedelecs) represent 15% of sales.

conventional cyclists. However, existing qualitative research on e-bike users' experiences seems to contradict this view. Some e-bikers feel safer and more confident than with conventional bicycles due to their ability to keep up with the flow of motor traffic and accelerate more quickly from a stop (T. Jones, Harms, et al., 2016; Popovich et al., 2014; Rose, 2012). Conversely, e-bikers may feel less safe when approaching an intersection because motorists tend to misjudge their speed (T. Jones, Harms, et al., 2016; Popovich et al., 2014), leading to critical situations and potentially crashes (Petzoldt, Schleinitz, Heilmann, et al., 2017).

Only few studies have considered individual differences in perceived safety among e-bike users, although they tend to be older and have a different characteristics compared to conventional cyclists (Fishman & Cherry, 2016). In Denmark, Haustein & Møller (2016b) found higher perceived safety among e-bikers was related to being male, being excited by e-bike use, having the same riding style on a conventional and electrically assisted bike, and having greater e-bike experience, while lower perceived safety was related to being female, being older than 60, and cycling regularly on longer daily distances. Road infrastructure has been shown to play a crucial role in conventional cyclists' perceptions of safety (Aldred et al., 2017; Lawson et al., 2013). Comparing commuters who used e-bikes and conventional bicycles, Rérat (2021b) found that despite having an electrical assistance, e-bikers felt less at ease in most traffic situations. Much remains to be known about how individual e-bike users perceive safety when riding in different road situations.

The aim of this paper is twofold. First, to gain a better understanding of how e-bike users perceive safety in different situations, and how it varies depending on their personal characteristics. Secondly, to offer a segmentation of e-bike users based on their perceived safety and explore the factors which influence it.

Our theoretical framework is inspired by the social sciences and aims to situate cycling safety within a system of vélomobility, which includes the individual as well as the physical and social environment (i.e., infrastructure, power relations, representations, and experiences) (Cox, 2019; Koglin & Rye, 2014; Watson, 2013). Scholars from the social sciences have criticized approaches focusing on individual attitudes and preferences for underplaying the role of road infrastructure and relations with other road users (i.e., motorists) in cyclists' safety (Spotswood et al., 2015). Drawing on the definition of vélomobility by Rérat (2021b, 2021a), we consider e-bike users' perceived safety as the meeting point between, on one hand, individuals with specific characteristics (age, gender, cycling experience) and uses of the e-bike (frequency, trip motives), and on the other hand, a spatial and social environment which is more or less amenable to cycling.

Based on our theoretical framework, the next section starts by defining perceived safety, before providing an overview of the factors which affect perceived cycling safety at an environmental level (traffic conditions, cycling infrastructure, external conditions), and at an individual level (gender, age, frequency of cycling, experience). Due to the lack of e-bike specific research, most literature comes from conventional cycling research.

8.4 Literature review

8.4.1 Perceived cycling safety

Perceived or "subjective" safety refers to people's evaluation of the risk of cycling and their feelings and experiences of dangerous situations, in contrast to "objective safety" which refers to crashes (rather than “accidents”[67]) which are recorded in official police or hospital statistics (Chaurand & Delhomme, 2013). Bicycle crashes may not accurately represent cycling safety conditions because a large proportion of them go unreported (Winters & Branion-Calles, 2017), and crash rates tend to be lower in places where there are fewer cyclists if they do not take into account exposure or the number of kilometers cycled (Buehler & Pucher, 2017). Moreover, perceived and objective safety often do not match. People tend to underestimate the risk of single-vehicle crashes (i.e., falling) relative to collisions with motor vehicles (Schepers et al., 2020). In some situations, crash risk may be underestimated by individuals because of overconfidence in their abilities to control the situation (Puchades et al., 2018). Recent research has emphasized the important of “near-accidents” such as “close passes” by motor vehicles, “dooring”, “hooking” and blocking, which happen much more often than crashes and strongly influence how cyclists perceive safety (Aldred, 2016; Sanders, 2015). Scholars have argued cycling safety should be seen as a pyramid, where crashes represent just the “tip of the iceberg” while dangerous situations (near-accidents) and perceived safety represent the broad base which concerns all cyclists as well as potential cyclists (Juhra et al., 2012; Winters & Branion-Calles, 2017).

The perception of safety or risk has two dimensions: a cognitive dimension – risk as an analysis of a situation- and an emotional dimension – risk as a feeling (Slovic et al., 2004), with emotions having the most influence on behavior (Loewenstein et al., 2001). According to Møller & Hels (2008), the cognitive level of perceived risk refers to how dangerous cycling is perceived to be, in other words, the perceived probability of being involved in a cycling accident in a given situation. On the emotional level, perceived safety refers to a general fear caused by the presence of motor traffic and the danger imposed by cars upon cyclists (Jacobsen et al., 2009; Jacobsen & Rutter, 2012). “Fear of cycling” can also be seen as a social construction (Horton, 2007) which is related to broader stigmatization of cyclists in society, body-shaming, verbal and physical harassment (Heesch et al., 2011; O’Connor & Brown, 2010). This fear of cycling is shaped by gender, migration background, and personal experiences, and includes not only fear of injury but also a fear for personal safety, as well as other fears such as bicycle theft, getting lost, mechanical problems, or relations with the police (Ravensbergen et al., 2020).

Two main groups of factors influence perceived cycling safety. On one hand, factors linked to the environment including traffic conditions, road design and cycling infrastructure as well as weather and surface conditions. On the other hand, determinants related to individual characteristics such as age, gender, cycling frequency and level of experience.

8.4.2 Environmental factors

Perceived safety is strongly linked to ***traffic conditions*** and road characteristics. The speed and volume of motor traffic, width of a street, number of lanes, or presence of parked cars have all been found to have a negative effect on cyclists’ perceived safety (Sorton & Walsh, 1994; Parkin, Wardman, et al., 2007; Manton et al., 2016). The presence of intersections of a larger size, complexity (number of exits), and a lack of traffic signals have been associated with lower perceived safety (K. Wang & Akar, 2018b).

The presence of any kind of ***cycling infrastructure*** improves perceived safety compared to mixed traffic, although cycle lanes which provide only visual separation have been found to be much less effective at improving perceived safety for infrequent cyclists than off-street bike paths or tracks which are physically separated from motor vehicles (Manton et al., 2016; Parkin, Wardman, et al., 2007; K.

[67] The British medical journal has banned use of the word “accident”, as it suggests that such an event occurred by chance, which is often not the case (Davis & Pless, 2001).

Wang & Akar, 2018a). A well-known typology of cyclists proposed four groups of cyclists based on comfort for cycling in different types of cycling infrastructure: those who do not need any or “strong and fearless”, those confident to cycle on-road or “enthused and confident”, those who prefer to be separated from traffic and are “interested but concerned”, and those who would never cycle regardless, or “no way no how” (Dill & McNeil, 2013; Geller, 2006).

External conditions relating to weather and road surfaces influence perceived safety and seasonal variations of cycling. The presence of ice and snow, slippery surfaces linked to rain, and lack of lighting, are known deterrents of cycling (Winters et al., 2011). In winter, cold temperatures, surface slipping and low visibility lead to a higher perceived risk and reduced cycling frequency (Kummeneje et al., 2019).

8.4.3 Individual factors

Gender has a strong influence on perceived cycling safety. Across studies, women tend to show a systematic preference for infrastructure providing physical separation from traffic, and lower comfort for cycling in mixed traffic (Aldred et al., 2017; Garrard et al., 2008). Possible mechanisms explaining these differences include greater psychological aversion to risk, slower cycling speeds due to lower physical capacities, but also, increased household roles and serve-passenger trips, cycling trips with children, as well as personal safety concerns linked to harassment (Emond et al., 2009; Garrard et al., 2012; Aldred et al., 2017).

The effect of ***age*** on perceived cycling safety is less clear than that of gender (Aldred et al., 2017). Older cyclists generally have lower visual capacities, slower reflexes, and are more physically vulnerable than younger cyclists (Van Cauwenberg, de Geus, et al., 2018). They also have less time constraints and tend to cycle for fitness and recreation trips rather than commuting (Zander et al., 2013). Older cyclists have been found to dislike high traffic volumes and speeds, and to prefer physically separated infrastructure (Van Cauwenberg, Clarys, et al., 2018; Winters et al., 2015). They are more likely to cope with risk by avoiding cycling in traffic (Chataway et al., 2014). In addition to collisions, older cyclists are more fearful of single-vehicle accidents (falling off a bicycle) than younger cyclists due to their physical frailty (Schepers et al., 2020).

Frequency of cycling and perceived safety are closely related and may influence each other. On one hand, an individual’s cycling frequency may be linked to their perception of safety. Infrequent cyclists tend to be more fearful of cycling in mixed traffic and prefer physically separated cycle paths (Chataway et al., 2014). On the other hand, cycling frequently may lead to accumulating experience over time, and tends to decrease the influence of perceived safety in whether or not to cycle (Sanders, 2015).

Cycling experience accumulated throughout time has been linked to higher perceived safety (Manton et al., 2016). It has two opposite effects. On one hand, it improves perceived safety and is a motivating factor for cycling (Winters et al., 2015). However, it also increases exposure to accidents as well as near misses (Sanders, 2015), which negatively impact perceived safety. As a result, paradoxically, regular cyclists tend to worry more about being involved in an accident, and are more aware of dangerous situations than occasional cyclists (Sanders, 2015).

The next section presents our methods and data, which comes from a survey of e-bike users conducted in the city of Lausanne, Switzerland.

8.5 Methods

8.5.1 Context and data

Lausanne, in the French-speaking part of Switzerland, is the 4th largest city in the country, with a population of 140'000 inhabitants in the municipality and 415'000 in the urban area (FSO, 2018). The city offers an interesting setting for e-bikes as it is particularly hilly. It has the lowest cycling share among large cities in Switzerland (1.6% of trips compared to 7% nationally), fewer e-bike owning households (3.1% compared to 7% nationally) and fewer conventional bicycle owning households (41.7% compared to 65% nationally) (FSO and FOSD, 2017). In a national survey of commuter cyclists, Lausanne ranked last out of 24 cities as 34% felt unsafe (compared to 14% nationally) and 55% did not feel respected by other road users (compared to 32% nationally) (Rérat, 2021a). Most of the cycling infrastructure is recent and consists of on-road cycle lanes, bus lanes, and some mixed-use paths and sidewalks shared with pedestrians, and a pedestrian zone where bicycles are tolerated. The length of cycle lanes grew from 9.8 km in 2000 to 71.5 km in 2019 (Ville de Lausanne, 2020b).

Since the year 2000, the municipality of Lausanne offers a subsidy for the purchase of an e-bike[68]. With the municipality's approval, we used this database to contact over 3400 people who had received an e-bike subsidy with both online and postal surveys in June and July 2018, yielding 1466 responses with a combined (postal and online) 45% response rate after excluding invalid addresses. The survey had a general goal of assessing e-bike users profiles and experiences and contained three parts: (1) mobility equipment including current e-bike (model, date of purchase, etc.) and motivations for purchase (2) travel habits (trip motives, frequency, duration) and barriers (3) experiences of e-bike use and comfort in different situations (4) profile and socio-demographic information. For this study, we selected only questions relative to safety.

8.5.2 Survey items

Perceived safety was measured using 13 statements which could be answered on a 4-point Likert scale (strongly disagree, rather disagree, rather agree, strongly agree) (Table 2). Participants were asked to assess their level of comfort for using an e-bike in different situations, namely cycling in mixed traffic with cars, crossing an intersection, cycling on a bus lane, cycling on a contraflow lane, cycling on a sidewalk or pedestrian area, cycling on a cycle lane or path. Although the distinction between on-road cycle lanes and separated paths is known to be important, we did not make the distinction because there are almost no cycle paths in Lausanne and we hypothesized that most users would not be able to make the difference between the two. Participants were also asked about the influence of barriers in preventing them from using their e-bike, as well as their overall level of safety, satisfaction with available cycle infrastructure and feeling of being respected by other road users.

To test which factors had an influence on individuals' perceived safety, we used several explanatory variables. Socio-demographic information was collected about age, gender, e-bike type (pedelec or s-pedelec). Participants were asked whether they used their e-bike for five types of activities (work/study, leisure, shopping, social outings, recreation) creating three categories of e-bike use: utilitarian (work/study, shopping, going to leisure activities), recreational (trips with the sole purpose of recreation), and mixed (a mix of utilitarian and recreational activities). Frequency of e-bike use was

[68] At the time of the study, this subsidy amounted to 15% of the price of an e-bike, with a maximum of 500 Swiss Francs, with another smaller subsidy for the purchase of an e-bike battery.

assessed with three categories (every day or almost, several times per week, a few times per month or less). We also asked participants whether they continued to cycle in winter, a binary variable. To account for experience of conventional cycling, participants were asked which mode of transport was previously used for trips now taken by e-bike and this was recoded into a binary variable for previous cycling. Lastly, experience of e-bike use was measured using the date of purchase of the e-bike (< 2 years, > 2 years).

8.5.3 Analysis

All analyses were conducted with SPSS version 26. First, descriptive statistics were used to highlight differences in measures of perceived safety in terms of gender and age, using chi-square tests. In a second step, underlying factors were extracted from the 13 initial variables using principal component factor analysis (PCA) with orthogonal rotation (Varimax). We retained three components which had eigenvalues over 1 (Kaiser's criterion) and explained in combination 54% of the variance (Table 3). Sampling adequacy was verified with the Kaiser-Meyer-Olkin measure (KMO 0.814), with all individual items being greater than 0.697, above the accepted limit of 0.5 (Kaiser & Rice, 1974). In a third step, to create groups of e-bike users, we ran cluster analysis based on the 3 components. To determine the optimal number of clusters, we conducted a hierarchical cluster analysis using Ward's method and analyzed the dendrogram. K-means clustering was then used to create four groups of e-bike users.

The next section discusses our results. We start by describing the characteristics of our sample of e-bike users (4.1). We then describe our chosen measures of perceived safety and their variations (4.2). Later, we present our segmentation of four groups of e-bike users, and the factors which affect their perceived safety (4.3).

8.6 Results

8.6.1 E-bike users' characteristics

Table 1 shows the characteristics of our sample of e-bike users. There are slightly more women (53%) than men. Most e-bike users are either middle-aged (40-59 years old) or younger than 40, whereas older adults (>60) are a minority. A higher share of women are under 40 years whereas more men are over 60 years. This reflects the increasing diffusion of e-bikes to women buyers over the years. Most e-bike users live in a household composed of couples with or without children, with the remainder living alone with or without children. Half of all users are employed full-time, one in three part-time, whereas retirees, students and unemployed are a minority. This contrasts with existing studies where retired e-bike users were more common, especially in the Netherlands or Denmark (Haustein & Møller, 2016a; Kroesen, 2017) but also in Austria (Wolf & Seebauer, 2014).

The vast majority of participants own a regular pedelec with an assistance until 25 km/h rather than a faster s-pedelec reaching 45 km/h, though men own them much more often than women, as do middle-aged users. Three out of four users own at least one private car, a similar amount own a conventional bicycle, half own a public transport pass, and one in four own a motorcycle or scooter.

Frequency of e-bike use is high, with four out of ten users cycling every day or almost, one in three cycling several times per week, and one in five less often. A higher share of women cycle on a daily basis compared to men, as well as half of all younger users under 40 compared to only one in four aged over 60. Additionally, three quarters of participants continue to use their e-bike in winter, even if less often than other seasons, whereas one in four stop cycling. Among older users, four out of ten stop cycling in winter.

In terms of trip purposes, six out of ten users (e-)cycle for a mix of both recreational (e.g., bicycle tours) and utilitarian activities (e.g., work trips, groceries), while utilitarian-only users account for a third, and strictly recreational users are a minority. Mixing utilitarian and recreational trips is more prevalent among women, whereas men tend to cycle more for either utilitarian or recreational trips.

Experience of conventional cycling is overall quite low, as only one user in four previously cycled for trips now done by e-bike, with men being more experienced than women. However, experience of e-bike use is higher, as more than half of all participants have owned their e-bike for more than two years, including two thirds of older adults.

Table 21: Respondent characteristics.

Variable name	Categories	Percentage	Gender differences (chi-square test)	Age differences (chi-square test)
Gender	Female	53%	-	p<0.001
	Male	47%		
Age	<40 years	36%	p<0.001	-
	40-59	45%		
	>60 years	19%		
Household type	Alone	18%	p<0.001	p<0.001
	Alone with children	6%		
	Couple without children	29%		
	Couple with children	43%		
	Other	4%		
Employment	Student	3%	p<0.001	p<0.001
	Part-time employed	30%		
	Full-time employed	52%		
	Retired	11%		
	Unemployed or other	4%		
E-bike category	Pedelec (25 km/h)	85%	p<0.001	p<0.001
	S-Pedelec (45 km/h)	16%		
Car ownership	No	23%	p<0.05	p<0.001
	Yes	77%		
Conventional bicycle ownership	No	27%	n.s.	p<0.001
	Yes	73%		
Motorcycle/scooter ownership	No	76%	p<0.05	p<0.001
	Yes	24%		
Public transport pass	No	49%	p<0.05	p<0.01
	Yes	51%		

Frequency of e-bike use	Every day or almost	42%	p<0.01	p<0.001
	Several times per week	36%		
	A few times per month or less	22%		
Weekly duration of e-bike use	Less than 1 hour	31%	n.s.	n.s.
	Between 1 and 4 hours	56%		
	More than 4 hours	13%		
Winter use of e-bike	Yes, like other seasons	25%	n.s.	p<0.001
	Yes, but less often	48%		
	No	27%		
Type of e-bike use	Utility only	32%	p<0.01	p<0.001
	Mixed	59%		
	Recreational only	9%		
Cycling experience (previously cycling for trips by e-bike)	No	73%	p<0.001	p<0.001
	Yes	27%		
E-bike experience (date of purchase)	<2 years	44%	p<0.001	p<0.001
	>2 years	56%		

8.6.2 Perceived e-bike safety and variations by age and gender

Table 2 shows the 13 items used to measure perceived safety. Overall, perceived safety appears to be low among e-bike users. Only one in six users find the available infrastructure (cycle paths and lanes) to be sufficient, and less than one in three feel safe in traffic or respected by other road users. Women are more critical than men in terms of satisfaction with available cycle lanes and paths and feeling of safety in traffic, as are older users above 60 years compared to those aged 40-59 or under 40.

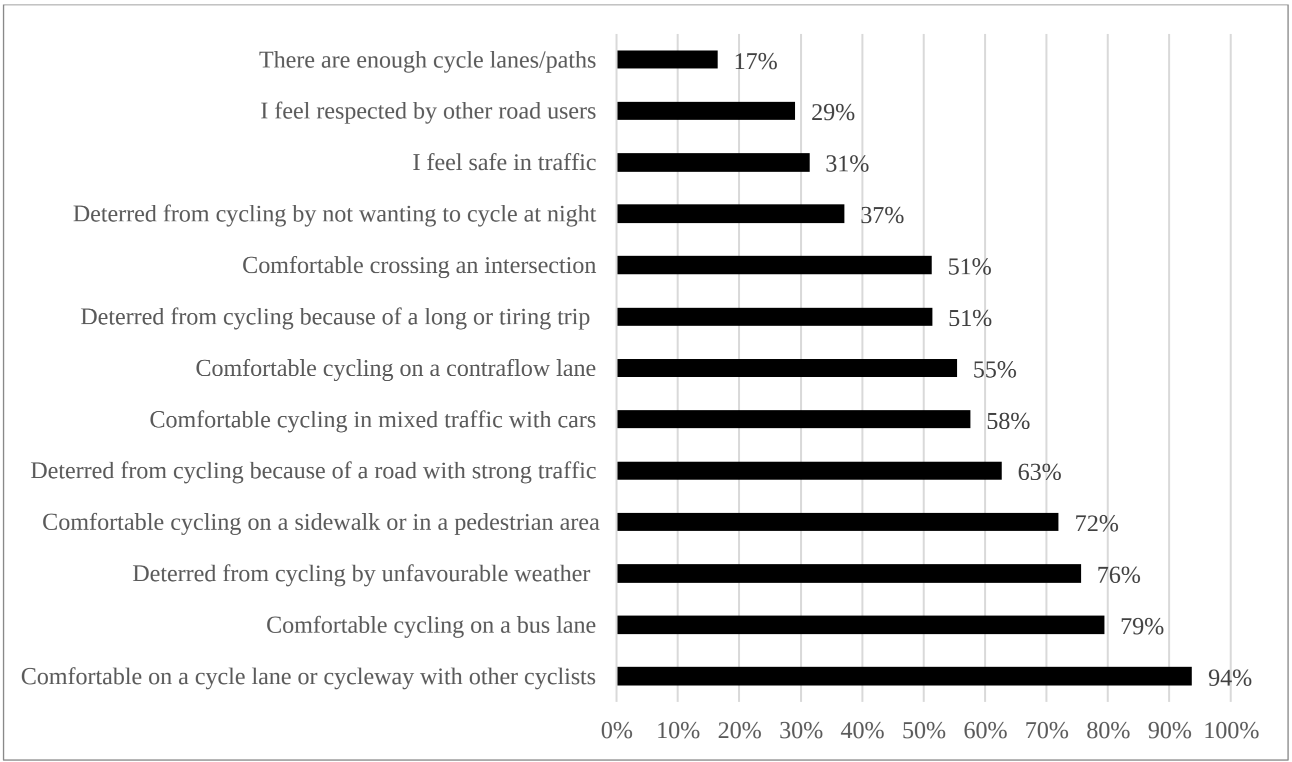
A majority of e-bike users agree to cycling less because of unfavorable weather conditions or having to use roads with a lot of traffic. About half of all users are deterred by a long or tiring trip, and a third by having to cycle at night. Older e-bike users are significantly more affected by barriers than younger age groups, especially cycling at night (64% agree vs. 37% overall), having to use roads with high traffic, a long or tiring trip, and, to a lesser degree, unfavorable weather. Women are also more affected than men by barriers, especially having to use a road with strong traffic, a long or tiring trip, cycling at night, as well as unfavorable weather.

E-bike users' degree of comfort varies strongly when cycling in different types of infrastructure, depending on the level of separation offered from motor traffic. Only slightly more than half of e-bike users are comfortable using their e-bike where there is no separation, such as in mixed traffic with cars, crossing an intersection, or cycling on contraflow lanes in the opposite direction to the flow of traffic. Gender differences for cycling in non-separated conditions are substantial; fewer women are at ease than men in mixed traffic with cars (48% vs. 67%), crossing an intersection (46% vs. 58%) and cycling on contraflow lanes (50% vs. 61%). Age differences are also significant. Compared to younger users, only 35% of people over 60 feel comfortable crossing an intersection (vs. 61%), and 42% for cycling in mixed traffic (vs. 61%).

Comfort is noticeably higher, with 3 in 4 users at ease when cycling on infrastructure shared with slower users like sidewalks and pedestrian areas and bus lanes, two situations which provide some degree of separation from motor traffic. However, comfort on bus lane is also lower for older e-cyclists as well as women, which may reflect a fear of motor vehicles (buses).

As expected, almost all e-bike users feel comfortable or very comfortable cycling on cycle lanes or dedicated cycle paths separated from the road, the only infrastructure which is only shared with other cyclists. There is no difference in comfort among men or women, and only small differences between age groups.

Figure 48: Measures of perceived e-bike safety. Only positive responses (agree or rather agree). N=1260.



8.6.3 Groups of e-bike users

We now aim to differentiate e-bike users depending on their perception of safety. In a first step, we perform a factor analysis (principal component analysis) to extract three components (Table 3). The first component, “comfort (for cycling in different situations)”, loads onto items which represent the perceived comfort for cycling in different road infrastructures and situations, from sidewalks shared with pedestrians to mixed traffic. The second component, “satisfaction (with cycling conditions)”, includes assessments of the overall safety level (“I feel safe in traffic”), of relationships with other road users (“I feel respected by other road users”), and of satisfaction with the cycling network (“There are enough cycle lanes/paths”). Two items, “comfortable cycling in mixed traffic” and “comfortable crossing an intersection”, load onto both dimensions of satisfaction as well as comfort, indicating that ease for cycling in traffic is strongly related with how cycling conditions are perceived. The third and last component, “barriers”, represents both practical barriers to cycling (weather, night-time or tiredness) but also barriers related to lack of safety, such as roads with a lot of traffic, an item which also loads onto the dimension of satisfaction.

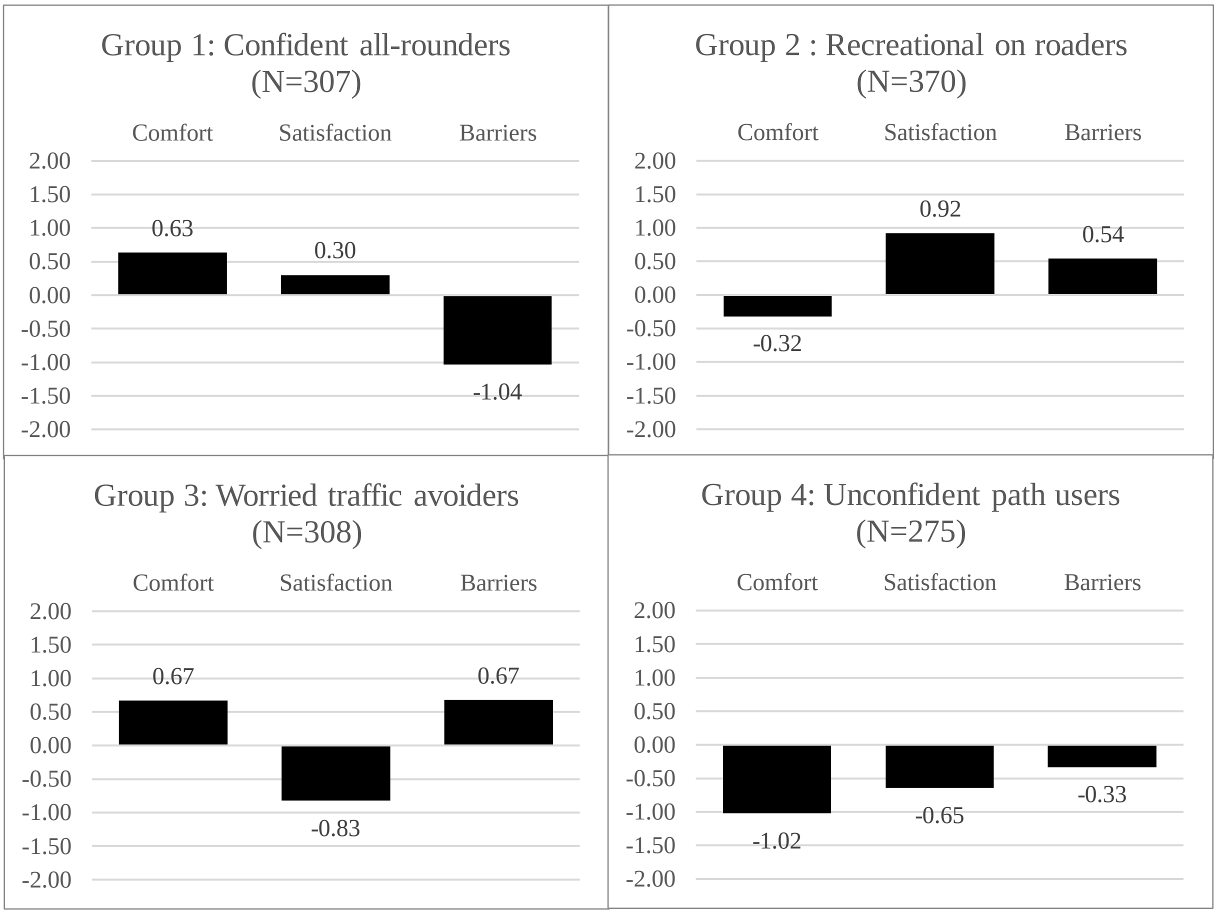
Table 22: Components of perceived e-bike safety. N=1260.

	Component loadings (values over 0.4 in bold)		
Items	Comfort	Satisfaction	Barriers
Comfortable cycling on a bus lane	**0.76**	0.12	-0.09
Comfortable cycling on a sidewalk or in a pedestrian area	**0.73**	-0.06	0.09
Comfortable cycling on a cycle lane or cycleway with other cyclists	**0.67**	0.06	-0.01
At ease cycling on a contraflow lane	**0.65**	0.15	-0.12
I feel safe in traffic	0.22	**0.78**	-0.13
There are enough cycle lanes/paths	-0.09	**0.75**	0.14
I feel respected by other road users	0.07	**0.70**	0.14
Comfortable cycling in mixed traffic	**0.49**	**0.52**	-0.33
Comfortable crossing an intersection	**0.47**	**0.49**	-0.26
Deterred from cycling by not wanting to cycle at night	-0.17	-0.05	**0.73**
Deterred from cycling by unfavorable weather	0.00	0.04	**0.72**
Deterred from cycling by a long or tiring trip	0.03	0.17	**0.66**
Deterred from cycling by having to use a road with high traffic	-0.10	**-0.42**	**0.56**
Cronbach's Alpha	0.77	0.75	0.63

After performing a cluster analysis based on the three components (comfort, satisfaction, and barriers), we identify four groups of e-bike users. Figure 49 shows each group and their average component loadings for the three components. To further describe each group, we conduct four separate binary logistic regressions (Table 4) showing which variables significantly predict membership of each group. The variables which had the most effect were demographic characteristics including gender and age category, frequency of e-bike use, and winter e-bike use. Meanwhile, trip motives (utilitarian, recreational, and mixed) only had a reduced effect. We did not find any significant effect for previous experience of conventional cycling, nor e-bike experience (years since purchase).

The first group, *confident all-rounders* (N=307, 24.4%) are comfortable when cycling in any kind of infrastructure, even without any separation from traffic, such as crossing an intersection (mean score: 3.12 out of 4) or cycling in mixed traffic with cars (3.25). However, they have average values for the component “satisfaction”, because although they feel quite safe in mixed traffic (2.54), they are unsatisfied with available cycle lanes and paths (1.72) and do not feel respected by other road users (2.13). A low score for “barriers” means they do not avoid cycling because of external conditions such as unfavorable weather (2.35), a long or tiring trip (1.99), roads with strong traffic (1.88) or cycling at night (1.3). The regression model shows that being a member of this group is strongly associated with being male rather than female, and with daily cycling frequency, suggesting users from this group are regular e-bike users. Being in group 1 is also negatively associated with reducing or interrupting e-bike use in winter, indicating a low sensibility to weather or traffic conditions.

Figure 49: E-bike user groups and average component loadings. N=1260.



The second group, *recreational on roaders* (N=370, 29.4%) show the highest satisfaction with current cycling conditions, including cycle lanes/paths (2.41), feeling respected by other road users (2.55), and feeling safe in traffic (2.52). Their level of comfort is average overall but shows no difference when cycling without separation - in mixed traffic (2.73) or an intersection (2.63) – and when using separated infrastructure such as sidewalks shared with pedestrians (2.76), bus lanes (2.95) and contraflow lanes (2.44), though they still prefer cycle lanes (3.29). They are quite sensitive to practical barriers which deter them from cycling such as bad weather (3.45), long and tiring trips (3.01), or night-time conditions (2.61). Being a member of this group is positively associated with e-biking only few times per week rather than daily, and with interrupting or reducing e-bike use during winter. Users in this group are very likely to use their e-bike strictly for recreational trips (e.g., bicycle tours), suggesting that the e-bike is not their main mode of transport. This might explain why they have lower expectations in terms of cycling safety than other groups.

The third group, *utilitarian traffic avoiders* (N=308, 24.4%) are very comfortable when using infrastructure separated from traffic such as cycle lanes (3.64), sidewalks (3.42), bus lanes (3.42), but feel uneasy when mixing with cars in traffic (2.33) or crossing an intersection (2.25). In terms of satisfaction with cycling conditions, they are the most critical, both in terms of overall safety in traffic (1.64), cycle lane/path availability (1.31), and of the lack of respect of other road users (1.77). They are also very sensitive to safety-related barriers to e-bike use such as having to cycle in strong traffic conditions (3.47), as well as unfavorable weather (3.49). Being a member of this group is significantly associated with being either middle-aged (40-59) and older than 60 years, and with female gender, two characteristics which may explain their aversion to traffic. It is also associated with reducing or completely stopping e-bike use in winter, indicating a sensibility to external conditions.

The fourth and last group, *unconfident path-users* (N=275, 21.8%) score negatively on all three components. They have the lowest comfort for cycling in mixed traffic (1.99), intersections (1.92), contraflow lanes (1.96) but also in separated infrastructure like sidewalks shared with pedestrians (2.35) or bus lanes (2.39), and are only at ease on dedicated cycle lanes or paths (2.89). They are also very dissatisfied with cycling conditions, both in terms of cycle lanes/paths (1.39), overall safety in traffic (1.62) and relations with other road users (1.62). However, they are not very sensible to barriers linked to external conditions including weather (2.81), tiredness (2.2) or night-time (2.09), though they will avoid cycling on roads with strong traffic (3.02). According to the regression model, being a member of this group is only statistically associated with being female, with no other significant characteristic, suggesting gender represents the main factor for their low safety.

Table 23: Average scores by group (1 = disagree, 2 =rather disagree, 3 = rather agree, 4 = agree).

Cluster group	Group 1		Group 2		Group 3		Group 4		Total	
Variables	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Comfortable crossing an intersection	3.12	0.7	2.63	0.7	2.25	0.8	1.92	0.7	2.5	0.8
Comfortable cycling on a contraflow lane	3.08	0.8	2.44	0.8	2.81	0.9	1.96	0.8	2.58	0.9
Comfortable cycling in mixed traffic with cars	3.25	0.6	2.73	0.7	2.33	0.8	1.99	0.7	2.6	0.8
Comfortable cycling on a sidewalk or in a pedestrian area	3.24	0.8	2.76	0.8	3.42	0.7	2.35	0.8	2.95	0.8
Comfortable cycling on a bus lane	3.56	0.6	2.95	0.7	3.42	0.6	2.39	0.8	3.09	0.8
Comfortable on a cycle lane or cycleway with other cyclists	3.7	0.5	3.29	0.6	3.64	0.5	2.89	0.7	3.39	0.6
There are enough cycle lanes/paths	1.72	0.7	2.41	0.6	1.31	0.5	1.39	0.6	1.75	0.8
I feel respected by other road users	2.13	0.7	2.55	0.6	1.77	0.7	1.62	0.6	2.05	0.8
I feel safe in traffic	2.54	0.7	2.52	0.6	1.64	0.6	1.62	0.6	2.12	0.8
Deterred from cycling by unfavorable weather	2.35	1.0	3.45	0.6	3.49	0.7	2.81	0.9	3.05	0.9
Deterred from cycling by having to use a road with high traffic	1.88	0.9	2.68	0.9	3.47	0.8	3.02	1.0	2.75	1.1
Deterred from cycling by a long or tiring trip	1.99	0.9	3.01	0.8	2.8	0.9	2.2	0.9	2.53	1.0
Deterred cycling by not wanting to cycle at night	1.3	0.5	2.61	1.0	2.62	1.0	2.09	1.0	2.18	1.0

Table 24 : Comparison of 4 logistic regression models. N=1260.

Dependent variable	Group 1		Group 2		Group 3		Group 4	
Independent variable	Sig.	Exp(B)	Sig.	Exp(B)	Sig.	Exp(B)	Sig.	Exp(B)
Male	0***	2.274	0.781	0.962	0.009**	0.671	0.016*	0.684
Age: 40-59 (REF)	0.036*		0.332		0.012*		0.663	
Age: under 40	0.131	1.277	0.138	1.251	0.005**	0.633	0.828	0.964
Age: 60+	0.101	0.628	0.674	1.093	0.77	1.065	0.436	1.196
Frequency: every day or almost (REF)	0.009**		0.013*		0.887		0.917	
Frequency: a few times per week	0.002**	0.565	0.003**	1.628	0.765	1.054	0.68	0.926
Frequency: a few times per month or less	0.327	0.768	0.098	1.447	0.834	0.951	0.893	0.967
Winter e-bike use: yes, same as other seasons	0***		0.002**		0.002**		0.167	
Winter e-bike use: Yes, but less often	0***	0.338	0.001**	1.842	0.001**	1.922	0.248	1.267
Winter e-bike use: No	0***	0.128	0.001**	2.104	0.001**	2.238	0.059	1.602
Mix of utilitarian and recreational trips (REF)	0.252		0.074		0.152		0.802	
Utilitarian trips only	0.529	1.108	0.175	1.232	0.123	0.773	0.617	0.917
Recreational trips only	0.149	0.535	0.039*	1.714	0.16	0.654	0.733	1.107
Previously cycling for trips	0.486	1.125	0.875	0.975	0.802	1.044	0.35	0.844
E-bike purchase >2 years	0.313	1.172	0.057	0.764	0.947	1.01	0.202	1.223
Constant	0.015*	0.594	0***	0.186	0***	0.275	0***	0.233
Significance level: *p<0.05; **p<0.01; ***p<0.001.								

8.7 Discussion and conclusion

This section compares our results within existing literature and offers some conclusions for policy and future research. This paper had two objectives: (1) to understand how e-bike users perceive safety when cycling in the city; (2) to differentiate e-bike users based on their level of perceived safety. We used 13 items to measure perceived safety, which we reduced to three components: comfort for cycling in different situations, satisfaction with cycling conditions, and barriers to cycling.

Overall, we found levels of perceived safety to be low among e-bike users in the city of Lausanne. Notably, fewer than 2 in 10 users were satisfied with cycle infrastructure (the availability of cycle lanes and paths), only 3 in 10 felt respected by other road users or safe cycling in traffic with motor vehicles. Consistent with existing literature on conventional cyclists' preferences (Aldred et al., 2017), we found e-bikers' comfort for cycling varied strongly depending on the level of infrastructural separation offered; while 9 in 10 e-bike users felt at ease on a cycle lane, and 7 in 10 on a sidewalk or bus lane, only about half still felt comfortable when cycling in mixed traffic among cars, or using contraflow lanes. Despite e-bikes' technical advantages over conventional bicycles (ease of maintaining a higher speed, stronger acceleration), e-bike users still have a strong preference for separated infrastructure. Roads with strong traffic were (after unfavourable weather) the most common barriers to e-bike use, affecting two thirds of e-bike users.

We identified four cluster groups of e-bike users. ***Confident all-rounders*** are mostly male, frequent e-bikers who are comfortable cycling in any road conditions and are unaffected by practical or weather-related barriers, but are wary of current cycling conditions. ***Recreational on roaders***, who are very satisfied with cycling conditions and relatively comfortable cycling in traffic, but mostly use their e-bike for less frequent recreational trips*;* ***Worried traffic avoiders*** are older, mostly female cyclists who are uncomfortable without separation from motor traffic, fearful of cycling conditions and likely to avoid cycling in strong traffic; ***Unconfident path users*** are mostly female users who are uncomfortable in most situations except dedicated cycle paths and very unsatisfied with cycling conditions. These four groups are similar to typologies of conventional cyclists based on comfort for cycling in different kinds of cycling infrastructure (Dill & McNeil, 2013). Confident all-rounders would cycle regardless of the absence of infrastructure, while recreational on readers may prefer using the road rather than sharing space with pedestrians or buses. Meanwhile, worried traffic avoiders would feel uncomfortable without separation from traffic and unconfident path-users would avoid anything less than a dedicated cycle lane or path. This suggests that despite electrical assistance, which may reduce barriers linked to physical capabilities and "equalize" between different users, important differences in e-bike users' perceived safety remain.

Gender differences proved to be significant for e-bike users' safety perceptions, as they have been shown to affect conventional cyclists (Aldred et al., 2017; Garrard et al., 2008). Women were generally less satisfied with cycling conditions and perceived safety to be lower, preferred separated infrastructure (e.g., sidewalks and cycle lanes) and were more affected by barriers to e-bike use. The importance of age and gender confirms findings on e-bike users by Haustein & Møller (2016) that being a woman and being older than 60 were associated with lower perceived safety levels. Women's greater emphasis on safety could reflect differences in familial roles (e.g., more serve trips, parental duties) and shorter, more frequent cycle trips. Indeed, a higher share of women in our sample used their e-bike daily compared to men (46% vs. 37%). Others have explained gender differences in safety by womens' lower cycling experience, going back until childhood (Emond et al., 2009). In our sample, we found fewer women previously used a conventional bicycle, and that women had owned an e-bike for less time than men, though this may also reflect differences in age between male and female e-bike users. Lastly, gender differences may also be due to men's higher confidence, or a propensity to minimize fears when answering survey questions (Garrard et al., 2012).

Age differences were also significant for e-bikers' safety. Older adults (<60) felt less safe overall, both in mixed traffic, but also on bus lanes and cycleways shared with other cyclists. They were also much more deterred than younger users by night conditions, high traffic, and long or tiring trips. Older adults have been shown to be more sensible to motor traffic and to specific barriers (e.g. cycling at night) because of lower physical capacities such as eyesight and reaction time, as well as greater vulnerability in case of a crash (Van Cauwenberg, Clarys, et al., 2018). Our results tend to confirm that older e-bike users too, may have more difficulties cohabiting with other cyclists and pedestrians (Winters et al., 2015)

We also found a higher frequency of e-bike use, as well as continuing to cycle in winter, to be significantly related to e-bike safety, specifically to being a member of group 1 (confident all rounders). Of course, causality could be reversed, with users who feel safest being the ones that cycle most often, and those that continue to cycle in winter. Existing studies have shown frequency of cycling to affect safety in two opposite ways. A high frequency of use may reduce safety-related barriers for conventional cycling (Sanders, 2015). Conversely, Haustein & Møller, (2016a) found that the length of daily kilometers cycled by e-bike (related to frequency) was associated with lower perceived safety as a result of encountering dangerous situations.

We did not find e-bike experience (number of years since e-bike purchase) to have any significant effect on perceived safety, in contrast to Haustein & Møller (2016b) who found greater e-bike experience improved perceived safety. Similarly, we also found no effect for previously using a conventional bicycle for trips now made by e-bike. This confirms results by Haustein & Møller, (2016), who also found no such effect, but contradicts a Canadian study where e-bike users who switched from conventional cycling to the e-bike were more comfortable in traffic than those returning to cycling (Edge et al., 2018). An explanation for this result may be that the variable we used to assess cycling experience only addresses previously cycling for trips which are now made by e-bike, excluding other kinds of trips (e.g. sports cycling) which could constitute a form of cycling experience.

Future research should aim to further understand which experiences and events may influence perceived safety from the individual's point of view. Negative experiences such as crashes and near misses have been shown to reduce perceived safety (Lee et al., 2012; Sanders, 2015). Biographical or longitudinal designs could help to understand how a person's perception of cycling safety varies throughout the life course.

Our results offer some lessons for designing infrastructure for diverse profiles of e-bike users. Implementing cycle paths separated from motor traffic, and traffic-calmed intersections, would greatly improve comfort for women, older and more safety-conscious e-bike users, while also improving satisfaction among experienced cyclists. Types of infrastructure which offer some separation but are shared with other road users such as sidewalks, bus lanes, or contraflow lanes, should, however, be avoided as they do not cater to both ends of the spectrum, namely those most confident and those least confident in traffic. Finally, given the importance of differences in e-bike users' profiles, ample width should be provided on cycle lanes or paths to overtake other cyclists, and accommodate increasing numbers of conventional and electrically assisted cyclists.

Beyond comfort for cycling in different situations, other dimensions of perceived safety should also be addressed. Reducing barriers to e-bike use linked to external conditions, and increasing winter use of e-bikes, could be enabled by improved street lighting and year-round maintenance of cycle infrastructure. Improving satisfaction with cycling conditions, as well as respect by other road users, could be addressed by awareness campaigns promoting a positive image of e-biking, for example by focusing on its advantages for health, efficiency and enjoyment, rather than on the dangers posed by road accidents. This would help to deconstruct the image of (e-) cycling as a dangerous practice.

Regarding the generalization of our results, they represent e-bike users' perceptions of safety in a low-cycling context with a specific topography and mobility culture (Aldred & Jungnickel, 2014; Klinger et al., 2013). Nonetheless, we believe they may provide a useful comparison point for other low-cycling contexts where cycling infrastructure is recent, and e-bike uptake has been strong. In cities where cycling was previously not considered feasible, e-bikes have enabled more people to cycle than would have been possible with conventional bicycles. However, this has also opened up new challenges by highlighting the inadequate infrastructural conditions cyclists face. While e-bikes have succeeded in attracting a variety of cyclists with different profiles and levels of experience, improving perceived safety will be necessary in order to keep them in the future.

8.8 Appendix

Table 25: Measures of perceived safety by age and gender.

Variables	<40 years	40-59 years	>60 years	Statistical test (chi-square)	Women	Men	Statistical test (chi-square)
Comfortable on a cycle lane or cycleway with other cyclists	95%	94%	90%	p<0.05	94%	93%	n.s.
Comfortable cycling on a bus lane	84%	80%	67%	p<0.001	76%	81%	p<0.05
Deterred from cycling by unfavorable weather	74%	76%	83%	p<0.05	79%	74%	p<0.05
Comfortable cycling on a sidewalk or in a pedestrian area	69%	74%	71%	n.s.	72%	71%	n.s.
Deterred from cycling by having to use a road with high traffic	58%	63%	79%	p<0.001	67%	60%	p<0.01
Comfortable cycling in mixed traffic with cars	61%	59%	42%	p<0.001	48%	67%	p<0.001
Comfortable cycling on a contraflow lane	56%	57%	50%	n.s.	50%	61%	p<0.001
Deterred from cycling by a long or tiring trip	50%	49%	64%	p<0.001	57%	48%	p<0.01
Comfortable crossing an intersection	61%	50%	35%	p<0.001	46%	58%	p<0.001
Deterred from cycling by not wanting to cycle at night	27%	38%	64%	p<0.001	42%	34%	p<0.01
I feel safe in traffic	35%	31%	24%	p<0.01	28%	34%	p<0.05
I feel respected by other road users	30%	28%	30%	n.s.	28%	30%	n.s.
There are enough cycle lanes/paths	21%	14%	13%	p<0.01	13%	20%	p<0.001

9. Conclusion and discussion

This final chapter aims to bring together the different elements of the thesis. In section 9.1, we start by highlighting the main findings of the questionnaire survey conducted among e-bike users, and of the five articles. Afterwards, we reflect on the contribution of the thesis to existing literature, and the research gaps it has addressed (section 9.2). We also reflect critically on the limitations of our work, and how future research could expand our findings (section 9.3). To conclude, we formulate a series of recommendations for putting the findings of this thesis into practice through public policies (section 9.4).

9.1 Main findings

9.1.1 Results of the survey

Women represent a slight majority of e-bike users (53%) compared to men (47%). E-bike users in Lausanne are younger than in other studies, with a mean age of 44 years. The socio-demographic profile of e-bike users is skewed towards middle-aged people in the active stage of life (35-64 years), because of the absence of teenagers, children, and old adults over 75. Due to this, e-bike users have higher education levels than in the population. Two thirds of participants have adopted the e-bike only recently, in the two and a half years before the survey (2016, 2017, mid-2018), while only 42% have owned an e-bike for longer. Most are onto their first e-bike (80.2%), but some have already owned two or even more (18.8%). Over time, the profile of e-bike users has evolved with an increase in the share of women and of young users below 40. These characteristics suggest that following growing sales, e-bikes are increasingly diffusing into the population. In terms of their residential location and workplace, 72.7% of e-bike users in the survey live less than 10 km away from their workplace, a feasibly cycling distance by e-bike.

Regarding their access to vehicles and transport passes, 85% of participants own a pedelecs with an assistance until 25 km/h, while 15% own a speed-pedelec until 45 km/h. The role of the subsidy was mainly to trigger the decision to purchase an e-bike (68%), but also to upgrade to a better model or buy accessories (41%). E-bike users have higher ownership of individual modes (car, bicycle, scooter), but a lower share of public transport passes than the general population, suggesting a preference for individual modes of travel.

In terms of use, e-bikes serve, on the one hand, as a mode of transport for utilitarian trips like commuting to work, shopping or going to leisure activities, and on the other hand, as a form of recreation or exercise. E-bikes are not just owned, but also frequently used, with three quarters of e-bike users (77.7%) cycling several times per week. During the winter season, three quarters of e-bike users (74.8%) continue to cycle rather than stopping. Based on the types of trips for which the e-bike is used, participants can be classified into utilitarian users (32.1%, of which 7.4% are strictly commuters), mixed users (58.7%) combining utility and recreational trips, and purely recreational users (9.2%).

Adopting an e-bike leads to substituting trips which were previously made by other travel modes. Three separate effects of substitution are considered: previous use, reduction of trips, and abandoning ownership. Firstly, the most previously used travel modes for e-bike trips are public transport (64.8%), walking (49.9%), or driving (48.3%), with only 27.1% previously cycling (unassisted). Secondly, the travel modes whose use was most reduced after e-bike adoption were public transport (61.1%), car use (51.1%), and conventional cycling (46%, but 8% also increased its use). Thirdly, e-bike adoption leads to give up ownership, or a planned purchase, of motor two wheelers (scooters, mopeds) (42.9%), public transport passes (34.5%), bicycles (33.8%), and cars (18.6%), although this decision is a more long-term one than for other modes. These results suggest that, overall, e-bikes are reducing trips by public transport, cars and conventional cycling, while replacing the need for owning a motor two-wheeler.

What are the motivations and barriers related to e-bike adoption, or in terms of vélomobility, how do e-bike users appropriate this mode of transport as their own? The most important motivations for using an e-bike in Lausanne are the ability to cycle despite the gradient or slope (95.8%), which can be explained by the city's topography. The e-bike also offers an alternative to the car or public transport in city traffic (89.3%). Using it offers a dose of exercise (86.7%). The e-bike is also a way to be able to continue cycling, or to cycle more (84.5%). Other motivations include the pleasure which e-cycling provides (79.8%), the innovativeness (i.e. sustainability) of this mode of transport (78.6%), the ability to travel faster or further than with a conventional bike (72.3%), while the possibility to carry goods or children by e-bike motivates mainly young parents with children (36.5%). Among the barriers limiting the use of the e-bike, the most prominent are bad weather (76.1%), the difficulty of carrying the e-bike in the train or metro (68.7%), having to use roads with strong traffic (63.6%), fatigue due to a long trip (52.1%), having to carry goods or children (51.9%), the risk of theft or vandalism (40.5%), having to cycle at night (38%), insufficient battery (33.5%), and not wanting to sweat (21.2%). Some of these barriers are the same as for conventional cycling, such as fear of traffic, while others are e-bike specific (difficulty of carrying e-bike due to weight, battery issues).

The skills which e-bike users possess fall into two categories: cycling skills and mechanical skills. Cycling skills are measured through comfort when cycling in different situations, which largely depends on the level of separation from motor traffic. While almost all e-bike users are at ease on dedicated cycle lanes or paths with other cyclists (93.4%), not all are comfortable sharing bus lanes (78.5%) or mixed-use pedestrian paths or sidewalks (71.7%). Even fewer e-bike users are comfortable when the road needs to be shared with motor vehicles in mixed traffic with cars (56.5%), on a contra-flow lane (55.3%), or when crossing an intersection or roundabout (51%). Mechanical skills for fixing a flat tyre or doing mechanical maintenance on an e-bike are held by only one e-bike user out of three. This is likely due to the higher weight of e-bikes and complexity of the electric assistance, which discourage from performing mechanical tasks.

Lastly, the experiences of e-bike users of cycling in Lausanne emphasize the need to improve e-bikers' perceived safety. The majority of e-bike users are not satisfied with the available cycle infrastructure (82.8%), encounter dangerous situations (79.6%), do not feel safe in traffic (78.7%) or respected by other road users (71%). However, parking conditions are judged as sufficient for most e-bikers both at the home (67.4%) and destination or workplace (67%). Lastly, the social stigma related to considering the use of an e-bike as "cheating" is relatively low (21%).

9.1.2 E-bike adoption

Our first research question asked: "*Why do people choose to use an e-bike and under which circumstances do they adopt it over their life course?"*

In the first article, we used a qualitative, retrospective biographical approach to analyse the cycling trajectories of e-bike users. We found two main cycling trajectories. In restorative trajectories, the e-bike serves to resume cycling after an interruption, or start cycling regularly. Within restorative trajectories, there are three sub-trajectories: people who returned to cycling after an interruption (1), who started to cycle for transport (2), and those who continued a return to cycling they had already started (3). In resilient trajectories, the e-bike serves to continue cycling despite changes in the spatial context such as relocations, or the advance of age. Among resilient trajectories, some e-bike users replaced conventional cycling by the e-bike (1), while other users alternate between conventional and electrically-assisted bicycles depending on the situation (2). These trajectories suggest that the adoption of the e-bike should be seen as a continuation of conventional cycling over the life course (H. Jones et al., 2014), where it serves as a way to restart or resume cycling, or to keep cycling.

The second article further developed our understanding of the two cycling trajectories by adopting a mixed-method approach to understand the differences between these two trajectories. Resilient trajectories were found to account for 27% of e-bike users, while restorative trajectories accounted for 73%. A logistic regression model found that resilient e-bikers were more likely to be male, of mature age (40-59) or older than 60, had mobility practices centred around cycling (unlikely to own a car, likely to own a conventional bicycle and car-sharing pass), and to have a higher weekly frequency of e-bike use, to continue cycling in winter, and, surprisingly, to cycle more for leisure. Conversely, restorative e-bikers were likely to be female, younger, and more reliant on motorized modes of transport, and to have a mixed e-bike use combining recreational and leisure cycling. These results show the changes in terms of profile occurring with the diffusion of e-bikes. E-bikes are progressively being adopted by more women, younger users, and people who were previously not cycling regularly. This finding confirms that e-bikes are enlarging the public of cyclists by enabling “more people to cycle more” (Behrendt, 2018).

The third article focused on the role of key events, motivations and past experiences in adopting an e-bike. Using retrospective biographical interviews, we found that over half of e-bike users (14 out of 24) had adopted their e-bike following a key event or combination of events. Among the rest, many were older adults whose e-bike adoption was not related to a specific event, but could be linked to a long-term process of aging. Three categories of events were found. First, contextual changes which modify the spatial context (i.e. longer distance to work) or social context (i.e. cycle-friendly environment) for cycling. Second, biographical changes (e.g. childbirth, health events) which modify the conditions for cycling and the individual’s capacities. Third, partner-related events (e.g. the purchase of a first e-bike), which influence the decision to adopt an e-bike. Several of the effects of key events were found to be the opposite of those known for conventional cycling: longer distances, childbirth and health events served as reasons to adopt an e-bike rather than reducing cycling. Moreover, motivations and past experiences were found to play a role as mediating factors in the adoption of the e-bike. This result confirms that e-bike adoption plays two roles: for restorative trajectories, adopting an e-bike unleashes a latent demand for cycling, while for resilient trajectories, switching from a bicycle to an e-bike represents an adaptive change to be able to maintain cycling (Janke & Handy, 2019). The results of this study indicate that e-bike adoption can be explained, in part, by the effects of key events in the life course, a finding which confirms the importance of considering such events and the individual’s position in the life course when addressing cycling (Chatterjee et al., 2013; Janke & Handy, 2019). It also suggests that focusing on key events may be a purposeful way to promote e-bikes, which may be better suited than conventional bicycles to avoiding interruptions in cycling over the life course, due to their greater ease of use and range.

9.1.3 Individual and environmental determinants of e-bike use

Our second research question was: “*How are e-bikes used and what is the influence of individual characteristics (mobility potential) and environmental characteristics (territorial potential)?*”

The fourth article focused on the determinants affecting the frequency of e-bike use. It used the conceptual framework of a system of vélomobility to consider e-bike uses as the meeting between individuals' potential for mobility (access, skills, and motivations and barriers), and the territorial hosting potential or "bikeability" (spatial context, bikeability, and rules and norms).

We found e-bikes to be used frequently, with 44% of participants e-cycling daily, 38% pluri-weekly (several times per week) and 18% a few times per month or less (i.e. "occasionally"). Variables related to e-bike uses had the strongest association with frequency, including e-biking for utilitarian trips (work, shopping, or going to leisure activities) and having previously travelled by public transport rather than by car, increased the frequency of e-bike use. At the level of the territorial hosting potential, frequency of e-bike use was associated with proximity to the workplace (working in the same city), but neither residential neighbourhood density, nor the presence of cycling infrastructure and traffic-calmed streets, or bicycle parking at the workplace had a significant effect. The individual mobility potential also had a strong effect on frequency of e-bike use through access to transport modes (lack of a public transport pass, having purchased an e-bike less than two years previously), cycling skills (i.e. ease of cycling in different kinds of infrastructure), motivations (using an e-bike for utilitarian reasons), barriers (having a lower sensibility to barriers), while socio-demographic characteristics (employment and gender) had a reduced effect.

These results suggest that frequency of e-bike use is affected by a combination of individual, territorial, and use or trip-related characteristics. The fact that many e-bike users did not previously cycle suggests that in a low-cycling city like Lausanne, e-bikes appeal to a broad audience (including women and younger users), widening the appeal of cycling. E-bike use also seems to reduce reliance on other modes of transport like public transport, car use, and to replace motor two-wheelers, especially for the most frequent users. The territorial hosting potential affects e-bike use mainly through proximity, which remains important despite the e-bikes' greater range. However, the low effect of measures of bikeability is likely due to the limited supply of cycling infrastructure in the city, while the effect of population density is likely smaller at the scale of a city than for a region or country. Lastly, barriers to cycling related to safety or traffic remains significant for frequency of e-cycling despite e-bikes' technological advantage. This relates to the next section.

9.1.4 Perceived safety of e-bike users

Our third research question was: *"How do e-bike users perceive cycling safety according to their personal characteristics, skills and experiences?*"

Within our framework of the system of vélomobility, we conceptualized perceived cycling safety as a friction resulting from the meeting of individuals' mobility potential and the environment's hosting potential or bikeability. From the viewpoint of the adoption of the e-bike, perceived safety represents a barrier to the diffusion and use of the e-bike.

In the fifth article, we found many e-bikers to have a low perception of safety, with only one third feeling safe when cycling or feeling respected by other road users, and one in six being satisfied with cycling infrastructure. Women and older users were particularly critical towards existing cycling infrastructure, sensible to barriers (especially traffic, night-time, fatigue, and weather) and were overall less comfortable cycling in unseparated infrastructure, intersections, and contraflow lanes.

Based on three dimensions of safety (comfort in different situations, satisfaction with cycling infrastructure, sensitivity to barriers), we identified four clusters of e-bike users. The first group,

confident all-rounders, are mostly male, frequent cyclists who are comfortable in any situation, insensitive to most barriers, but critical of the cycling situation. The second group, ***recreational on-roaders*** are less frequent e-bike users who tend to stop cycling in winter. They use the e-bike for recreational trips, are quite satisfied with current cycling conditions, have an average comfort level regardless of the degree of separation, and are sensitive to barriers of weather, fatigue, and night-time. The third group, ***utilitarian traffic-avoiders*** are mostly female, middle-aged or older cyclists who are very uncomfortable e-biking without separation from traffic (e.g. in mixed traffic and intersections), and are very critical of cycling conditions. The fourth and last group, ***unconfident path-users*** are the least confident when cycling in all situations except on dedicated cycle paths, are dissatisfied with current cycling conditions, but are not very sensitive to barriers.

These findings indicate that despite the adoption of the e-bike, perceived safety represents a significant barrier for many existing e-bike users. Even though e-bikes make cycling more accessible, there remain important differences in e-bikers' perceived safety depending on gender, age, and cycling frequency. The four groups we identified are comparable to existing typologies of cyclists by (Geller, 2006; Dill & McNeil, 2013, 2016), who found only a minority of cyclists were at ease in unseparated "vehicular cycling" (Schultheiss et al., 2018) conditions, while the majority of current and potential cyclists would prefer cycle paths which provide a physical separation from traffic. Thus, improving cycling conditions (bikeability) through a continuous network of separated cycling infrastructure is necessary to accompany the development of e-bikes. Moreover, other dimensions of perceived safety, such as the satisfaction with cycling infrastructure and sensitivity to barriers, should also be addressed by improving lighting and maintenance of infrastructure, as well as promoting awareness by other road users and a positive image of e-cycling.

9.2 Contributions to existing research

We now reflect on how our research contributes to the knowledge on cycling, e-bike use and mobility research in general. We identify four main contributions.

The first contribution of this thesis to e-bike research is the use of a biographical approach to analyse e-bike adoption within the cycling trajectory over the life course, rather than only at a given time point. Our second contribution is to view e-bike use within a systemic theoretical framework, vélomobility, which underlines the relationship between e-bike uses, individuals' cycling potentialities, and the possibilities offered by the territorial hosting potential. Our third contribution is the need to reconsider e-bike safety beyond crashes, by focusing on perceived safety as the biggest barrier to cycling within low-cycling contexts. Lastly, on a methodological level, we contribute to e-bike research by showing the importance of mixing qualitative and mixed method designs for a better understanding of cycling practices.

9.2.1 Biographical approaches to cycling

This research fits within the paradigm of mobility biographies research, which aims to address the limitations of conventional transport and travel behaviour research, including a simplistic understanding of modal choice, a cross-sectional view of mobility practices, a failure to address the role of habits and past experiences, and a lack of consideration of the influence of other domains of life on mobility practices (Lanzendorf, 2003; Scheiner & Rau, 2020). Using a biographical approach to analyse e-bike use has proved useful as a way to go beyond traditional, cross-sectional approaches which tend to view cycling at a given time point, separating people into cyclists or non-cyclists, rather than as a lifelong activity with ups and downs depending on the phases of life (Bonham & Wilson, 2012).

Applying the concept of a cycling trajectory (Chatterjee et al., 2013) has been very useful to link the two sub-practices of conventional cycling and electrically-assisted cycling at the level of the individual's life course, rather than treating both as separate practices. This approach has also given us a better understanding of e-bike users' past cycling experiences and the role e-bikes play within their broader mobility patterns and relationship to cycling. Furthermore, focusing on the role of key events related to e-bike adoption has shown how events from outside the domain of mobility (e.g. health, childbirth, contextual changes) affect cycling, acting as "triggers" or "turning points" for changes in cycling (Chatterjee et al., 2013). We have seen how the assistance provided by e-bikes dramatically changes the role of key events for cycling, enabling the continuation of cycling despite biographical, contextual, or health-related changes, whereas these events would have led to a decrease or interruption of cycling otherwise. This important finding suggests that e-bikes should be considered as a way to avoid disengagement with cycling over the life course, and could be promoted as such during key events (e.g. residential relocations, job relocations) or at specific life stages (e.g. entry into retirement).

9.2.2 A systemic approach to cycling and e-bikes

As we have discussed, cycling literature has been heavily influenced by transport research and has often focused on individual behaviour, attitudes, and perceptions of cycling. However, social science approaches have underlined the need to consider cycling beyond modal choice, as a practice that is socially, spatially and historically situated, and which competes with other mobility practices for people's time (Watson, 2013). The specific role of cycling as an embodied activity has meant that it is highly dependent on the spatial environment to enable its practice.

Thus, we have applied a systemic framework of vélomobility, proposed by Rérat (2021), to the adoption of the e-bike. This framework has the advantage of considering cycling as the result of the meeting between an individual mobility potential and a territorial potential. The notion of a potential for mobility which is unequally distributed (Flamm & Kaufmann, 2006) highlights the inequalities which exist between cyclists, both in terms of individual characteristics – differences in gender, age, and cycling experience – and in terms of territorial hosting potential – cycling infrastructure, the location of activities, norms and rules. By adding a temporal dimension to this framework with the notion of a cycling trajectory, we have also considered the importance of the accumulation of cycling experiences and the linkages between mobility, personal and work domains. However, this framework does not view cyclists as purely determined by their personal characteristics, their biography, nor passively influenced by a set of external factors. Rather, it considers individuals as having some degree of agency in terms of their preferences and strategies for e-bike use, their choice of ownership of travel modes, and the location of their activities.

With the fourth article, we have applied this framework to the determinants of e-bike use, which had not been the subject of much research (with the exception of Haustein & Møller, 2016a). Here, we have also investigated for the first time the combined effects of individual and territorial factors, on e-bike use. This framework of the system of vélomobility could be used further to study the experiences of e-bike users, as well as conventional cyclists, within their spatial context.

9.2.3 A reconsideration of e-bike safety

We have framed the question of safety as the friction resulting from the consequences of the adoption of the e-bike, and the result of the inadequacy between an individual potential for mobility, and a spatial context which does not offer a sufficient hosting potential for it.

Our fourth article fits within a larger movement to reconsider cycling and e-bike safety and to move away from a focus on crashes, as the "tip of the iceberg" of safety (Juhra et al., 2012; Hamann & Peek-Asa, 2017), to a consideration of perceived safety as the biggest barrier to cycling in low-cycling contexts. Recent research from the social sciences has emphasized the extent to which fear of traffic, and frequent near misses, which are unrecorded by accident statistics, shape individuals' (and society's) perceptions of cycling negatively (Aldred, 2016; Sanders, 2015).

Research on e-bike safety has focused mainly on rising e-bike accidents (Hertach et al., 2018), without considering the context of the increase in e-bike sales. Our study fills a gap in research on the perceived safety of e-bike users, which despite a few studies (Haustein & Møller, 2016b) remains relatively unexplored. We have found that despite the provision of electrical assistance, which could provide greater confidence for cycling in traffic, e-bikers still suffer from low perceived safety due to lacking cycling conditions. Although e-bikes "equalize" cycling levels, important individual difference in perceived safety remain related to gender, old age, and frequency of cycling, suggesting that differences in the individual cycling potential are also significant among e-bike users, especially given their older age and over-representation of women. Our result emphasizes the importance of the territorial context for expanding e-bike use, confirming that electrical assistance is not a "technological fix" for cycling safety. This shows the continued importance of improving bikeability by developing a network of safe, dedicated cycling infrastructure to enable the use of e-bikes as well as their cohabitation with conventional bicycles, users of all ages, and micro-mobility devices. By appealing to a wider demographic and increasing the range and number of cycling trips, e-bikes highlight the existing deficiencies of the territorial hosting potential.

9.2.4 Qualitative and mixed method designs

Another limitation of transport research is the divide between quantitative and qualitative research, an over-reliance on statistical associations, and a resulting lack of understanding of causal mechanisms related to mobility. Social science approaches to mobility have thus sought to promote new methods of research, with a view of better understanding mobility as a social phenomenon (Aldred, 2013b; Sheller & Urry, 2006). This has led to a renewed interest in qualitative research designs, as well as mixed methods, and mobile methods (Büscher & Urry, 2009; Merriman, 2014). In line with mobility biographies research, qualitative retrospective interviews such as the ones used in articles 1 to 3 allow a more in-depth understanding of the causal processes underpinning key events, changes in mobility practices, and variations in cycling throughout the cycling trajectory, which could not have been assessed purely by quantitative data (H. Jones et al., 2010; Manton et al., 2016; Rau & Manton, 2016).

A particularly useful way to integrate qualitative and quantitative data is by using mixed method designs, such as we did in article 2. Mixed methods combine the advantages of quantitative data for detecting statistical tendencies across large groups, and of qualitative data for an in-depth understanding of individual agency and can thus offer the best of both worlds (Creswell & Clark, 2017). At the level of this thesis, qualitative articles (articles 1 to 3) are complemented by quantitative articles (articles 4 and 5), yielding a richer and more nuanced understanding of e-bike use. This complementarity increases our understanding of e-bikes within individuals and households' mobility practices, which have become increasing complex and multimodal.

9.3 Limitations and further research

9.3.1 Expanding the study of e-bikes to other spatial contexts and e-bike types

A recurring problem of cycling research is the difficulty in comparing the results of studies in different contexts, due to large differences in cycling practices and levels (Buehler & Pucher, 2021b). Therefore, one of the limitations of this study is the limited spatial area which it focuses upon. The city of Lausanne offers a very specific context for the study of cycling, and a high potential for e-bikes due to its hilly topography. However, it remains a starter cycling city (Silva, Teixeira, & Proença, 2019) with a very low modal share and difficult cycling conditions, despite the city's ambitious plans[69]. Currently, e-biking and cycling generally remain a minority practice (Prati et al., 2017), in contrast with their role in more established cycling cities.

To further understand the role of e-bikes, research should compare e-bike use across different spatial contexts, between low-cycling and high-cycling cities, and small and large cities. In large cities with an established tradition of cycling, e-bikes may play a different role within the transport system and in relationship to conventional cycling. For young urban dwellers who travel very short distances in dense urban centres, e-bikes might be seen as superfluous, or bringing additional constraints (such as a need for secure parking). In existing high-cycling cities like Copenhagen or Amsterdam, cycling works because it is a cheap and "low-tech" mode of transport. Thus, the largest potential for e-bikes might lie elsewhere.

One of the most promising contexts for developing e-bikes, which has largely not been investigated, are suburban and peri-urban areas. According to the 2015 Swiss census on mobility and transport, these are the territories where most e-bike owners live (Ravalet et al., 2018). Suburban areas fall within a manageable distance of core cities, are highly populated, and in low-cycling contexts, have much potential for the development of cycling and e-bikes. However, they have long suffered from automobile-oriented planning and the presence of high volumes of car traffic which result in spatial segregation and discourage cycling. Recent initiatives such as the creation of networks of "cycle highways"[70] (Liu et al., 2019), which aim to offer high-quality (wide, dedicated) cycling corridors outside built-up areas, might make these territories more attractive for e-bike commuters or recreational users. In this context, more research is needed to understand how e-bikes fit within suburban lifestyles – housing and mobility patterns – and how e-bikes adapt to less dense, car-centric urban environments. Moreover, recreational uses of e-bikes have also not been explored much outside of older adults (e.g. Spencer et al., 2019), and may provide an entry into cycling for younger users as well.

Rural or "peri-urban" areas, meanwhile, are located further away from core cities but are still well connected to transport networks (highways and regional railways, buses) and inhabited by both younger city-working families, but also, increasingly older adults. In these contexts, e-bikes' flexibility could

[69] The city announced in its "Climate plan" that it would seek to reach a modal share of 15% of all trips by cycling within 2035 (Ville de Lausanne, 2021b).

[70] The term « highway » is ambiguous because cycling infrastructure should not take example on automobile infrastructure by considering only speed and capacity, but rather also consider the cyclists' specific experience of the environment.

serve several functions, both as a means of recreation, for short local daily trips such as groceries or to go to leisure activities, and as a long-distance commuting option. In these contexts, faster "speed-pedelecs" which have an assistance until 45 km/h could rival car trips on commuting routes to urban centres. Research on speed pedelecs has only just begun, with very few studies to date (Hendriks & Sharmeen, 2019; Rotthier et al., 2016, 2017). Moreover, in several European countries, the potential of this category of e-bikes remains limited by strict legislation forbidding their use on cycle infrastructure, with only Switzerland and Belgium being an exception. To understand the needs of speed-pedelecs users, further studies of their preferences and motivations are needed, for example to assess whether they prefer cycling on the road or on dedicated infrastructure. A further category of e-bikes which could increase the utilitarian potential of e-bikes are cargo bikes, which may also be used for urban logistics. Cargo bikes have specific needs regarding handling (width), storage, or safety conditions when carrying children, which are different from those of e-bike users (Hess & Schubert, 2019; Liu et al., 2020). Understanding their characteristics, uses, motivations, barriers and experiences in a spatial context will be essential for accompanying their full-scale development.

9.3.2 Long-term view of e-bike ownership and use

In the present survey conducted in 2018, our sample included a mix of experienced e-bike users as well as newer, less experienced users who had owned their e-bikes for less than two years. Now that e-bikes have been mainstream for several years, the number of experienced e-bike users has naturally increased. Future research on e-bike users should aim to understand how long-term ownership of e-bikes has affected people's use, experiences, and travel habits. One of the questions relative to this is the long-term substitution effects of e-bikes. Giving up a transport mode, especially a motor vehicle, is a complicated process which can take many years to complete. After a few years of ownership, it would be interesting to follow up on the adoption of e-bikes to evaluate whether e-bikes have had a substitution effect on car ownership or other modes.

Moreover, cycling trajectories could be further analysed for e-bikes. While in the present study, there were not many people who had abandoned using an e-bike, more people may have stopped after a few years. It would therefore be useful to assess the magnitude of these "diminishing trajectories" (H. Jones et al., 2015) and the reasons which might exist for interrupting e-bike use. Furthermore, as many people who had adopted e-bikes had an existing relationship to cycling and some continued to use their conventional bicycle alongside it, it would be interesting to see whether some people have given up e-bikes to return to conventional bicycles, by using the e-bike as a "stepping stone" to get back into cycling (Rérat, 2021c).

9.3.3 Better data on e-bike users, uses, and cycling infrastructure

Although we have managed to obtain data on e-bike users through a municipal database, one of the difficulties of conducting e-bike research remains how to recruit them. Without subsidies, identifying e-bike users is difficult, and it may require a much larger sample to obtain a significant number of e-bike users. Current census data is also insufficient on e-bike use. In Switzerland, the current data rests on the 2015 edition of the micro-census on mobility and transport, which has been updated in 2021 but is not yet analysed and published. Beyond this, there is a dire need for systematically including e-bike users as a category in mobility surveys, and ideally, distinguishing e-bike categories (pedelec/s-pedelec) and types (city bike, cargo bike, mountain bike), and including questions on specific aspects of e-bikes (e.g. battery management).

An obvious limitation of this study is the lack of information on origin-destination e-bike trips. This would enable more complete analyses of trip patterns, beyond the environment around the residence. Including questions about actual cycling trips through surveys or mobility journals may be one way to do so. Another way is to use GPS tracking data, which has already been done in a few studies (Behrendt, 2018; Lopez et al., 2017; Plazier et al., 2017). Mixed-use designs, where GPS data can be used to discuss cycling trips with participants, can also yield valuable impressions and strategies of e-bike users (Behrendt et al., 2021; Plazier et al., 2017).

Another significant limitation in terms of data is the lack of up-to-date spatial information on cycling infrastructure at all urban scales, notably outside of larger cities in Switzerland. Increasing the availability and access to data related to cycling, be it for cycling infrastructure, traffic counts, crashes and their location, would enable a deeper investigation of the factors affecting e-bike use and cycling. This would enable a better understanding of the territorial hosting potential for cycling (bikeability), which is particularly important when considering a systemic approach to cycling. In the case of Switzerland, for example, there is a large disparity in the number of automated cycling counters between cities and regions (Baehler et al., 2018, 2019, 2020; Marincek & Rérat, 2021). Having more information about cycling infrastructure would also contribute to make cycling and e-bike use more visible in policy debates.

9.4 Conclusions and policy recommendations

As this thesis has shown, e-bikes hold an important potential for the future of cycling. They can help to get a wider proportion of people cycling, increase the trips which can be accomplished by bicycle, and more generally, expand the practice of cycling. In light of the results of this thesis, we now offer a few conclusions and policy recommendations for promoting e-bike use. Returning to our framework of a system of vélomobility, it is possible to act upon both the individual potential for mobility and the territorial hosting potential.

To act on the individual potential for mobility, a first recommendation is to increase access to e-bikes through incentives and subsidies. E-bikes may reduce some of the skills or physical abilities (strength, stamina) required to cycle, especially in a hilly context. As we have suggested, biographical key events represent windows of opportunity for influencing the adoption of the e-bike. On the one hand, e-bikes could be promoted to re-engage new or returning cyclists by attempting to "unleash their latent demand for cycling" (Janke & Handy, 2019) through work mobility schemes such as restrictions on car parking, or the provision of secure, covered bike parking and bike pumps at the workplace. Older people may also be convinced by incentives to give up their car in exchange for an e-bike, to keep an active mobility and greater independence in later age. On the other hand, e-bikes could be promoted to retain existing cyclists and avoid interruptions to cycling, for example by subsidizing e-bikes for new university students or employees in suburban locations, offering discounts for cargo bikes, seats or trailers for young parents, or special offers to households after a residential relocation. Helping e-bikers to develop their skills and confidence for cycling in different conditions and performing mechanical tasks may also be done through courses or club rides, although this will not replace the need for safer infrastructure. Lastly, a further way to act on the individual potential for mobility could be through the dimension of appropriation, by setting up public awareness campaigns to promote the benefits of e-bikes. In place of negative accident prevention campaigns, they could focus on the benefits of e-bike use as a healthy, enjoyable, and efficient activity, and as a practice adapted to people of all ages, abilities, and socio-economic backgrounds.

The most pressing issue for the development of e-bikes is to act on the territorial hosting potential, to make it suitable for a wide variety of individual cycling potentials. Reducing the "frictions" affecting e-bikes would increase their use among existing cyclists and help their diffusion among a broader scope of population categories. This requires improving perceived cycling safety and reducing other barriers to e-bike use related to traffic conditions.

In the city of Lausanne, as in many low-cycling cities, current cycling conditions mean that only the most expert cyclists truly feel comfortable e-biking for all their trips. A primary objective should be to increase perceived safety among categories of e-bike users who are sensitive to cycling conditions but who may be "interested but concerned" (Geller, 2006). This can firstly be achieved by developing a network of dedicated cycling infrastructure such as cycle paths, which increase comfort for all categories of cyclists by providing a superior level of protection from traffic than bicycle lanes. Increasing the width of cycling infrastructure is also required to accommodate the increasing numbers of bicycles and e-bikes, and allow for safe overtaking of slower cyclists, as well as cargo bike use. A second way to improve safety is to slow down and reduce the volume of motor traffic. Continuing the development of traffic-calmed zones (30 km/h, 20 km/h and pedestrian areas) or introducing "bicycle streets" where cyclists have priority, can help to make streets more "human-sized", and increase the competitiveness of e-bikes compared to cars for urban trips. Some of these changes have begun to take place in Lausanne in the few years since our study. In 2021, the city introduced a general 30 km/h per hour limit at night. Work has started on a refurbishment of a central road artery (Rue du Grand-Pont) which will cut of automobile traffic through the city centre, drastically changing conditions for cycling in the city centre. In the meantime, the number of kilometres of cycling infrastructure has continued increasing in the city, reaching 111 km in 2020, or a 55% increase since 2019 (Ville de Lausanne, 2021a). There is evidence that these policies are having an effect. Bicycle counts have increased significantly across the city, with a claimed increase of +84% between 2017 and 2020, although from a very low starting level (Ville de Lausanne, 2021a). However, there is still much to be done to reach the city's objective of a 15% cycling modal share by 2030 (Ville de Lausanne, 2021b).

In suburban or peri-urban areas outside city centres, there have been much fewer efforts to provide cycling infrastructure. As a result, very few trips are currently taken by e-bike, even among expert cyclists. This calls for expanding bicycle planning to the scale of the urban area, rather than just the city centre. Developing a continuous network of fast, prioritized "cycle highways" which link the suburbs to the centre of an urban area would dramatically increase the potential of e-bikes and, especially, of speed-pedelecs, due to their greater range and speeds. Such an infrastructure would serve the needs of a large group of existing e-bike owners who, according to census data already live in suburban and peri-urban municipalities (Ravalet et al., 2018), but are not cycling as much as urban dwellers (Hiselius & Svensson, 2017).

To further improve safety for e-bike users, new standards of cycling infrastructure are also needed. One critical measure would be to redesign intersections and roundabouts which are currently uncomfortable for a large proportion of e-bike users, and are particularly accident-prone for e-bikes due to underestimation of speeds by motorists (Petzoldt, Schleinitz, Heilmann, et al., 2017). Intersections would need to be redesigned with cycle paths on the outside, in order to avoid breaks in continuity with off-street bicycle paths (where a cyclist would need to return onto the carriageway). The Dutch model of roundabouts and intersections is the most well-known way to apply this, although it may require legal adaptation of priority rules for bicycle crossings.

Other types of barriers to e-bike use should also be addressed. The barrier of bicycle theft could be minimized by increasing the supply of secure bicycle parking. This could be done by installing secured and covered bicycle parking at workplaces, which would encourage e-bike use for commuting trips. Moreover, better capacity for secure and covered bicycle parking at train stations and facilitating the transport of e-bikes (through increased capacity) on trains may also encourage their use for intermodal, regional-level trips.

Lastly, acting upon the norms and rules associated with e-bikes may also be a way to increase e-bike use. Recent measures introduced in Switzerland, such as the possibility to turn right turn at a red light for cyclists, make cycling more efficient and legitimize its use in public space (OFROU, 2021). However, other planned legislation changes such as requiring mandatory tachymeters on speed-pedelecs, and the use of lights at daytime for regular e-bikes (OFROU, 2022), may have counterproductive effects by making the practice of e-biking appear complicated and out of reach. By contrast, opening e-bike use to younger groups such as teenagers (currently allowed from 14 to 16 with a moped license) without the need for a license, would further aid the diffusion of e-bikes among the population, potentially avoiding interruptions to cycling during teenage years. Although highly efficient for longer trips, the potential of speed-pedelecs remains unjustly neglected in most European countries except Switzerland and Belgium (Rotthier et al., 2016). In other European countries, relaxing the laws limiting the use of speed-pedelecs on cycle paths would offer a worthy alternative to the car for suburban and peri-urban commuters.

To conclude this thesis, what does the future hold for e-bikes? Their diffusion does not seem to be slowing down. At the current rate, it is estimated that the number of e-bikes sold per year in Europe will grow from 4 to 17 million by the year 2030 (CONEBI, 2020; Reid, 2020). The role of e-bikes could be central in the context of a transition towards sustainable mobility. E-bikes have the potential to reduce dependence on private cars and contribute to reducing greenhouse gas emissions by fossil-fuel cars. Within the landscape of transport modes, their hybrid status fills an important gap between motor vehicles, public transport, and active mobilities. Developing e-bikes can also address many challenges facing cities, by easing traffic congestion and providing much-needed physical activity. Given these benefits, what will be the impact of e-bikes on the future of cycling? E-bikes have helped to reduce many of the constraints and inequalities of conventional cycling, enabling people to start, resume, or prolong cycling over the life course. Although it is unlikely that e-bikes will replace the bicycle, as we have seen, both will increasingly be interconnected as part of a variety of cycling practices, and at various stages of the life course. Thus, in this future diversity of vélomobilities, it is likely that e-bikes will play an important role.

10. References

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11. Appendix A: Postal survey

Questionnaire sur le vélo à assistance électrique (VAE)

UNIL | Université de Lausanne

Vous avez bénéficié d'une subvention de la Ville de Lausanne à l'achat d'un vélo à assistance électrique (VAE). Pour accompagner le développement de ce mode de transport, la Ville de Lausanne finance une recherche de l'Université de Lausanne sur le sujet.

Vous pouvez également remplir ce questionnaire en ligne à l'adresse suivante : **bit.ly/enqueteVAE**

En remplissant ce questionnaire, vous avez la possibilité de prendre part à un tirage au sort pour gagner l'un des 10 bons « entretien vélo électrique » d'une valeur de 120 CHF offerts par le magasin Tandem.
Nous vous remercions par avance pour votre participation. Vos réponses seront traitées de manière entièrement anonyme.

1 Votre équipement en moyens de transport

1. Dans quel type de ménage vivez-vous ?

1 ☐ Personne vivant seule 2 ☐ Personne seule avec enfant(s) 3 ☐ Couple sans enfant
4 ☐ Couple avec enfant(s) 5 ☐ Colocation 6 ☐ Autre

2. Dans votre ménage, combien y a-t-il :

de voitures .... 1 ☐
de motos/scooters/vélomoteurs .... 2 ☐
de vélos à assistance électrique (VAE) .... 3 ☐
de vélos mécaniques (sans assistance électrique) en état de rouler .... 4 ☐

3. Avez-vous le permis de conduire automobile ?

1 ☐ Oui 2 ☐ Non

4. Êtes-vous membre d'une organisation d'autopartage (p.ex. Mobility) ?

1 ☐ Oui 2 ☐ Non

5. Avez-vous un abonnement de transports publics ?

1 ☐ Oui → s'agit-il…
- 1 ☐ d'un abonnement général
- 2 ☐ d'un abonnement demi-tarif
- 3 ☐ d'un abonnement Mobilis
- 4 ☐ autre

2 ☐ Non

6. Au total, combien de VAE avez-vous personnellement possédés ?

Nombre de VAE ☐

7. Pouvez-vous nous donner quelques informations sur votre VAE actuel ?

Année d'achat	☐☐☐☐
Catégorie de VAE	1 ☐ VAE 25 km/h (sans plaque d'immatriculation) 2 ☐ VAE 45 km/h (avec plaque d'immatriculation)
Modèle de VAE	1 ☐ Vélo de ville 2 ☐ Vélo tout-terrain (VTT) 3 ☐ Autre : …………………
Lieu d'achat	1 ☐ Magasin spécialisé (Tandem, M-way, …) 2 ☐ Grande surface (Décathlon, Jumbo, …) 3 ☐ Autre: …………………
Commune du lieu d'achat	………………………………………
Prix approximatif (sans subvention)	☐'☐☐☐ Frs
Autres subventions reçues que celle de la Ville de Lausanne	1 ☐ Oui 2 ☐ Non

8. Quel a été le rôle de la subvention de la Ville de Lausanne ?

	Pas du tout d'accord	*Plutôt pas d'accord*	*Plutôt d'accord*	*Tout-à-fait d'accord*
La subvention m'a décidé(e) à acheter un VAE	1 ☐	2 ☐	3 ☐	4 ☐
La subvention m'a incité(e) à acheter un VAE plus performant (ou des accessoires)	1 ☐	2 ☐	3 ☐	4 ☐

9. Quelles sont les raisons qui vous ont poussé(e) à acheter un VAE ?

	Pas du tout d'accord	*Plutôt pas d'accord*	*Plutôt d'accord*	*Tout-à-fait d'accord*
Faire plus de vélo ou continuer à en faire	1 ☐	2 ☐	3 ☐	4 ☐
Aller plus vite ou plus loin qu'avec un vélo mécanique	1 ☐	2 ☐	3 ☐	4 ☐
Pouvoir faire du vélo malgré la pente	1 ☐	2 ☐	3 ☐	4 ☐
Disposer d'une alternative à la voiture/aux transports publics	1 ☐	2 ☐	3 ☐	4 ☐
Transporter des enfants/affaires	1 ☐	2 ☐	3 ☐	4 ☐
Profiter du plaisir de rouler en VAE	1 ☐	2 ☐	3 ☐	4 ☐
Adopter une mobilité innovante	1 ☐	2 ☐	3 ☐	4 ☐
Faire de l'exercice en se déplaçant	1 ☐	2 ☐	3 ☐	4 ☐

Commentaires sur vos motivations à acheter un VAE : ……………………………………………
……………………………………………………………………
……………………………………………………………………
……………………………………………………………………

10. Utiliser un VAE vous a-t-il incité(e) à renoncer à la possession de…

une voiture	1 ☐ Oui	2 ☐ Non
une moto/un scooter/un vélomoteur	1 ☐ Oui	2 ☐ Non
un vélo mécanique	1 ☐ Oui	2 ☐ Non
un abonnement de transports publics	1 ☐ Oui	2 ☐ Non

11. Depuis que vous possédez un VAE, utilisez-vous plus ou moins les modes de déplacement suivants ?

La voiture	1 ☐ Plus	2 ☐ Moins	3 ☐ Pas de changement / ne s'applique pas
La moto/le scooter/le vélomoteur	1 ☐ Plus	2 ☐ Moins	3 ☐ Pas de changement / ne s'applique pas
Le vélo mécanique	1 ☐ Plus	2 ☐ Moins	3 ☐ Pas de changement / ne s'applique pas
Les transports publics	1 ☐ Plus	2 ☐ Moins	3 ☐ Pas de changement / ne s'applique pas
La marche	1 ☐ Plus	2 ☐ Moins	3 ☐ Pas de changement / ne s'applique pas

12. Comment vous déplaciez-vous avant pour les trajets que vous faites aujourd'hui en VAE ?
(plusieurs réponses possibles)

1 ☐ Marche   2 ☐ Vélo mécanique   3 ☐ Moto/scooter/vélomoteur

4 ☐ Voiture   5 ☐ Transports publics   6 ☐ Je ne faisais pas ces déplacements

13. Quelle image avez-vous du vélo à assistance électrique ?

	Pas du tout d'accord	*Plutôt pas d'accord*	*Plutôt d'accord*	*Tout-à-fait d'accord*
Rend autonome/libre	1 ☐	2 ☐	3 ☐	4 ☐
Pratique/fonctionnel	1 ☐	2 ☐	3 ☐	4 ☐
Rapide	1 ☐	2 ☐	3 ☐	4 ☐
Confortable/agréable	1 ☐	2 ☐	3 ☐	4 ☐
Économique/pas cher	1 ☐	2 ☐	3 ☐	4 ☐
Écologique	1 ☐	2 ☐	3 ☐	4 ☐
Sûr	1 ☐	2 ☐	3 ☐	4 ☐

14. Quelle image avez-vous de la voiture ?

	Pas du tout d'accord	*Plutôt pas d'accord*	*Plutôt d'accord*	*Tout-à-fait d'accord*
Rend autonome/libre	1 ☐	2 ☐	3 ☐	4 ☐
Pratique/fonctionnelle	1 ☐	2 ☐	3 ☐	4 ☐
Rapide	1 ☐	2 ☐	3 ☐	4 ☐
Confortable/agréable	1 ☐	2 ☐	3 ☐	4 ☐
Économique/pas chère	1 ☐	2 ☐	3 ☐	4 ☐
Écologique	1 ☐	2 ☐	3 ☐	4 ☐
Sûre	1 ☐	2 ☐	3 ☐	4 ☐

15. Quelle image avez-vous des transports publics ?

	Pas du tout d'accord	*Plutôt pas d'accord*	*Plutôt d'accord*	*Tout-à-fait d'accord*
Rendent autonome/libre	1 ☐	2 ☐	3 ☐	4 ☐
Pratiques/fonctionnels	1 ☐	2 ☐	3 ☐	4 ☐
Rapides	1 ☐	2 ☐	3 ☐	4 ☐
Confortables/agréables	1 ☐	2 ☐	3 ☐	4 ☐
Économiques/pas chers	1 ☐	2 ☐	3 ☐	4 ☐
Écologiques	1 ☐	2 ☐	3 ☐	4 ☐
Sûrs	1 ☐	2 ☐	3 ☐	4 ☐

2 Vos habitudes de mobilité

16. À quelle fréquence pratiquez-vous les activités suivantes et quels modes de déplacement utilisez-vous pour vous y rendre ?

Activité	*Fréquence*	*Mode(s) de déplacement utilisé(s)* *Plusieurs réponses possibles*
Aller sur mon lieu de travail ou d'études	1 ☐ Tous les jours ou presque 2 ☐ Plusieurs fois par semaine 3 ☐ Plusieurs fois par mois 4 ☐ Plusieurs fois par année 5 ☐ Jamais	1 ☐ marche 2 ☐ vélo mécanique 3 ☐ VAE 4 ☐ moto/scooter/vélomoteur 5 ☐ voiture 6 ☐ transport publics
Aller faire des achats/services/ accompagnements	1 ☐ Tous les jours ou presque 2 ☐ Plusieurs fois par semaine 3 ☐ Plusieurs fois par mois 4 ☐ Plusieurs fois par année 5 ☐ Jamais	1 ☐ marche 2 ☐ vélo mécanique 3 ☐ VAE 4 ☐ moto/scooter/vélomoteur 5 ☐ voiture 6 ☐ transport publics
Aller dans des lieux de loisirs (cinéma, restaurant, salle de sport, bar, etc.), rendre visite à des proches	1 ☐ Tous les jours ou presque 2 ☐ Plusieurs fois par semaine 3 ☐ Plusieurs fois par mois 4 ☐ Plusieurs fois par année 5 ☐ Jamais	1 ☐ marche 2 ☐ vélo mécanique 3 ☐ VAE 4 ☐ moto/scooter/vélomoteur 5 ☐ voiture 6 ☐ transport publics
Se promener ou faire des sorties sportives à pied ou en vélo	1 ☐ Tous les jours ou presque 2 ☐ Plusieurs fois par semaine 3 ☐ Plusieurs fois par mois 4 ☐ Plusieurs fois par année 5 ☐ Jamais	1 ☐ marche 2 ☐ vélo mécanique 3 ☐ VAE 4 ☐ moto/scooter/vélomoteur 5 ☐ voiture 6 ☐ transport publics

17. À quelle fréquence utilisez-vous actuellement le VAE ?

1 ☐ Tous les jours ou presque
2 ☐ Plusieurs fois par semaine
3 ☐ Plusieurs fois par mois
4 ☐ Plusieurs fois par année
5 ☐ Jamais

18. Combien de temps par semaine en moyenne utilisez-vous actuellement votre VAE ?

1 ☐ Moins de 30 minutes
2 ☐ Entre 30 minutes et 1 heure
3 ☐ Entre 1 heure et 2 heures
4 ☐ Entre 2 heures et 4 heures
5 ☐ Plus de 4 heures

19. Quelles raisons vous empêchent d'utiliser davantage votre VAE ?

	Pas du tout d'accord	*Plutôt pas d'accord*	*Plutôt d'accord*	*Tout-à-fait d'accord*
L'obligation d'emprunter une route à fort trafic	1 ☐	2 ☐	3 ☐	4 ☐
Le transport d'enfants/d'affaires	1 ☐	2 ☐	3 ☐	4 ☐
Pas envie de rouler la nuit	1 ☐	2 ☐	3 ☐	4 ☐
Une météo défavorable	1 ☐	2 ☐	3 ☐	4 ☐
Un trajet trop long ou trop fatiguant	1 ☐	2 ☐	3 ☐	4 ☐
La difficulté de prendre le VAE dans le train ou le métro	1 ☐	2 ☐	3 ☐	4 ☐
Pas envie de transpirer, ou de se décoiffer	1 ☐	2 ☐	3 ☐	4 ☐
Un risque de vol ou de vandalisme	1 ☐	2 ☐	3 ☐	4 ☐
L'autonomie trop faible de la batterie (ou une batterie déchargée)	1 ☐	2 ☐	3 ☐	4 ☐

20. Pour rejoindre une activité donnée, jusqu'à quelle distance êtes-vous prêt(e) à utiliser le VAE ?

1 ☐ 5 km
2 ☐ 10 km
3 ☐ 15 km
4 ☐ 20 km
5 ☐ Plus de 20 km

21. Continuez-vous à utiliser le VAE en hiver ?

1 ☐ Oui, comme pendant les autres saisons
2 ☐ Oui, mais moins souvent
3 ☐ Non

22. Comment jugez-vous votre état de forme physique ?

1 ☐ Très bon
2 ☐ Plutôt bon
3 ☐ Moyen
4 ☐ Plutôt pas bon
5 ☐ Pas bon du tout

3 Votre expérience du VAE

23. Les affirmations suivantes correspondent-elles à votre expérience du VAE ?

	Pas du tout d'accord	*Plutôt pas d'accord*	*Plutôt d'accord*	*Tout-à-fait d'accord*
Je me sens en sécurité dans le trafic	1 ☐	2 ☐	3 ☐	4 ☐
Il y a suffisamment de pistes/bandes cyclables	1 ☐	2 ☐	3 ☐	4 ☐
Je me sens respecté(e) par les autres usagers de la route	1 ☐	2 ☐	3 ☐	4 ☐
Je rencontre des zones et des intersections dangereuses	1 ☐	2 ☐	3 ☐	4 ☐
J'ai de bonnes conditions de stationnement vélo à mon domicile	1 ☐	2 ☐	3 ☐	4 ☐
J'ai de bonnes conditions de stationnement vélo à destination (travail, etc.)	1 ☐	2 ☐	3 ☐	4 ☐
Je me sens un peu comme un(e) « tricheur(se) » par rapport au vélo mécanique	1 ☐	2 ☐	3 ☐	4 ☐

24. Considérez-vous qu'il serait pertinent d'installer des bornes de recharge pour les VAE en ville de Lausanne ?

1 ☐ Pas du tout d'accord 2 ☐ Plutôt pas d'accord 3 ☐ Plutôt d'accord 4 ☐ Tout à fait d'accord

25. Êtes-vous à l'aise dans les situations suivantes avec un VAE ?

	Pas du tout à l'aise	*Plutôt pas à l'aise*	*Plutôt à l'aise*	*Tout-à-fait à l'aise*
Circuler dans le trafic automobile	1 ☐	2 ☐	3 ☐	4 ☐
Rouler sur une bande ou piste cyclable avec des vélos mécaniques	1 ☐	2 ☐	3 ☐	4 ☐
Rouler sur un trottoir ouvert aux vélos ou dans une zone piétonne	1 ☐	2 ☐	3 ☐	4 ☐
Rouler sur une voie de bus ouverte aux vélos	1 ☐	2 ☐	3 ☐	4 ☐
Rouler dans un contresens cyclable	1 ☐	2 ☐	3 ☐	4 ☐
Traverser une intersection (giratoire, feux)	1 ☐	2 ☐	3 ☐	4 ☐
Gérer la batterie de mon VAE	1 ☐	2 ☐	3 ☐	4 ☐
Réparer moi-même une crevaison	1 ☐	2 ☐	3 ☐	4 ☐
Faire de l'entretien mécanique (chaîne, etc.)	1 ☐	2 ☐	3 ☐	4 ☐

26. Quelles précautions prenez-vous pour éviter le vol de votre VAE ?
(plusieurs réponses possibles)

1 ☐ Je ne fais rien de particulier
2 ☐ J'utilise un cadenas ou un antivol renforcé
3 ☐ Je choisis les rues dans lesquelles je stationne mon VAE
4 ☐ J'évite de laisser mon VAE la nuit dans la rue
5 ☐ J'ai une puce GPS en cas de vol
6 ☐ J'ai souscrit à une assurance spécifique VAE en cas de vol
7 ☐ Autre : ……………………….

Commentaires sur votre expérience du VAE à Lausanne et dans la région : ……………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

4 Votre profil

27. En quelle année êtes-vous né(e) ?

Année : ☐☐☐☐

28. Êtes-vous une femme ou un homme ?

1 ☐ Femme 2 ☐ Homme

29. Quelle est votre situation professionnelle ?

1 ☐ Étudiant(e)
2 ☐ Actif/active à temps partiel
3 ☐ Actif/active à temps plein
4 ☐ En recherche d'emploi
5 ☐ Homme/femme au foyer
6 ☐ Retraité(e)
7 ☐ Autre

→ Quelle est la distance entre votre logement et votre lieu de travail/d'études ? ☐☐☐ km

→ Dans quelle commune votre lieu de travail/d'études se situe-t-il ?
1 ☐ Lausanne
2 ☐ Autre : ……………………

30. Quelle est votre commune de résidence ?

1 ☐ Lausanne 2 ☐ Autre : ……………………….

31. Quel est votre niveau de formation ?

1 ☐ Scolarité obligatoire
2 ☐ Apprentissage, CFC
3 ☐ Maturité gymnasiale ou professionnelle
4 ☐ Brevet, maîtrise, école professionnelle supérieure
5 ☐ Université, école polytechnique, haute école spécialisée ou pédagogique
6 ☐ Autre :…………………….

32. Quel est votre revenu net mensuel ?

1 ☐ Moins de 3'000 Frs
2 ☐ Entre 3'000 et 6'000 Frs
3 ☐ Entre 6'000 et 9'000 Frs
4 ☐ Entre 9'000 et 12'000 Frs
5 ☐ Plus de 12'000 Frs

33. À la suite de cette enquête, nous allons réaliser des entretiens individuels avec des usagers du VAE. Acceptez-vous d'être recontacté(e) à cette fin ?

1 ☐ Oui 2 ☐ Non

34. Souhaitez-vous participer au tirage au sort permettant de gagner l'un des 10 bons « entretien vélo électrique » offerts par le magasin Tandem ?

1 ☐ Oui 2 ☐ Non

35. À quelle adresse mail pouvons-nous vous recontacter si vous avez accepté de participer à la suite de cette enquête ou au tirage au sort ?

Adresse mail : …………………………………………………………

L'enquête est maintenant terminée. Nous vous remercions vivement pour votre participation.

Si vous souhaitez être informé(e) des résultats de l'étude, merci de nous le faire savoir en nous écrivant à enquete.VAE@unil.ch ou en indiquant votre adresse e-mail dans les commentaires.

Commentaires généraux : ……………………………………………………………………………………
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✉ Veuillez renvoyer le questionnaire d'ici le 08 juillet avec l'enveloppe-réponse déjà affranchie.

Institut de géographie et durabilité
Université de Lausanne
Géopolis - 1015 Lausanne
enquete.VAE@unil.ch

12. Appendix B: Interview guide

GRILLE D'ENTRETIEN – VÉLO À ASSISTANCE ÉLECTRIQUE

Introduction : explication de la démarche

L'Institut de Géographie et de Durabilité (IGD) de l'Université de Lausanne mène actuellement une recherche sur le vélo à assistance électrique (VAE) en partenariat avec la Ville de Lausanne. Elle vise à connaître précisément le profil des usagers du VAE à Lausanne et les différentes dimensions de leurs pratiques.

Contrat : Préciser que l'entretien sera anonyme (personnes pas reconnaissables). Êtes-vous d'accord d'être enregistré(e) ?

PROFIL & ÉQUIPEMENT	
Présentation	- Bonjour, pouvez-vous vous présenter ? *(âge, profession, lieu d'habitation, lieu de travail, taux d'occupation, ménage – enfants)*
Autres moyens de transport	- Pour vos déplacements, quels autres moyens de transport ou abonnements de transports avez-vous à disposition ? *(Vélos, voitures, deux-roues motorisés, abonnement Mobilis, AG, Mobility)*
LE CHOIX DU VAE	
Processus d'achat	- Pouvez-vous nous raconter comment vous en êtes venu à acheter un VAE ? ce qui vous a poussé à acheter un VAE ? - Comment s'est fait ce choix? A quel moment avez-vous commencé à y réfléchir ? - Lors de l'achat, quels étaient vos critères? Subvention O/N - Dans les semaines suivantes, par rapport à vos attentes, comment cela s'est-il passé avec le VAE?

Motivations **(Pourquoi)**	- Quelle est pour vous la motivation principale d'avoir un VAE ? - *fonctionnel : rapidité/flexibilité* - *confort : moindre effort (pente), remplacement du vélo/continuation du vélo* - *écologie : réduire les trajets en voiture* - *santé : volonté de faire du sport/rester en forme* - *économie : frais d'entretien plus bas que d'autres modes de transport* - *autonomie : se déplacer de manière indépendante* - *esthétique : parce que le véhicule me plaît, ou l'image qui va avec* Relance : pourquoi pas les autres critères ?
Biographie de mobilité	- Trajectoire vélo-VAE: Depuis combien de temps faites-vous du vélo/VAE ? - Eléments déclencheurs/événements: Votre contexte personnel familial, de domicile ou de travail a-t-il changé votre manière de vous déplacer dans les dernières années ? - Comment votre manière de vous déplacer a-t-elle changée depuis que vous avez un VAE?
USAGES	
Types de trajets effectués	- *Pour quelles activités et combien de fois par semaine utilisez-vous votre VAE ?* - *Décrivez-vous votre trajet type? (distance, durée)* - *Pour quels déplacements n'utilisez-vous pas le VAE?*
Types de trajets	- Qu'est-ce que l'achat du VAE a changé dans vos habitudes de déplacement ? *Trajet plus rapide/long, lieux d'achat et d'activité, etc.* - Quels moyens de transport avez-vous remplacé par le VAE et dans quel cas ? Lesquels pas ?
EXPÉRIENCES	
Compétences spécifiques au VAE	- Quelles nouvelles habitudes avez-vous dû apprendre avec le VAE ? *Différence par rapport au vélo conventionnel, circulation, recharge, stationnement* - Comment gérez-vous la batterie de votre VAE ? - Faites-vous personnellement de l'entretien/de la mécanique sur votre VAE ?
Freins/ **Obstacles**	- Quels inconvénients ou contraintes voyez-vous à l'utilisation du VAE *?* - Prix - Poids - Rayon d'action

	- Sûreté/vols - Stationnement - Sécurité/cohabitation - **Image du VAE** - *Réticences avant l'achat ? Qu'est*-ce qui vous empêche de pratiquer le VAE plus souvent ? Pour quels trajets évitez-vous de prendre le VAE ?*
Infrastructures et circulation	- Vous sentez-vous à l'aise à circuler en VAE à Lausanne et dans les environs ? *Avez-vous vécu des situations dangereuses ? Dépassements, priorité, intersections, giratoires* - Les trajets que vous parcourez le plus souvent à Lausanne et dans les environs comprennent-ils des bandes cyclables (ligne non séparée) ou pistes cyclables (séparé) ? - Disposez-vous d'un lieu de stationnement pour vélos à la maison ou au travail ? *Couvert/sécurisé ? Comment jugez-vous la qualité du stationnement ?*
BILAN	
	- Comment jugez-vous votre expérience du VAE jusqu'ici ?