Comparative Analysis of User Characteristics and Use Patterns in Free-Floating and Station-Based E-Bike Sharing Systems – Insights from the Basel Metropolitan Area

Michael Stiebe, Widar von Arx

Conference paper June 2024

STRC | 24th Swiss Transport Research Conference
Monte Verità / Ascona, May 15-17, 2024

STRC 2024 conference paper

Comparative Analysis of User Characteristics and Use Patterns in Free-Floating and Station-Based E-Bike Sharing Systems – Insights from the Basel Metropolitan Area

Michael Stiebe
Institute of Tourism and Mobility, Lucerne University of Applied Sciences and Arts (HSLU)
Rösslimatte 48, 6002 Lucerne, Switzerland

Phone: +41- 41 349 36 24
E-Mail: michael.stiebe@hslu.ch

June 2024

Abstract

Over recent years, shared micromobility services have gained substantial momentum all around the globe. Along with shared e-scooters, e-bike sharing systems (EBSS) have seen significant growth in various Swiss cities and are assumed to bear great potential as a possible catalyst for the sustainable multimodal mobility transition in urban and peri-urban contexts (e.g., Julio et al., 2022). While societal and political optimism favoring the promotion of EBSS prevail in most cases, it must not be neglected that there is growing number of studies identifying undesirable public transport substitution effects (Zhou et al., 2023). To date, there some noteworthy international (e.g., Bieliński et al., 2021) and Swiss (e.g., Reck et al., 2021; Hess et al., 2019; Guidon et al., 2019) studies that have explored shared e-bike use patterns and user behavior. Our data-driven analysis adds to the existing body of knowledge and understanding of user characteristics and use dynamics in EBSS by providing a comprehensive comparison of user characteristics and spatiotemporal usage patterns in free-floating and station-based EBSS in the still under-researched Basel metropolitan area. We draw on extensive user and rental datasets from two leading EBSS providers in Basel covering a period of more than four years, one million rentals and 80,000 users.

Keywords

E-Bike Sharing; Free-Floating; Dock-Based; Sustainable Mobility; Micromobility; Urban Mobility Transformation; Cycling; Shared Mobility

Preferred citation style

Stiebe, M., von Arx, W. (2024). Comparative Analysis of User Characteristics and Use Patterns in Free-Floating and Station-Based E-Bike Sharing Systems – Insights from the Basel Metropolitan Area, presented at the *24th Swiss Transport Research Conference (STRC 2024)*, Ascona, May 2024.

Table of Contents

Table of Figures

Table of Tables

1. Introduction

The transport sector produces most greenhouse gas emissions in Switzerland accounting for 33% (excl. air travel) of CO_2 emissions (FOEN, 2024). Legally binding climate targets make the acceleration of the decarbonization of transport essential. In growing urban and peri-urban areas, existing infrastructures like public transportation (PT) systems are strained, leaving only limited expansion possibilities. Thus, urban and peri-urban areas must develop new mobility solutions, and foster mobility behavior change. Promising options are active and micro-mobility, alone or in combination with other modes of transport in a flexible multimodal mobility system. Different components, such as (e-)bike and walking and PT are flexibly combined. Individuals may use different mobility mixes based on weather conditions, varying mobility needs, or the departure time (e.g., peak vs. off-peak hours). Such flexibility enhances the chances of large-scale implementation of active and multimodal mobility, as it can accommodate various user needs. A possible solution gaining traction in several Swiss cities are e-bike sharing systems (EBSS), either dock-based/station-based or free-floating, allowing users to combine e-bike (fast and convenient for short distances) with PT (for longer distances). From a societal perspective, this mobility type offers several opportunities. It can help persuade people not to own a car/reduce car use, decrease CO_2-emissions, atmospheric air pollution (e.g., NO_x, $PM_{2.5}$), noise, traffic congestion, and parking space demand. It can reduce peak demand in PT, which is important in cities aiming to reduce private motorized transport but whose PT systems are strained during peak hours. This can help solve the first/last-mile problem in peri-urban areas. Albeit, both EBSS and concepts for combining EBSS and PT are still in their infancy. Several Swiss cities have provided some basic infrastructure for EBSS, such as parking spaces or booking platforms, and incentives (special EBSS tariffs in combination with a PT subscription). However, only 1.5% of the Swiss adult population is member of a bike sharing system, with substantial differences between spatial types, i.e., 2% in urban, 0.9% in intermediate, and 0.5% in rural regions (FSO, 2023a). Research has shown that on average 50% of registered shared micro-mobility users in Switzerland are dormant, i.e., inactive users (Reck & Axhausen, 2021). Comparable findings were reported by Zhou et al. (2022). There are also several studies that identified undesirable PT substitution effects in urban contexts (Bieliński et al., 2021; Guidon et al., 2019; Zhou et al., 2023). There exist research gaps regarding how EBSS can be integrated into flexible multimodal mobility systems as well as how their potential can be leveraged to make a noteworthy contribution to the sustainable mobility transition.

1.1. Aim and Research Questions

This paper aims to explore the differences and commonalities in the user base and the spatiotemporal usage patterns of free-floating and station-based EBSS. Drawing on the exemplary area of Basel and its metropolitan region (only Switzerland; the German and French metropolitan catchment areas are excluded from the study), this research comparatively explores the user characteristics and usage patterns in free-floating and station-based EBSS. Several reasons speak for the chosen case: Basel features multiple EBSS of which Pick-e-Bike even covers peri-urban and partly rural areas that are highly under-researched in this context. Basel has the lowest motorization rate of all Swiss cities, and high modal shares of active travel and PT (Bau- und Verkehrsdepartement des Kantons Basel-Stadt, 2023). Basel aims for climate-neutrality by 2037 (supported by popular vote in late 2022), placing it at the forefront of Swiss cities needing a mobility transition. The paper is guided by the overarching research question: How do different groups of people use different types of e-bike sharing services?

2. Background

This chapter outlines important background information as well as a thorough review of preceding literature from the research area.

2.1. E-Bikes

The e-bike is a battery-powered bike that assists the rider's pedal-power with customizable levels of assistance. It reaches speeds of up to 25 km/h (for pedelecs) or 45 km/h (for speed-pedelecs) (Rérat, 2021). It is recommended that e-bikes should be considered a distinct transportation mode, separate from both conventional bicycles, as well as mopeds and motor-scooters (Popovich et al., 2014). E-bike sales have seen rapid growth since the middle of the fist decade of the 21st century which includes even a so-called *e-bike boom* during the Covid-19 pandemic (Arnegger, 2021). The share of e-bikes in the overall bike sales in Switzerland has increased within less than ten years from 20.5% in 2015 to 45.2% in 2022, signifying the increasing popularity of this mobility tool. Due to higher prices of e-bikes compared to regular bicycles, the average price of bikes sold in Switzerland has surged from roughly 0.63kCHF to in 2015 to 1.85kCHF in 2022, marking an increase in approximately 190% in average bike prices. According to Handy and Fitch (2022), e-bikes have important advantages over ordinary bicycles as they enable people to travel faster, thereby enabling them to reach more distant destinations in the same amount of time. Furthermore, Handy and Fitch (2022) explain that e-bikes reduce the effort required to go uphill, making them especially suited for hilly areas. Considering the generally hilly or even mountainous topography of Switzerland, the latter advantage of e-bikes over conventional modes of active travel may be one of the key potentials of this means of transport. These two benefits work together to allow travelers to choose destinations and routes that they would not if riding a conventional bicycle.

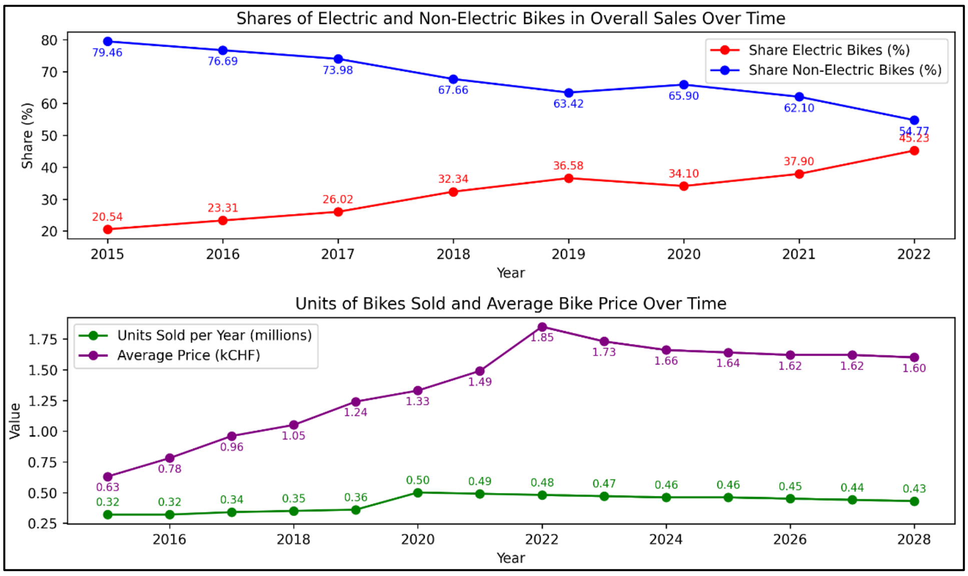

Figure 1 E-Bike Sales in Switzerland, based on Statista (2024)

A large-scale survey study (n = 15,792) by Shimano (2022) investigated motivations of Europeans of why they would buy or rent and e-bike. Economic factors, such as higher fuel prices, were the most significant driver, cited by 47% of respondents. Additionally, 41% mentioned the availability of e-bike subsidies as a key incentive. Environmental consciousness also played a role, with 33% expressing a desire to reduce their environmental impact. Health and fitness benefits were another notable motivator, cited by 32% of respondents. Infrastructure concerns, including cycling infrastructure and safe storage options, influenced 31% and 26% of respondents, respectively. A smaller proportion (18%) considered e-bikes as a means to avoid COVID-19 transmission. Interestingly, 17% highlighted the need for more education on e-bike benefits, suggesting potential gaps in awareness. However, 11% indicated none of the provided motivations applied to them, while 9% were uncertain. The same study (Shimano, 2022) also investigated the perceived target user demographics of e-bikes and e-bike sharing across different countries. While the overarching trend indicates that environmentally-conscious individuals and commuters are widely perceived as the primary users of e-bikes throughout Europe, a closer examination reveals nuanced variations among nations. In Austria, there is a notable association of e-bikes with the elderly, suggesting a recognition of e-bikes' accessibility and convenience for this demographic. Conversely, Spain stands out with a strong emphasis on e-bikes as a solution for commuters, highlighting the importance of addressing urban transportation challenges.

2.2. E-Bike Sharing Systems

Electric Bike Sharing Systems (EBSS) are an innovative transportation model that combines the flexibility of bike sharing with electric propulsion, offering an efficient, sustainable, and accessible urban mobility solution. The development of EBSS has been influenced by technological advancements and a growing awareness of environmental issues.

EBSS refer to the service where bicycles equipped with electric motors are made available for shared use to individuals on a short-term basis. The origins of bike sharing can be traced back to the 1960s with the launch of free bike sharing projects in Amsterdam (Ploeger & Oldenziel, 2020). The introduction of electric bikes into these systems began more recently, propelled by advancements in battery and motor technology, which enhanced the bikes' range and usability. These systems are designed to overcome the limitations of traditional bike sharing, such as physical exertion and travel distance, making them more appealing to a broader audience.

The operational concepts of EBSS include the integration of advanced technologies for bike tracking, battery management, and user interaction. Systems now often feature wireless network capabilities, GPS tracking, and automated docking stations that handle charging and security (Cherry et al., 2010). These technological enhancements facilitate easier management of the fleet and improve user experience by providing real-time data on bike availability and system health.

EBSS are claimed to offer multiple social, economic, and environmental benefits. Environmentally, they reduce greenhouse gas emissions and traffic congestion. Economically, they can provide a low-cost alternative to private motorized transport, especially private cars. Socially, they can increase accessibility to transportation and promote health through physical activity. In some cases, the systems have been shown to complement public transit by providing last-mile connectivity but in other cases they have shown to substitute walking and public transport (see e.g., Bieliński et al. (2021); Fukushige et al. (2021); Martin and Xu (2022); Oeschger et al. (2023)).

Despite their benefits, EBSS face several challenges, including battery life, operational costs, and system maintenance. Moreover, there is a continuous effort to better understand user behavior and system demand to enhance the service and increase its adoption (Bieliński & Ważna, 2020).

2.2.1. Delivery Modes

E-bike sharing operates under four primary models: station-based (bidirectional), station-based (one-way), free-floating, and peer-to-peer (Fistola et al., 2022). Table 1 provides an overview of the four modes. In the bidirectional station-based model, users retrieve and return bikes at designated stations, streamlining operations but confining users to the station network. Conversely, the one-way station-based system allows for drop-offs at different stations, enhancing user flexibility but requiring meticulous fleet management to prevent imbalances. Free-floating systems discard fixed stations, permitting pick-up and drop-off anywhere in the service area, demanding efficient vehicle redistribution strategies. Peer-to-peer sharing involves individuals offering their bikes via digital platforms, broadening access while utilizing community resources (Fistola et al., 2022).

Table 1. Overview of Four Common Service Provision Models in E-Bike Sharing, Based on Fistola et al. (2022)

Service Provision Type	Operational Model	User Flexibility	Payment Structure	Vehicle Return Requirement	Management of Vehicle Redistribution
Station-Based, Bidirectional	Vehicles picked up and returned to designated stations	Limited by station locations	Typically pay for entire reservation period	Must return vehicle to original station	Relatively easy due to fixed station network
Station-Based, One-Way	Vehicles picked up at one station and returned to another	Greater flexibility with multi-station usage	Pay based on distance or time traveled	Can return vehicle to different station	Critical for balancing fleet across stations
Free-Floating	Vehicles can be picked up and dropped off anywhere within service area	Maximum flexibility with no fixed locations	Pay based on usage duration or distance traveled	No fixed return location, can be dropped off anywhere	Essential to ensure equitable vehicle distribution
Peer-to-Peer	Individuals share privately-owned vehicles via digital platforms	Flexible access to diverse vehicle types	Payment varies, often facilitated through platform	Typically return to original location	Relies on peer participation for vehicle availability

2.2.2. Users and Usage

The characteristics of e-bike sharing system users are diverse and vary across different geographies, but certain common traits emerge from recent studies.

E-bike sharing users typically exhibit a higher level of education and are predominantly employed. A study conducted in Munich, Germany, identified bike sharing users - which includes e-bike sharing - as being mainly educated, employed males who value equity and adventure more than tradition. This demographic group appreciates the convenience, relaxation, and fun associated with biking compared to using private cars (Fuchs et al., 2021). In terms of age, younger individuals are more inclined to adopt shared micro-mobility solutions like e-bikes, often using them for leisure activities. This trend was particularly noted in a study from Tricity, Poland, which showed that e-bicycles are primarily used for short commutes to various places of interest and for leisure rides, with e-scooter users tending to be younger than e-bike users (Bieliński & Ważna, 2020). The demographic profile also shows a skew towards males with higher income levels. However, the adoption of e-bike sharing has not significantly addressed the gender gap nor helped retired and disabled individuals in adopting shared micro-mobility services, indicating a need for targeted interventions to increase inclusivity (Wang & Lindsey, 2019). The usage patterns between urban and suburban settings also differ. In urban environments, e-bikes tend to replace transit and walking trips, while in suburban areas, they more likely substitute for car trips. This highlights the adaptability of e-bike systems to meet different transportation needs based on the local environment (Zhou, 2022).

In the Swiss context, specifically Zurich, Reck and Axhausen (2021) showed that users of shared docked (e-) bike schemes have an average age of 36 years, with a predominantly male user base (82%). The majority of these users hold a university degree (78%) and are employed full-time (85%). Their mean monthly household income is 11,000 CHF. On the other hand, users of shared dockless e-bike schemes are slightly older, with an average age of 39 years, and also predominantly male (82%). Most of these users also hold a university degree (71%) and are employed full-time (85%). Their mean monthly household income is slightly higher at 11,400 CHF. Despite the slight difference in age, users of both docked and dockless e-bike sharing schemes exhibit similar sociodemographic characteristics in terms of gender distribution, education level, employment status, and household income.

2.2.3. Sustainability Impacts

EBSS are often discussed in the context of the a sustainable mobility transformation, especially in urban areas as a means to reduce air pollution, noise and greenhouse gas emissions, as well as PMT induced road congestion. To date, there exists and array of studies reporting on benefits (e.g. potential emissions reductions, mode shifts etc.) and disadvantages (e.g., PT substitution) of EBSS in urban contexts.

E-bike sharing systems have gained much attention for their potential to induce a mode shift toward a less carbon intensive modal split. Some studies claim or have found EBSS to contribute to reduction of final energy consumption and carbon emissions (e.g., Azevedo et al. (2023); McQueen et al. (2020); Raposo and Silva (2022); Zhou et al. (2023); Zhu and Lu (2023)).

The introduction of e-bike sharing systems plays a dual role: increasing public awareness about e-bikes and providing a practical demonstration of their viability for daily commuting. Handy and Fitch (2022) noted that this increased visibility could gradually lead to a reduction in car usage, as people consider alternative modes of transport. This suggests that e-bike sharing not only serves immediate transportation needs but also helps foster a cultural shift towards more sustainable commuting practices.

The effect of these systems on existing transportation modes varies. For instance, Fukushige et al. (2021) found that dockless e-bike sharing tends to substitute for shorter trips that would otherwise be made by walking or driving. This substitution is instrumental in decreasing the total vehicle miles traveled, thereby reducing related emissions. Such findings underscore the potential of e-bike sharing to aid in achieving urban sustainability objectives.

Nevertheless, the environmental impact of this shift varies. Kontar et al. (2022) highlighted that replacing short car trips with e-bike rides significantly cuts energy consumption and greenhouse emissions. In contrast, Raposo and Silva (2022) caution that substituting walks or bus rides with e-bike trips might not yield substantial environmental gains. Interestingly, while e-bikes effectively support first/last mile connectivity, enhancing public transport systems (Bieliński & Ważna, 2020), they do not always displace car trips. Instead, they often replace public transport journeys or supplement them (Bieliński et al., 2021), which may limit their impact on reducing car dependence.

The broader adoption of EBSS, however, faces several hurdles. Safety concerns, insufficient infrastructure, and lack of cycling skills deter potential users from embracing e-bike sharing, particularly the e-cargo variants (Hess & Schubert, 2019). Addressing these barriers is critical to enhancing the appeal and effectiveness of e-bike sharing systems. Furthermore, the likelihood of individuals adopting bike-sharing is influenced by a complex interplay of personal attributes, environmental settings, and travel behaviors, as demonstrated through mixed logit models (Ye et al., 2020). Understanding these dynamics can help tailor e-bike sharing systems to better meet community needs.

2.3. Description of Research Area Basel

Basel is strategically positioned in the northwest corner of Switzerland, where the country's borders meet France and Germany. This tri-national area is known as the *Dreiländereck* (Three Countries Corner). The city itself is set along the banks of the Rhine River, which not only serves as a major navigational and commercial waterway but also forms part of the border between France and Germany. Geographically, Basel lies on the Swiss Plateau, part of the larger European Plain, and is surrounded by the Jura Mountains to the north and the Vosges Mountains across the border in France. To the south, the landscape gently transitions into the rolling hills and plains that lead towards the Swiss Alps. This diverse topography contributes to Basel's mild, temperate climate, characterized by humid summers and cool winters. Basel's location has historically made it a hub for trade and transport. Its excellent transportation links include a well-developed rail network, the Rhine port - one of the largest inland ports in Europe - and the EuroAirport Basel-Mulhouse-Freiburg, which is operated jointly by Switzerland, France, and Germany. These factors not only enhance its economic status but also make it a focal point for cultural exchange in the region.

Figure 2 Location of Canton Basel-Stadt in Switzerland, adopted from Wikimedia (2024)

2.3.1. Sociodemographic, Socioeconomic and Political Situation

When comparing the socioeconomic profiles of Switzerland as a whole to Basel-Stadt, several notable distinctions emerge. Basel exhibits higher population density despite its smaller land area, with a growth rate slightly lower than the national average. Yet, it boasts a more diverse demographic with a higher percentage of foreign nationals. While age distribution patterns align closely, Basel shows smaller average household sizes, likely reflecting differences in lifestyle or housing dynamics. Economically, Basel leans heavily towards the tertiary sector, with a larger portion of its workforce engaged in services and commerce compared to the national average. However, the primary and secondary sectors play a minor role in Basel's economy. Politically, Basel showcases variations in voter shares, notably with higher support for the Social Democratic Party compared to the Swiss average. These differences show the unique socioeconomic dynamics within Basel and its situation within Switzerland. Understanding these nuances is essential for a comprehensive view of the region's socioeconomic landscape.

Table 2 Comparison of Regional Portraits, Switzerland and Basel-Stadt, from FSO (2023b)

Population		**CH**	**Basel**
Residents	2019	8,606,033	173,232
Change in %	2010 – 2019	9.4	6.1
Population density per km²	2019	215.2	7,263.4
Age distribution in %			
0-19 years	2019	20.0	16.9

20-64 years	2019	61.4	64.1
65 years or over	2019	18.7	19.0
Foreign nationals in %	2019	25.3	38.0
Components of population change			
Crude marriage rate	2019	4.5	5.2
Crude divorce rate	2019	2.0	2.0
Crude birth rate	2019	10.0	10.9
Crude mortality rate	2019	7.9	10.3
Private households	2019	3,811,306	87,344
Size of households in persons	2019	2.21	1.92
Area			
Total surface area in km²	2016	41,290.8	23.9
Settlement and urban area in %	2004/09	7.5	86.5
Change in ha	1979/85 – 2004/09	58,409	13
Agricultural area in %	2004/09	35.9	3.9
Change in ha	1979/85 – 2004/09	-85,056	-10
Wooded area in %	2004/09	31.3	3.6
Unproductive area in %	2004/09	25.3	6.0
Economy			
Employed total	2018	5,249,958	185,432
Primary sector	2018	161,497	27
Secondary sector	2018	1,091,626	34,946
Tertiary sector	2018	3,996,835	150,459
Business establishments total	2018	687,022	15,945
Primary sector	2018	53,457	11
Secondary sector	2018	95,687	1,362
Tertiary sector	2018	537,878	14,572
Construction and housing			
Dwelling vacancy rate	2020	1.72	0.95
New housing units per 1000 residents	2018	6.3	4.5
Social security			
Social assistance rate	2019	3.20	6.40
Voter shares of selected parties in % (National Council elections)			
FDP/PLR inclusive LP/PL-BS	2019	15.1	20.3
CVP	2019	11.4	4.1
SP	2019	16.8	34.0
SVP	2019	25.6	11.3
EVP/CSP	2019	2.3	1.5
GLP	2019	7.8	5.6
BDP	2019	2.4	0.4
PdA/Sol.	2019	1.0	0.0
GPS	2019	13.2	19.4
Small right-wing parties	2019	2.1	0.2

2.3.2. Mobility and Transport Situation

The following subsections shall give an overview of relevant transport and mobility facts regarding the research area of Basel.

2.3.2.1. Motorization Rate

Between 2010 and 2021, there were fluctuations and shifts in motorization rates across Swiss cities. Notably, some cities experienced declines in their motorization rates, indicating potential shifts in transportation preferences or policy interventions aimed at reducing car dependency. For instance, Basel's motorization rate decreased from 352 cars per 1,000 inhabitants in 2010 to 319 in 2021, suggesting a decreasing reliance on private vehicles over the decade. Conversely, some cities saw increases or relatively stable rates during this period. Lucerne's motorization rate, for example, experienced fluctuations but remained relatively high, indicating a persistent demand for private vehicle ownership. Meanwhile, St. Gallen and Winterthur showcased stability in their rates, suggesting consistent levels of car ownership over the years. These changes in major Swiss cities may be attributed to various factors such as changes in urban planning, improvements in public transportation infrastructure, shifts in economic conditions, and evolving societal preferences towards car usage, among others.

Table 3. Motorization Rate (No. of Passenger Cars per 1,000 Inhabitants), based on SKM (2023)

	2010	2015	2021
Basel	**352**	**334**	**319**
Bern	401	384	381
Lucerne	436	456	401
St. Gallen	435	452	451
Winterthur	404	409	400
Zurich	368	351	331

2.3.2.2. Modal Split

The modal split statistics in Table 4 below provide valuable insights into the distribution of transportation modes used by residents in each of the Swiss cities analyzed in the Städtevergleich Mobilität 2021 (SKM, 2023). Private motorized transport, including cars and motorcycles, dominates the modal split in most cities, with percentages ranging from around 43% to 62% of the average daily distance traveled. This underscores the continued reliance on private vehicles for commuting and daily travel needs, despite increasing efforts to promote alternative modes of transportation. Whereas St. Gallen has a private motorized transport modal share of 62% in the statistic, Basel's PMT modal share is around 43% which is the lowest of all Swiss metropolitan areas. Public transit plays an important role in urban mobility, with percentages ranging from approximately 27% to 40% of the average daily distance traveled. Walking emerges as a mode of transport across all cities, with varying percentages ranging from approximately 6% to 12% of the average daily distance traveled. Bicycling also holds a notable share of the modal split, albeit with lower percentages compared to walking. The percentage of distance traveled by bicycle ranges from around 3% to 12% across the cities while

Basel leads the ranking with the highest modal shares of both modes, i.e. 12% bicycle and 12% walking. Other modes of transport, such as taxis or shared mobility services, contribute minimally to the overall modal split, with percentages typically less than 2% across the cities.

Table 4. Distance Based Modal Splits in Swiss Cities, based on SKM (2023)

City	Unit	Avg Daily Distance Traveled	Walking	Bicycle	Public Transit	Private Motorized Transport	Other Modes of Transport
Basel	**km**	**18.8**	**2.3**	**2.2**	**6.1**	**8.2**	**0.1**
	%		**12.2**	**11.7**	**32.5**	**43.6**	**0.5**
Bern	km	25	1.8	1.5	9	11.9	0.1
	%		7.2	6.0	36.0	47.6	0.4
Lucerne	km	27.5	2.3	1	11.1	12.7	0.3
	%		8.4	3.6	40.4	46.2	1.1
St.	km	29	1.9	0.9	7.8	17.9	0.4
	%		6.6	3.1	26.9	61.7	1.4
Winterth	km	26.4	2	1.4	10.1	12.8	0.2
	%		7.6	5.3	38.3	48.5	0.8
Zurich	km	24.3	2.2	1.4	9.8	10.8	0.1
	%		9.1	5.8	40.3	44.4	0.4

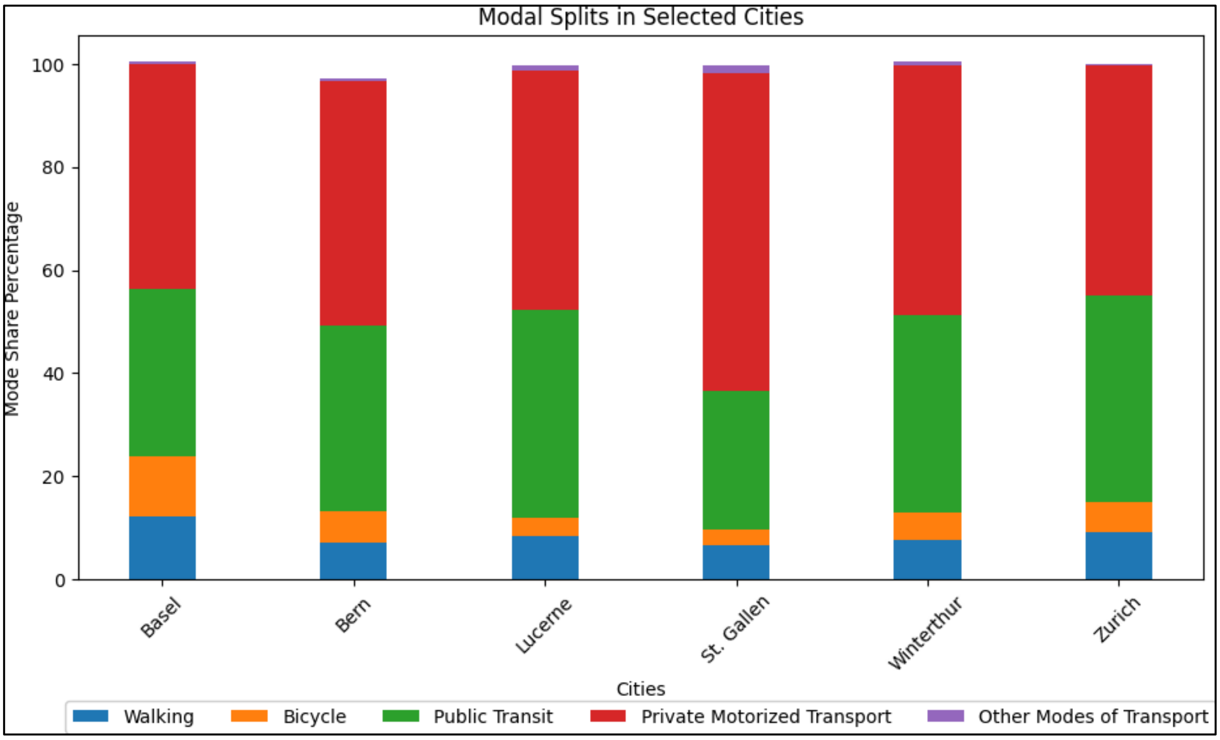

Figure 3 Distance Based Modal Splits in Swiss Cities, based on SKM (2023)

2.3.2.3. Cycling Infrastructure

It is evident that Swiss cities have invested in developing bicycle infrastructure along their roads, with varying degrees of emphasis on bike lanes versus separate bike paths. According to the *Städtevergleich Mobilität 2021* (SKM, 2023) which compares mobility related statistics in Basel, Bern, Lucerne, St. Gallen, Winterthur and Zurich, Basel has the highest percentage of its road network dedicated to bicycle infrastructure compared to Luzern and St. Gallen. However, it is important to note that data for Bern, Winterthur, and Zürich are not available, limiting the comprehensive understanding of bicycle infrastructure across all major Swiss cities.

Table 5. Bicycle Infrastructure in Basel, Lucerne and St. Gallen, based on SKM (2023)

City	Bicycle Infrastructure (km)	Bike Lanes (km)	Separate Bike Paths (km)	Bicycle Infrastructure Compared to Total Road Network (%)
Basel	**61**	**34**	**28**	**19**
Lucerne	43	32	11	18
St. Gallen	35	29	6	12

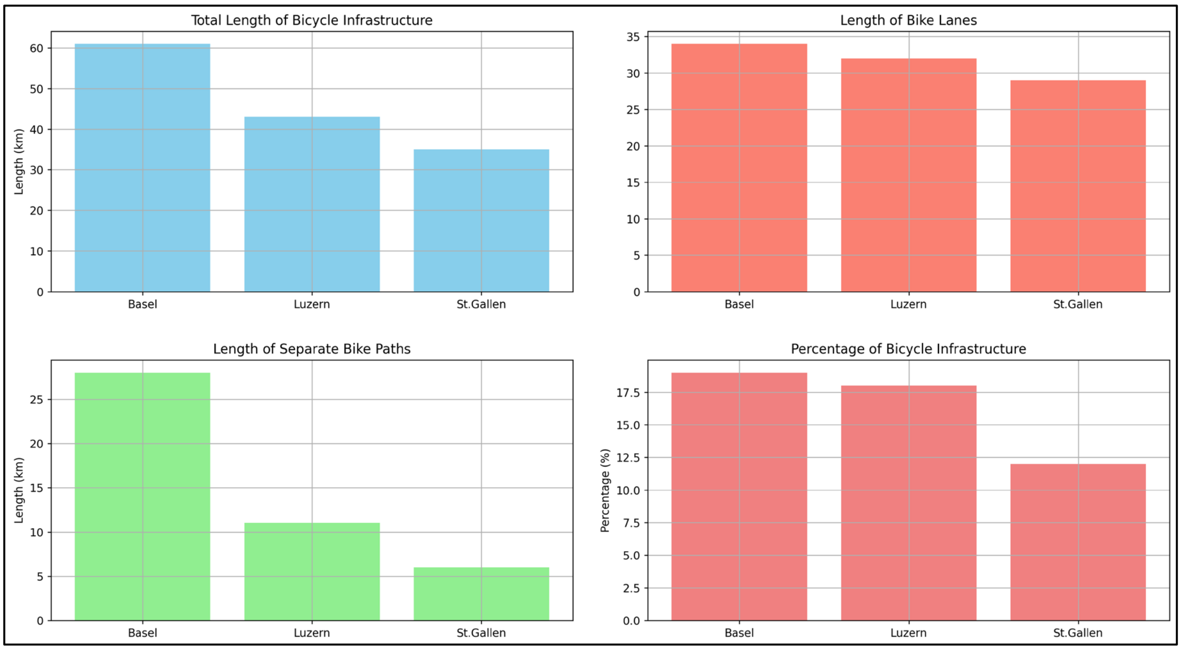

Figure 4. Bicycle Infrastructure Statistics as of 2021, Based on SKM (2023)

2.3.3. Climate

Since weather has been found to have strong impacts on micromobility usage behavior, the analyzed EBSS cases and their service areas must be put into a general climate context.

Located in the Rhine Valley, Basel experiences a temperate climate influenced by its geographical position. Under the Köppen-Geiger climate classification, Basel is classified as Cfb (= temperate oceanic climate or subtropical highland climate), although with notable continental influences due to its relatively far inland position with cool to cold, overcast winters and warm to hot, humid summers. The precipitation levels in the city of Basel are noteworthy, as there is a considerable amount of rainfall even during months that typically experience dry weather. The climate here is classified as Cfb by the Köppen-Geiger. The mean yearly temperature observed in Basel is recorded to be 10.5°C. The annual precipitation in this location is approximately 1274 mm.

Winter (December to February): Winters are cold with average temperatures ranging from 1.4°C in January to 2°C in February. Minimum temperatures often dip below freezing, reaching as low as -1.9°C in February, which makes it the coldest month on average. Precipitation is moderate but consistent, and days are relatively humid and short on sunshine, with December seeing only about 3.8 hours of sun daily.

Spring (March to May): Spring sees a gradual warming, with average temperatures increasing from 6°C in March to 14.2°C in May. Rainfall increases through the season, peaking in May with 135 mm. The number of sun hours rises significantly, reaching up to 9 hours in May, providing more pleasant and longer days.

Summer (June to August): Summers are warm with the highest average temperatures reaching 19.9°C in July. Nights remain mild with minimum temperatures around 14.8°C in July and August. Although this season is the sunniest, with up to 10.7 hours of sunshine in July, it also experiences a high amount of rainfall, around 127-128 mm in July and August.

Autumn/Fall (September to November): Temperatures start to decrease in autumn, moving from 15.5°C in September to 5.5°C in November. The weather remains relatively wet and humid, with precipitation slightly decreasing from 101 mm in September to 103 mm in November. Sunlight also reduces as the season progresses, culminating in around 4 hours of sun in November.

Cycling conditions in Basel offer considerable variety throughout the year, influencing when and how comfortably e-bikes can be used. Winter presents the most challenging season with cold, sometimes icy conditions, and limited daylight, requiring cyclists to be well-equipped with lights and appropriate winter gear. Despite these challenges, careful preparation can still make winter cycling feasible. From spring through autumn, conditions improve considerably, making these seasons ideal for e-biking. Spring sees milder temperatures and increasing daylight, although rain gear may be necessary. Summer provides the best conditions with warm weather, ample sunlight, and only occasional rain, perfect for longer rides and daily commuting. Autumn remains favorable early on but gradually transitions to cooler and wetter conditions, requiring increased caution as the season progresses. Except during the harsh winter days, Basel is favorable for cycling for the majority of the year.

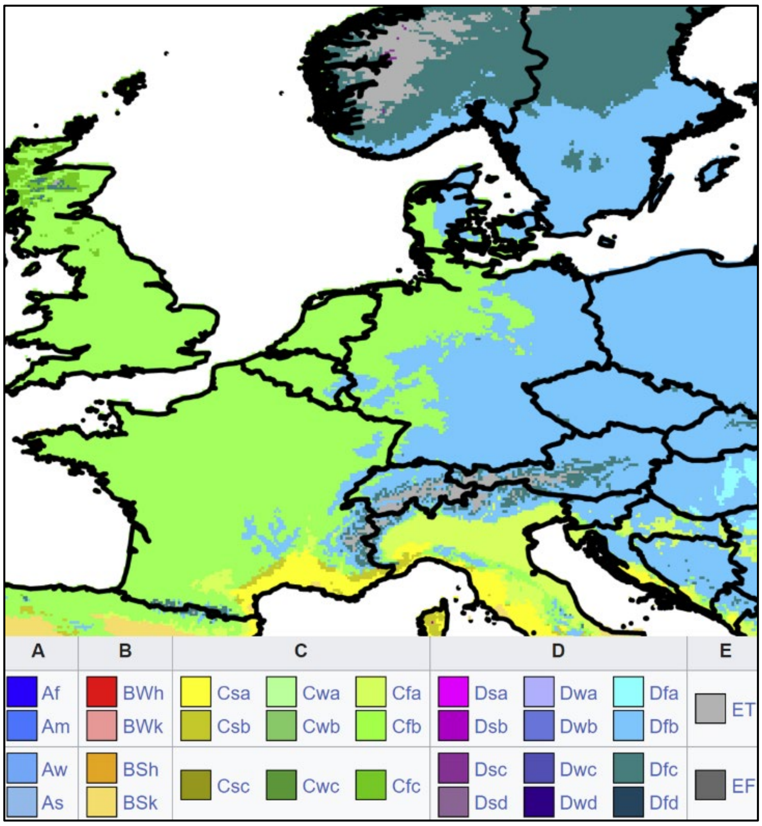

Figure 5. Köppen-Geiger Climate Classification, Based on Wikimedia Commons[1]

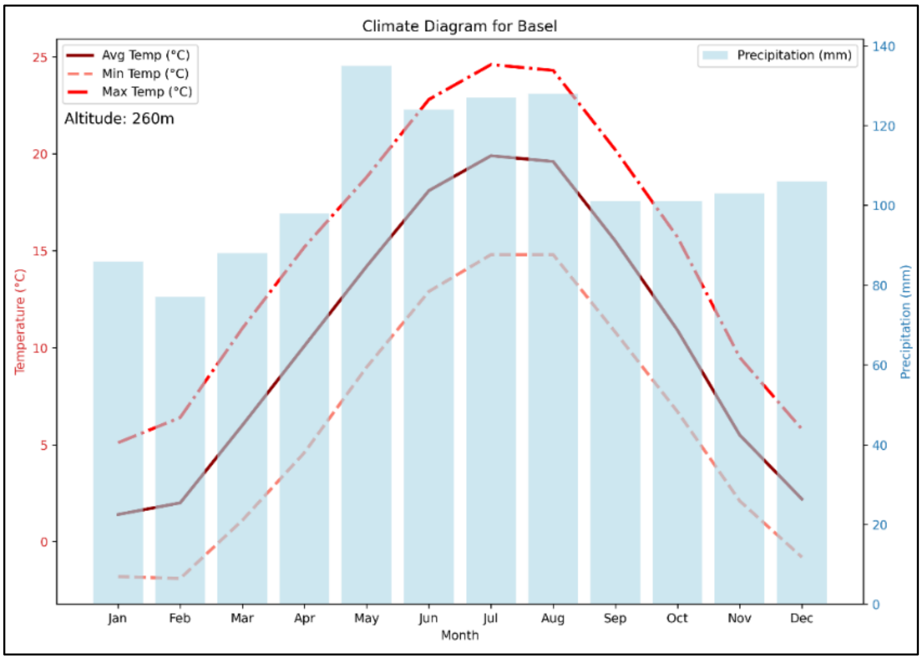

Figure 6. Climate Diagram for Basel-Stadt, Own Graph Based on Data from climate-data.org (2024)

[1] Beck, H.E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., & Wood, E. F., CC BY 4.0 <https://creativecommons.org/licenses/by/4.0>, via Wikimedia Commons

Table 6 Climate Data for Basel-Stadt, Based on Data from climate-data.org (2024)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temperature °C	1.4	2	6	10.1	14.2	18.1	19.9	19.6	15.5	10.9	5.5	2.2
Min. Temperature °C	-1.8	-1.9	1.1	4.6	9	12.9	14.8	14.8	10.8	6.7	2.1	-0.8
Max. Temperature °C	5.1	6.4	11	15.2	18.8	22.8	24.6	24.3	20.2	15.7	9.5	5.8
Precipitation (mm)	86	77	88	98	135	124	127	128	101	101	103	106
Humidity (%)	82	79	75	71	73	70	68	69	75	81	85	83
Rainy days (d)	10	9	10	11	13	12	12	11	10	9	10	11
Average Sun hours (h)	3.9	4.8	6.6	8.4	9	10.5	10.7	9.6	7.2	5.3	4	3.8

Table 7 Summary of Cycling Conditions Throughout Seasons

Season	Avg. Temp. (°C)	Precipitation	Daylight (h)	Cycling Conditions
Winter	1.4 - 2.2	Moderate	Low (3.8 - 4.8h)	Cold and icy; use lights and reflective gear; consider winter tires.
Spring	6 - 14.2	Moderate to High	Moderate to high (6.6 – 9h)	Milder; wet roads; good daylight; suitable for regular cycling with rain
Summer	18.1 - 19.9	High	High (9.6 - 10.7h)	Warm and pleasant; occasional rain; ideal for extended rides.
Fall	5.5 - 15.5	Moderate to High	Decreasing (4 - 7.2h)	Cooling temperatures; rainy; diminishing light requires lights on e-bike.

2.4. Research Partnership

For this research, embedded within the SFOE-funded (2023-2027) research project "POTEBS - Investigating the Potential of E-Bike-Sharing Systems for Sustainable Mobility in Different Spatial Types", we collaborate with two independent e-bike sharing providers that operate, among other Swiss urbanizations, in the Basel area. We focus on this service area. The EBSS vary in their operational models and have entered the market at different points in time.

The free-floating EBSS has its roots within a cantonal public transport operator and has conducted business in Basel since 2018, running a fleet of approximately 500 fast (up to 45 km/h) e-bikes including primarily e-bikes and approximately 90 moped-like e-scooters. This requires the users to be holders of a driver's license of category B or A45/M. Due to its roots in a public transportation operator and its mission to enable comfortable and affordable multimodal mobility, the company gives discounts to youth and holders of some local public transit subscriptions. Whereas there is an increasing number of fares and subscriptions, the most commonly used fare is the standard one, starting at 0.35 CHF/min + 1 CHF unlocking fee.

The dock-based EBSS partner has entered the Basel market later, namely in late 2021, and builds its business model renting out a fleet of approximately 500 regular e-bikes (up to 25 km/h) which do not require the users to have a driver's license, as well as reduces the minimum age of use to 14 years. Furthermore, the operator offers regular non-motorized bike rental and a hybrid form. The latter two are excluded from the analyses in this paper. The operator has rapidly increased its station network from initially 46 stations at market entry in 09-2021 to 291 stations in 01-2024. Also here, the operator offers various fares and subscriptions including B2B models and agreements.

3. Data and Methodology

3.1. Data

This study, featuring a close cooperation with two prominent e-bike sharing providers, draws on the use of various EBSS and external datasets.

3.1.1. EBSS Data

This section outlines the data used in this study, courteously provided by our free-floating and dock-based EBSS partners.

3.1.1.1. Rental Stations / Operational Area

The dock-based provider has shared a dataset containing 301 stations including a backend identifier (e.g., V-927), their names (e.g., "Viaduktstrasse 33 – Basel"), geocoordinates (e.g., Lat: 47.5488336, Lon: 7.5855905), their date of inauguration, and a remark whenever a station was removed from the network or temporarily suspended (e.g., due to road construction work). Figure 7 and Figure 8 show the expansion of the dock-based station network in Basel over time, from market entry in late 2021 to the end of 2023. As can be seen in said figures, the dock-based EBSS focuses primarily on covering the core urban area of Basel. Since the free-floating EBSS does not require stations in the closer sense, only an operational area can be outlined. This area, which does not only include the city of Basel but also outer areas and villages of the agglomeration (e.g. Allschwil, Oberwil, Liestal etc.), is depicted in Figure 9.

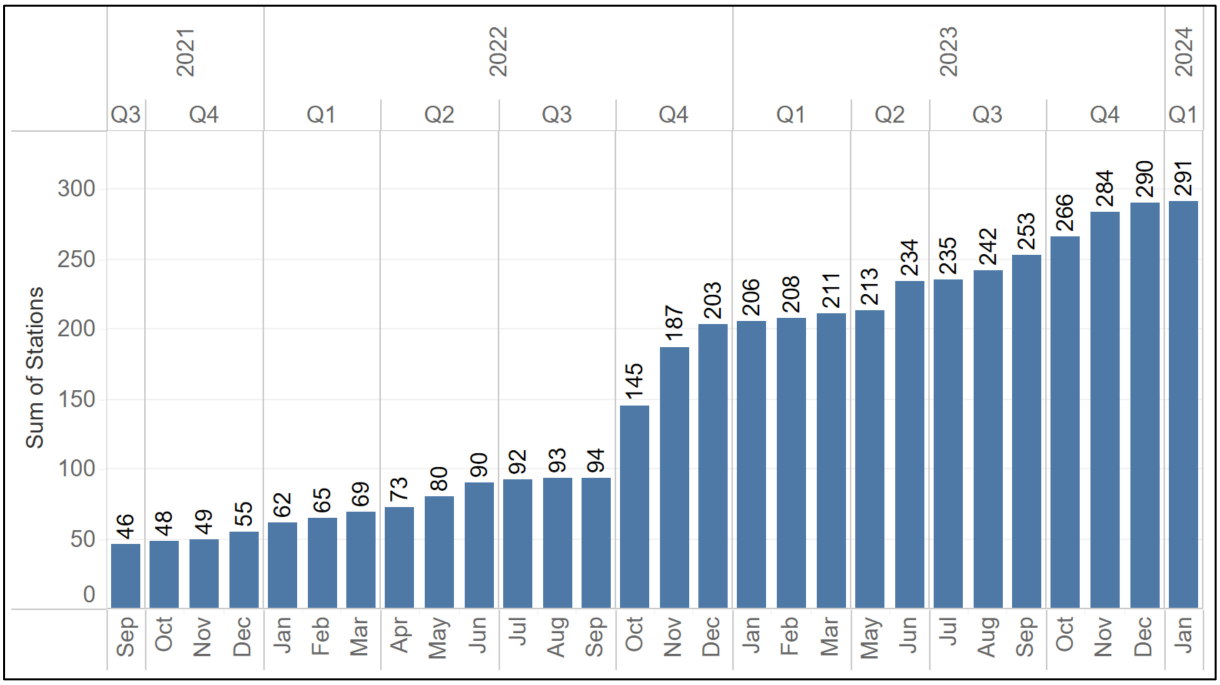

Figure 7 Monthly Growth of Dock-Based EBSS Stations in Basel

Figure 8 Expansion of Dock-Based EBSS Stations Over Time in Basel

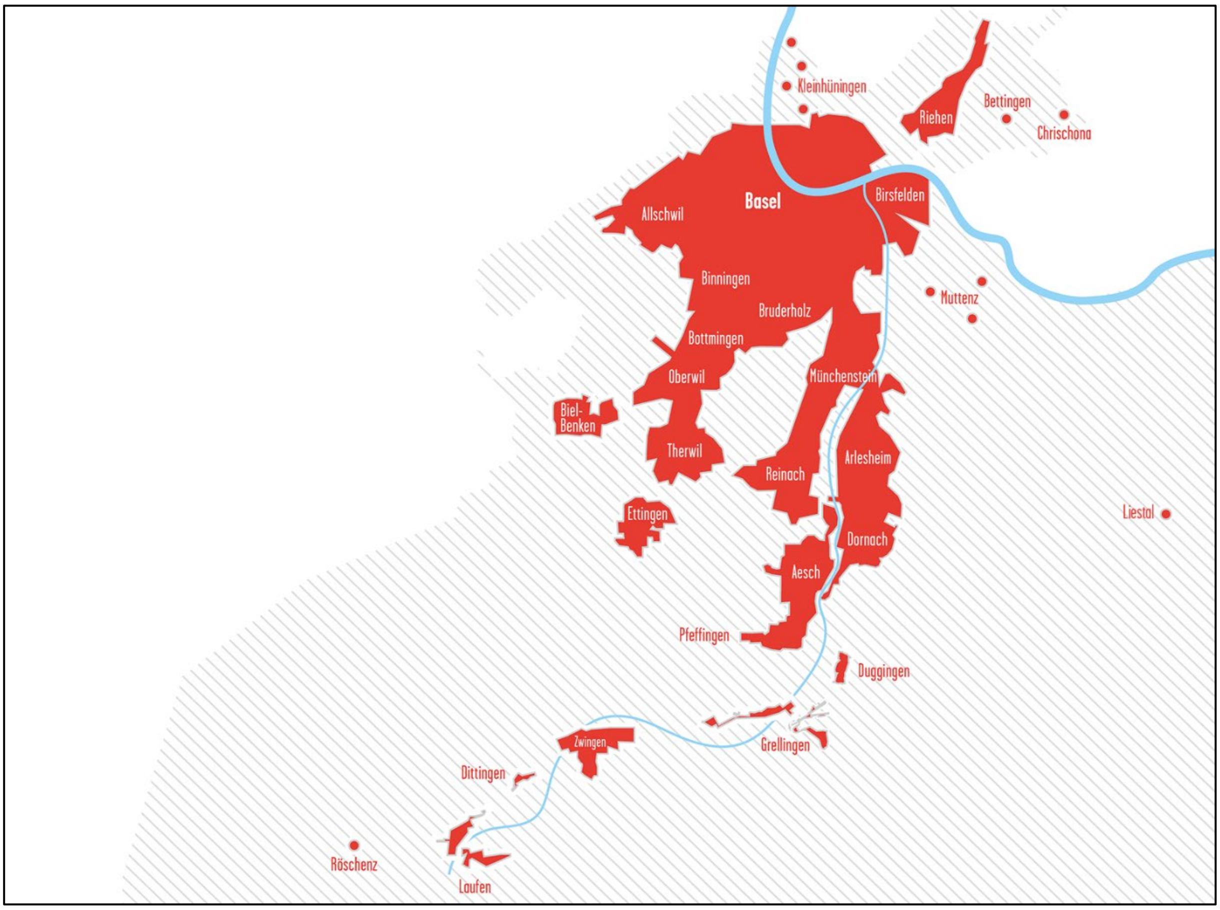

Figure 9 Operation Area of Free-Floating EBSS in Basel Area, adopted from https://basel.pickebike.ch

3.1.1.2. Rental Data

The provided data offers a comprehensive snapshot of e-bike rentals within two distinct systems: free-floating and dock-based. The rental datasets from the free-floating and dock-based EBSS were of varying granularity and quality. Since both operators have a fleet of various vehicles, i.e. dock-based: e-bikes, regular bikes, hybrid bikes, and free-floating: moped-type e-scooters and e-bikes, the analyzed e-bike sharing rentals represent only subsamples of the rental datasets.

Within the free-floating system, a total of 1,148,641 rentals were recorded, with 734,465 involving e-bikes. After filtering for valid data, 558,456 e-bike rentals remained, showcasing a substantial utilization of electric bicycles. The earliest rental within this system dates back to May 19, 2018, while the most recent record is from February 2, 2024, illustrating several years of consistent data collection. In contrast, the dock-based system exhibits lower rental volumes, with 41,780 total rentals and 24,373 on e-bikes. Upon validation, 24,372 e-bike rentals were deemed valid for analysis. The rental records within this system span from September 21, 2021, to December 31, 2023, providing a more recent but comparatively narrower timeframe for observation. A summary is provided in Table 8.

The dock-based EBSS rental dataset comprises 12 variables and essential elements for examining bike-sharing operations. It includes details such as the trip ID represented by an alphanumeric code, the type of fare applied denoted by text entries, and the start and end timestamps indicating when the rental began and ended, respectively. Each rental transaction is associated with a backend ID and station name for both the rental initiation and return locations, often including street addresses. Additionally, the dataset records the vehicle ID, categorized as either "Velo" (non-electric bicycle), "E-Bike" or "Hybrid" along with the estimated distance traveled during the rental period, calculated based on duration and standardized speed assumptions. User IDs, represented by 15-character alphanumeric codes, are also included, enabling the linkage of rental activities to specific users.

The dataset from the free-floating EBSS provides detailed information on e-bike sharing activities, containing a total of 60 variables. The most important key variables include an ID for unique identification of each rental transaction, indicating whether the rental is active or closed. Timestamps denote the start and end times of rentals, along with the date and time of the rental initiation. Additionally, the data is geocoded, helping us see where rentals start and end. Additionally, data on distance traveled, duration of the rental, and average speed offer insights into usage patterns. Pricing details, including discounts and net revenue generated, shed light on financial aspects. User-related variables such as user ID and subscription details provide valuable information on user behavior and preferences. Timestamps of checkout attempts and their outcomes offer insights into system reliability and user experience.

Table 8 Rental Data Samples Overview

	Free-Floating	Dock-Based
Rentals Raw	1'148'641	41'780
Rentals E-Bike	734'465	24'373
Rentals E-Bike Valid	558'456	24'372
Earliest Rental Record	2018-05-19	2021-09-21
Latest Rental Record	2024-02-02	2023-12-31

3.1.1.3. User Data

Both EBSS provided us with user datasets which were of very different granularity. Our free-floating EBSS partner provided us with a user dataset containing 41,471 registered users, the dock-based EBSS provider with a user dataset containing 48,074 registered users. Both datasets contained individual user identifiers, as well as information on the time of registration, birthdate, gender, town, zip codes and country of residence (dock-based EBSS dataset contained only zip code and country, among other information.

3.1.2. External Data

3.1.2.1. Spatial Typology by Federal Office for Spatial Planning (ARE)

To classify the start and end points (GPS coordinates) using the official Federal Office for Spatial Development (ARE) Typology of Municipalities. The typology of municipalities ARE is the result of a combination of the large regions, the agglomeration definition 2000 and the municipality typology of the Federal Office of Statistics (FSO). The geopackage file "gemeindetypen_2056.gpkg" is freely available online via the federal data.geo.admin.ch platform. This database uses the EPSG:2056 projected coordinate system for Liechtenstein; Switzerland.

Table 9 Spatial Typology by Federal Office for Spatial Development (ARE)

German Municipal Type	English Translation
Grosszentren	Big Centers
Nebenzentren der Grosszentren	Secondary Centers of Big Centers
Gürtel der Grosszentren	Crown Big Centers
Mittelzentren	Medium Centers
Gürtel der Mittelzentren	Crown Medium Centers
Kleinzentren	Small Centers
Periurbane ländliche Gemeinden	Peri-Urban Rural Communes
Agrargemeinden	Agricultural Communes
Touristische Gemeinden	Tourist Communes

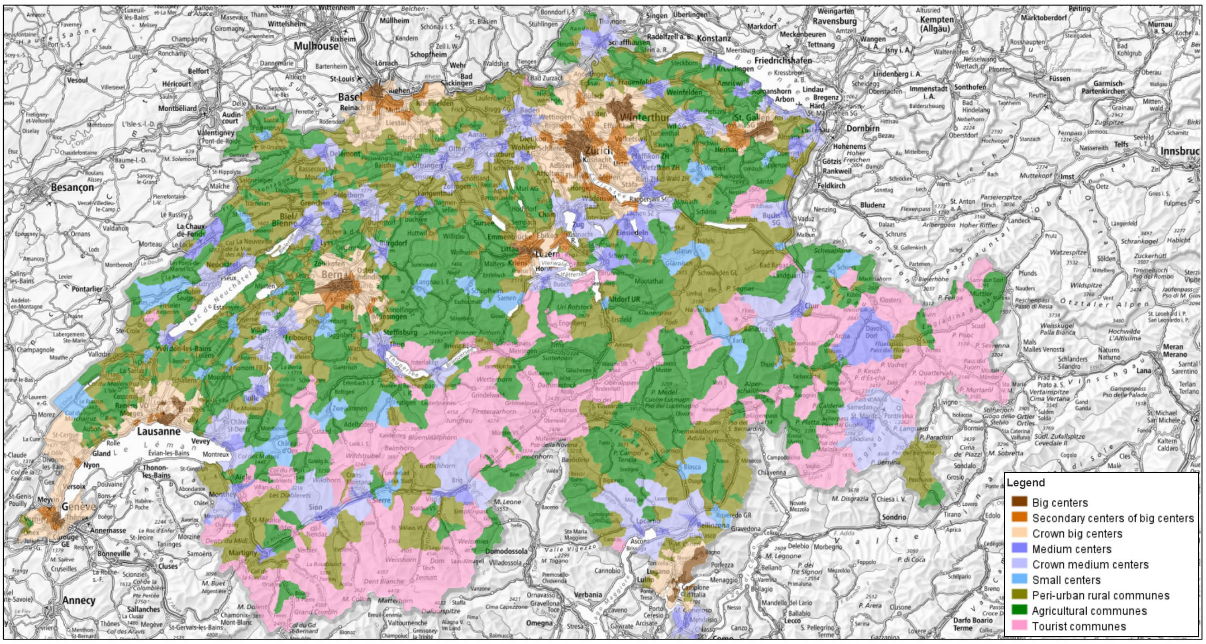

Figure 10 Typology of Municipalities by Federal Office for Spatial Development (ARE), https://map.geo.admin.ch/

3.1.2.2. Public Transport Stops

As one of our key concerns is whether and how EBSS are used in combination with public transport, an analysis of starting and stopping coordinates and their proximity to public transport stops should be conducted to build hypotheses on the usage patterns. For this, current external public transport stop data, i.e. "HaltestellenOeV.gpkg"[2], from the Swiss Federal Office of Transport (FOT) containing information on all Swiss public transport stops was obtained from the Swiss Federal geodata portal: data.geo.admin.ch.

[2] https://data.geo.admin.ch/browser/#/collections/ch.bav.haltestellen-oev/items/haltestellen-oev?.language=en

3.1.2.3. Weather Data

In our endeavor to comprehensively analyze the impact of meteorological factors on our EBSS datasets, we augmented our existing data with supplementary information sourced from *meteoblue*, a meteorology service headquartered in Basel (www.meteoblue.com). We conducted a CSV export encompassing the entire duration of our rental dataset, spanning from May 2018 to February 2024, with data captured at hourly intervals. The exported data encompassed a range of indicators, including timestamps and various meteorological parameters specific to Basel. These parameters comprised Basel Temperature (corrected for elevation at 2 meters), Basel Precipitation Total, Basel Relative Humidity (measured at 2 meters), Basel Snowfall Amount, Basel Snow Depth, Basel Wind Gust, Basel Wind Speed (measured at 10 meters), Basel Wind Direction (measured at 10 meters), Basel Cloud Cover Total, Basel Cloud Cover High, Basel Cloud Cover Medium, Basel Cloud Cover Low, Basel CAPE (Convective Available Potential Energy from 180 to 0 millibars above ground level), Basel Sunshine Duration, Basel Shortwave Radiation, and Basel Mean Sea Level Pressure (MSL).

3.2. Methodology

3.2.1. Data Preparation and Data Scrapping

The study utilized datasets from two distinct e-bike sharing systems, which were provided in various file formats including Excel spreadsheets (.xlsx) and Comma-Separated Values (.csv) files. These datasets were obtained directly from the respective e-bike sharing operators. Upon initial inspection, it was observed that the datasets had different delimiters, including semicolons (;) and commas (,). To ensure consistency, all datasets were standardized to use a uniform delimiter, with commas being chosen for compatibility with our analysis tools. The datasets also exhibited variations in timestamp formats, complicating temporal analysis. Some timestamps were in Coordinated Universal Time (UTC), while others were in local time. As part of the data cleaning process, all timestamps were converted to a standardized format and time zone, typically UTC, to facilitate accurate temporal analysis and comparisons across datasets. Different file formats required tailored approaches for data extraction and processing. For Excel files, Python libraries such as Pandas were utilized to read and manipulate the data. CSV files were directly parsed using Python's built-in CSV module or Pandas, depending on the complexity of the dataset. During data inspection, missing values were identified across the datasets. Missing data points were handled through exclusion, depending on the extent and impact of the missing information. After standardizing formats, delimiters, and timestamps, the datasets were partly integrated into unified datasets for comparative analysis, or kept separate for certain analyses and linked via unique identifiers in the datasets (e.g., user id, vehicle id, etc.). To validate the integrity of the integrated dataset, consistency checks were performed to ensure that the data aligns with expectations and domain knowledge.

3.2.2. Data Analysis

In this study, we employed several analytical and visualization methods using an array of software tools including MS Excel, Python, and Tableau. Data analysis entailed primarily descriptive and simple inferential statistical methods (e.g., independent samples t-tests) whenever suitable.

One key point in the user base analysis was the classification of the users. In the literature on shared micro-mobility and EBSS, there have been several reports of vast shares of registered users in micro-mobility sharing being inactive or “dormant” members. Reck and Axhausen (2021) classify users as dormant users or rather members and (active) users. They explain that the terms member and user are often used interchangeably, however, bearing different connotations, which is why they should be distinguished. They argue that the while term *member* has a static connotation comprising both active and inactive/dormant users, the term *user* has an active connotation linked to actual usage. For the purpose of their study, they defined users who use a shared micro-mobility scheme at least several times per month. Drawing on Reck and Axhausen (2021), we will use the same approach and classify users with an average of two or more trips per month as *active* and users with an average of below two trips per month as *dormant*. To filter out invalid trips, only trips with at least 100 meters recorded distance were considered in the calculation. Then, using the formula:

$$\frac{\text{Total EBSS Rentals of User}}{\text{Membership Length of User (in Months)}} = \text{Average Number of Trips per Month}$$

We enhance the classification by one more user category, namely those users who have registered an account but never appeared in the rental datasets. We call them *invisible users*. In summary, our user classification scheme is as follows:

Table 10 User Classification by Use Frequency

User Class	Condition
Active Users	On average at least 2 valid rentals per month
Dormant Users	More than 1 rental total, less than 2 valid rentals per month
Invisible Users	No appearance in rental dataset

Another key aspect of our analysis was the investigation of public transport and EBSS rental interaction. As we do not possess any transaction data on whether a person has traveled intermodally or in a combination of public transport and EBSS, we could only derive certain assumptions based on the proximity of the starting and ending coordinates of e-bike trips to public transport stops. For this, the three closest public transport stops, their name, type and official id were calculated using python and the aforementioned geopackage file from the Federal Office of Transportation containing locations and info for all Swiss public transport stops.

4. Results

This chapter presents key results from our analyses, beginning with a detailed account of the users of the two compared EBSS, followed by analysis results regarding the usage and user behavior.

4.1. EBSS User Base

The user samples outlined in Table 11 offer a detailed portrayal of the demographics and some behaviors associated with free-floating EBSS and dock-based EBSS users.

Firstly, concerning gender distribution, it is evident that free-floating EBSS users skew slightly more towards males, constituting 67.0% of the sample, whereas dock-based EBSS users show a slightly more balanced gender distribution, with males comprising only 61.0%.

Moving on to age demographics, free-floating EBSS users tend to be slightly older on average, with an average age of 41.3 years compared to dock-based EBSS users' average age of 38.6 years. This difference in mean age proves statistically significant ($p < 0.0001$) when applying a t-test with independent samples. Moreover, while both user groups have a significant representation in the 20-39 age bracket, dock-based EBSS users exhibit a higher proportion within this age range, with 56.0% falling into this category compared to 46.9% for free-floating EBSS users.

Regarding the geographical origins of users, the vast majority of both free-floating EBSS and dock-based EBSS users hail from Switzerland, although free-floating EBSS users demonstrate a slightly higher domestic representation at 95.0% compared to dock-based EBSS users' 90.2%. Interestingly, there are notable variations in city origins between the two user types, with free-floating EBSS users displaying a more even distribution across cities, whereas dock-based EBSS users predominantly originate from cities other than Basel.

Lastly, examining user status sheds light on engagement levels within each group. free-floating EBSS users exhibit a higher percentage of dormant users, comprising 56.8% of the sample, whereas dock-based EBSS users have a larger proportion of active users at 7.2%. Additionally, a considerable portion of free-floating EBSS users (41.0%) are categorized as silent users, indicating no rental activity, whereas the majority of dock-based EBSS users (93.0%) fall into this silent category.

Table 11 EBSS User Samples Summary

	Free-Floating	Dock-Based
Sample Raw	41'471	48'074
Sample Clean[3]	38'233	42'606
Gender (%)[4]		
Male	67.0	61.0
Female	33.0	39.0
Age (Years)		
Average	41.3	38.6
Median	38.2	36.0
Std. Dev.	13.2	13.2
<20 (Share in %)	1.7	2.0
20-39 (Share in %)	46.9	56.0
40-64 (Share in %)	47.2	38.9
65+ (Share in %)	4.3	3.2
Country Origins (%)		
Switzerland	95.0	90.2
Germany	2.6	3.4

[3] Plausibility check via user age (users > 100 years or under legal minimum age of 16/14 years = excluded)
[4] Missing values and non-binary gender statements excluded

France	0.9	1.0
Italy	0.1	2.9
Other Countries	1.3	2.4
City Origins (CH, %)		
Basel	28.4	10.0
Other Cities	71.6	90.0
User Status (%)		
Active (>= 2 Rentals per Month)	1.7	7.2
Dormant (< 2 Rental per Month)	56.8	0.1
Silent (No Rentals)	41.0	93.0

4.2. EBSS Usage

The EBSS journey metrics offer further insight into the dynamics of urban travel. On average, dock-based users cover a distance of 3.72 kilometers in 14.01 minutes per rental, indicating relatively shorter and quicker trips. In contrast, free-floating journeys span a longer distance of 4.94 kilometers on average, with an extended duration of 34.98 minutes per rental, reflecting a preference for leisurely exploration or longer commutes. Temporal analysis unveils the heartbeat of city movement, with clear peaks and troughs in activity. The consistency in the most active hours across both systems underscores the rhythm of urban life, while seasonal fluctuations reveal shifting preferences and habits. Fall emerges as the peak season for bike rentals, characterized by vibrant activity, while winter and spring witness a decline, perhaps influenced by weather conditions or seasonal routines.

Table 12 Overview of E-Bike Sharing Rental Data

	Free-Floating	Dock-Based
Number of Rentals Raw	1’148’641	41’780
Rentals E-Bike	734’465	24’373
Rentals E-Bike Valid[5]	558’456	24’372
Earliest Rental Record	2018-05-19	2021-09-21
Latest Rental Record	2024-02-02	2023-12-31
Distance and Duration per Rental		
Distance Traveled per Rental (Mean) (km)	3.7	4.9
Distance Traveled per Rental (Median) (km)	3.0	2.6
Distance Traveled per Rental (Std. Dev.) (km)	4.6	7.6
Duration per Rental (Mean) (minutes)	14.0	35.0
Duration per Rental (Median) (minutes)	9.3	9.0
Duration Traveled per Rental (Std. Dev.) (minutes)	58.4	242.8
Speed (Mean) (km/h)	20.1	18.0[6]
Speed (Median) (km/h)	20.7	n/A
Speed (Std. Dev.) (km/h)	14.7	n/A
Most Important Age Group (Based on Rental Share)	20-39 years	20-39 years
Least Important Age Group (Based on Rental Share)	<20 years	<20 years
Peaks and Seasons		
Most Active Day of the Week (Based on Rental Share)	Friday	Wednesday

[5] Plausibility check for min. 100m traveled distance
[6] Provider does not record speeds or actual distances traveled; provider assumes 18 km/h for an e-bike

Least Active Day of the Week (Based on Rental Share)	Sunday	Sunday
Most Active Hour (Workweek)	17:00-17:59	17:00-17:59
Most Active Hour (Weekend)	18:00-18:59	16:00-16:59
Least Active Hour (Workweek)	03:00-03:59	03:00-03:59
Least Active Hour (Weekend)	05:00-05:59	05:00-05:59
Most Active Month	August	September
Most Active Season	Fall	Fall
Least Active Month	January	February
Least Active Season	Winter	Spring
E-Bike Productivity		
Average Idle Time (h)	19.6	24.1
Median Idle Time (h)	18.0	6.8
Average Use per Day (h)	0.7	0.8
Median Use per Day (h)	0.4	0.2
Public Transport Proximity		
Average Starting Distance to PT Stop (m)	147.2	97.9
Median Starting Distance to PT Stop (m)	128.1	82.5
Std. Dev. Starting Distance to PT Stop (m)	338.5	56.7
Average Ending Distance to PT Stop (m)	147.2	98.2
Median Ending Distance to PT Stop (m)	127.4	83.2
Std. Dev. Ending Distance to PT Stop (m)	182.2	56.5

Table 13 Independent Samples t-Test Results for Distance and Duration in Dock-Based and Free-Floating EBSS

	Mean	Std. Dev.	Rentals	T-Value	DF	P-Value
Distance						
Dock-Based	3.72 km	4.64 km	558,456	-24.98	0.021827271	< 0.0001*
Free-Floating	4.94 km	7.55 km	24,372			
Duration						
Dock-Based	14.01 min	58.39 min	558,456	-13.46	40.268181	< 0.0001*
Free-Floating	34.98 min	242.82 min	24,372			

*statistically significant, p < 0.05

4.2.1. Productivity and Idle Times

The data presented in Table 14 offers a detailed comparison between Free-Floating Electric Bike Sharing Systems (FFEBSS) and Dock-Based Electric Bike Sharing Systems (EBSS), focusing on their idle times and productivity. It reveals that, on average, FFEBSS bikes have a shorter idle time of 19.6 hours compared to Dock-Based EBSS, which stands at 24.1 hours. This suggests that FFEBSS bikes are either in use more frequently or are being relocated more promptly than their dock-based counterparts, likely due to the flexibility they offer in parking. However, examining the median idle times provides a nuanced view. While the average idle time is lower for FFEBSS, the median idle time for FFEBSS (18.0 hours) is notably higher than that of Dock-Based EBSS (6.8 hours). This discrepancy indicates that while FFEBSS may have shorter idle periods on average, there are still instances of prolonged idle times, possibly indicating challenges in redistribution or maintenance.

In terms of productivity, both systems exhibit relatively low average and median usage per day, with FFEBSS slightly lower than Dock-Based EBSS. This suggests that the bikes in both systems may not be utilized to their full potential, prompting further inquiry into factors such as accessibility, convenience, or pricing structures. Furthermore, the data highlights potential differences in usage patterns between the two systems. Despite FFEBSS bikes having shorter average idle times, their usage per day is slightly lower compared to the dock-based EBSS.

Table 14 Idle Times and Productivity of Bikes FFEBSS and Dock-Based EBSS

	Free-Floating	Dock-Based
Average Idle Time (h)	19.6	24.1
Median Idle Time (h)	18.0	6.8
Average Use per Day (h)	0.7	0.8
Median Use per Day (h)	0.4	0.2

4.2.2. Quantitative Distribution of Rentals

As the analysis of the EBSS data showed, the activity status of users and the distribution of rentals per user vary substantially. While the 10% most active users in the datasets accounted for 59 to 68 percent of all valid e-bike rentals, the top 20% most active users accounted for more than three-quarters of all rentals, i.e. 76 to 82 percent (see Table 15). The distribution of rental shares in both EBSS datasets is highly uneven. The patterns are in line with findings from other studies.

Table 15 Distribution of Rentals in Top 10% and 20% of Users

	Free-Floating	Dock-Based
Top 10% of Users	59%	68%
Top 20% of Users	76%	82%

4.2.3. Spatiotemporal Distribution

As can be seen in Figure 11 and Figure 12, both the spatial distribution of the free-floating as well as dock-based e-bike rentals has changed over time, i.e. the operational territory has expanded, while the center area of Basel naturally remained the most frequented area.

Figure 11 Development of Spatial Distribution of Free-Floating E-Bike Rentals 2018 - 2023

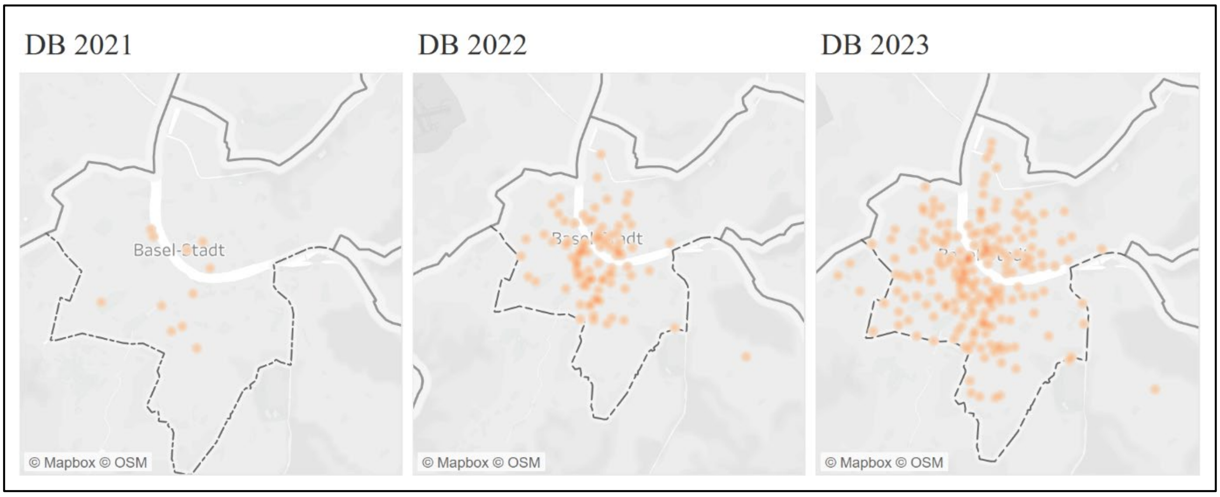

Figure 12 Development of Spatial Distribution of Dock-Based E-Bike Rentals 2021 - 2023

4.2.3.1. Spatial Relationships

As can be seen in Table 16 and Table 17, the free-floating EBSS data reveals a strong preference for rentals within urban centers, particularly big centers (in this case: Basel city) which account for 39.4% of total rentals. Substantial activity is also observed between big centers and their secondary counterparts, indicating the need for intra-urban connectivity. While rentals within crown big centers contribute notably, usage between these areas and peri-urban rural communes is minimal. This suggests potential challenges in extending e-bike sharing services to rural areas. Furthermore, it can be seen in Figure 14 that in the morning peak hours (6:00-8:59) the free-floating rental starting points are quite scattered across the serviced territory while the ending points of the rentals show a concentration in the inner city area of Basel, which may indicate commuting into Basel. Conversely, during the evening peak hours (16:00-18:59) there can be seen that more rentals end in the agglomeration of Basel than start there, which may indicate homebound commuting of residents of Basel's surroundings. A comparison to the dock-based EBSS proves to be difficult in this context dock-based EBSS' stations and therefore its service area only cover two spatial types, namely big centers and secondary centers of big centers. The distribution of rentals starting and ending in each type is approximately 99% of trips starting/ending in big centers and 1% starting/ending in secondary centers of big centers.

Furthermore, the analysis of the e-bike trips taken by users in relation to the average distance to public transportation stops shows that approximately 77% of free-floating e-bike rentals start and end within 200 meters distance from a public transport stop. Concerning the dock-based EBSS, it showed that even 96% of rentals start and end within 200 meters distance from a public transport stop. The usually closest PT stop shows to be Bus/Tram stops. This is visualized in Figure 15. Interestingly, approximately 10% and 9.5% of dock-based e-bike rentals start and end near Basel SBB train station, respectively. Regarding the free-floating system, only approximately 2% and 1.9% of all e-bike rentals start and end at Basel SBB, respectively.

Table 16 Distribution of FFEBSS Rentals by Spatial Type of Starting Point

Spatial Type (Start)	Share of Billable Duration (%)	Share of Traveled Distance (%)	Share of Total Net Revenue (%)
Peri-Urban Rural Communes	0.02	0.02	0.01
Secondary Centers of Big Centers	21.67	21.85	21.15
Crown Big Centers	26.78	28.94	23.38
Big Centers	51.53	49.20	55.46

Table 17 Spatial Type Relationships of Free-Floating EBSS Trips

Origin Spatial Type	Destination Spatial Type	Rental Count	Share
Big Centers	Big Centers	452208	39.4%
Crown Big Centers	Crown Big Centers	171755	15.0%
Secondary Centers of Big Centers	Secondary Centers of Big Centers	109847	9.6%
Big Centers	Secondary Centers of Big Centers	97125	8.5%
Secondary Centers of Big Centers	Big Centers	94763	8.3%
Crown Big Centers	Big Centers	76081	6.6%
Big Centers	Crown Big Centers	73424	6.4%
Secondary Centers of Big Centers	Crown Big Centers	36614	3.2%
Crown Big Centers	Secondary Centers of Big Centers	36486	3.2%
Crown Big Centers	Peri-Urban Rural Communes	76	0.0%

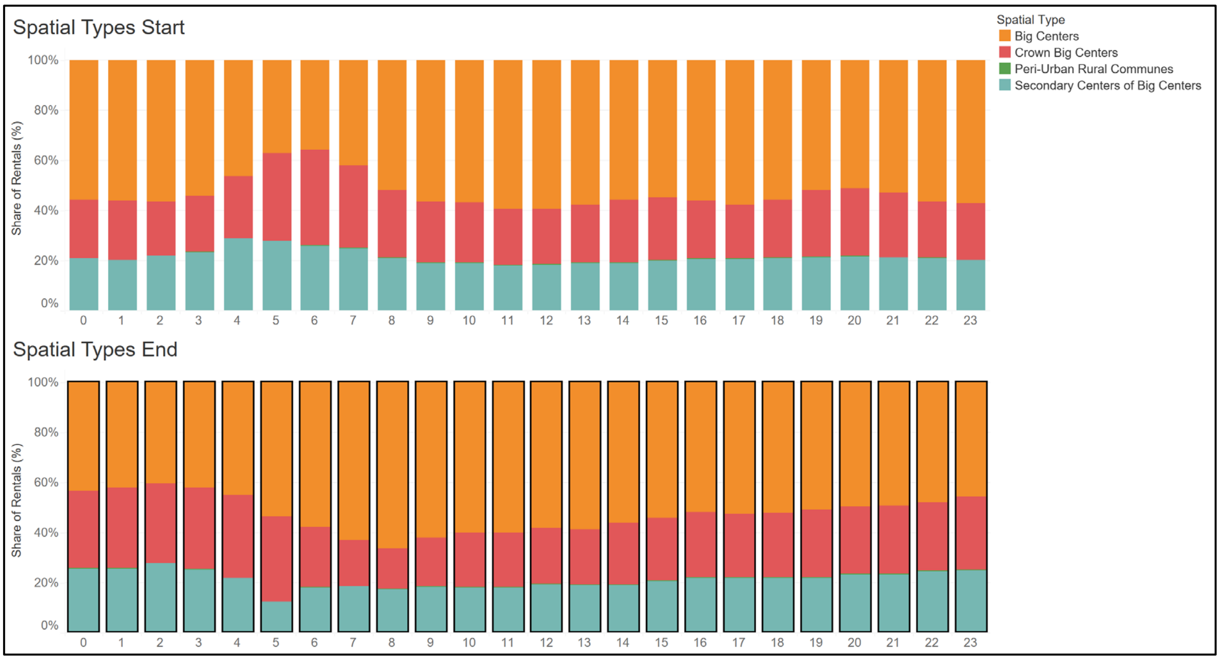

Figure 13 Spatial Type Relationships FFEBSS Throughout the Hours of the Day

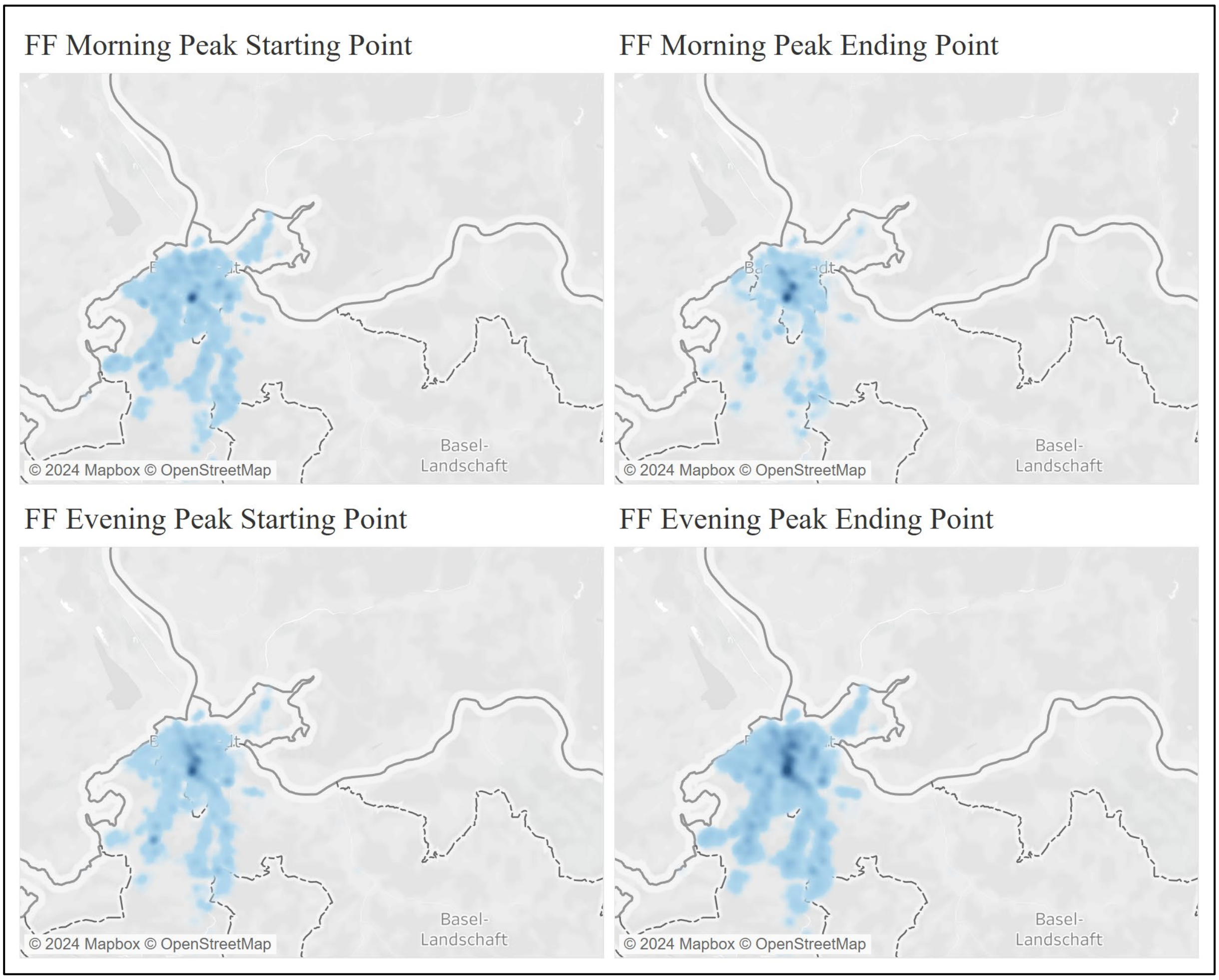

Figure 14 Spatial Distribution of Free-Floating E-Bike Rental Starting and Ending Points During Morning and Evening Peaks

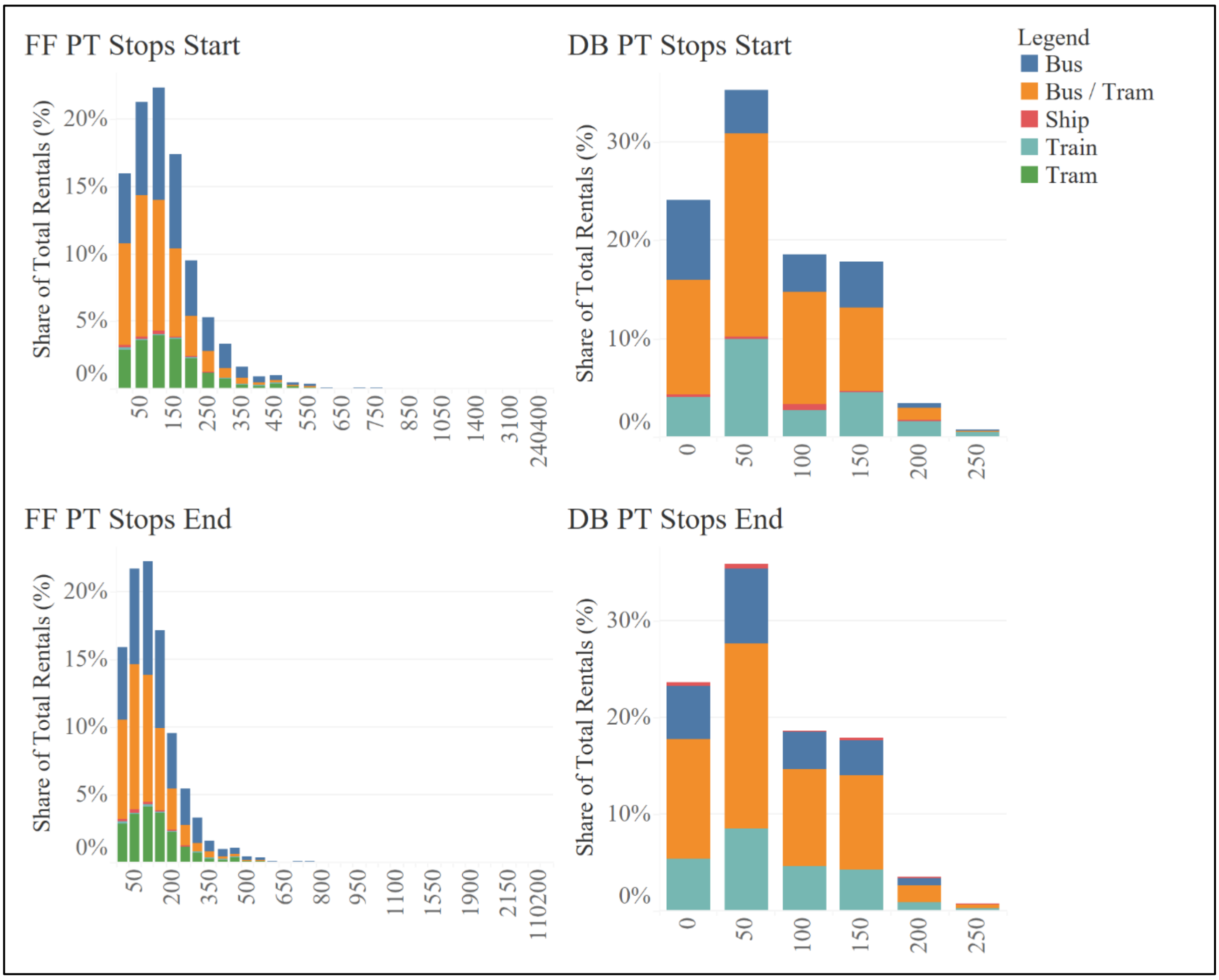

Figure 15 Rentals in Relation to Distance to Closest Public Transport Stop, Start and End of Rentals, X-Axis = Distance in Meters (50 Meter Bins)

4.2.3.2. Time and Seasonality

The research sheds light on the differing usage patterns of free-floating and dock-based e-bike sharing systems (EBSS) throughout various times and seasons, as documented in Figure 16, Figure 17, Figure 18, Figure 19, and Figure 20.

Daily and Weekly Patterns

The free-floating system experiences a steady increase in usage from the early morning hours on weekdays, reaching its peak during the late afternoon and early evening, which likely corresponds with the commuting patterns of work-related travel. This peak usually accounts for about 10-11% of the total rentals. In contrast, weekends see a shift in this pattern, with the peak occurring later in the morning and maintaining a steady rate throughout the day, suggesting a more leisure-oriented use of e-bikes, typically comprising around 6-7% of rentals.

The dock-based system follows a similar pattern on weekdays, with a notable increase from morning to early afternoon, peaking slightly earlier than the free-floating system, which could reflect its structured setup favoring regular commuters. This system also exhibits a weekend usage pattern akin to that of the free-floating system, maintaining steady usage from late morning onward.

Seasonal Trends

Both systems show a significant increase in rentals during the warmer months, with the highest activity recorded in August and September, where rental percentages climb to about 11.46% and 13.06% for the dock-based system, and 12.30% and 12.43% for the free-floating system. The colder months, such as January and February, see a sharp decline in usage, with rentals dropping to approximately 2.72% and 2.40% for the dock-based system and 6.34% and 5.03% for the free-floating system. The warmer seasons of spring and summer emerge as the peak rental periods, reflecting a heightened preference for outdoor activities and leisure travel under favorable weather conditions. Despite a slight drop in temperatures, fall still maintains relatively high rental activity. Winter, while the least active season, still retains a considerable portion of the market, indicating a dedicated segment of users who continue to utilize e-bikes throughout the year.

These observations underline the dual role of EBSS, i.e., catering primarily to commuters during weekdays, while also providing flexible options for recreational use during weekends. Seasonal fluctuations further highlight how weather and environmental factors significantly shape e-bike rental behavior.

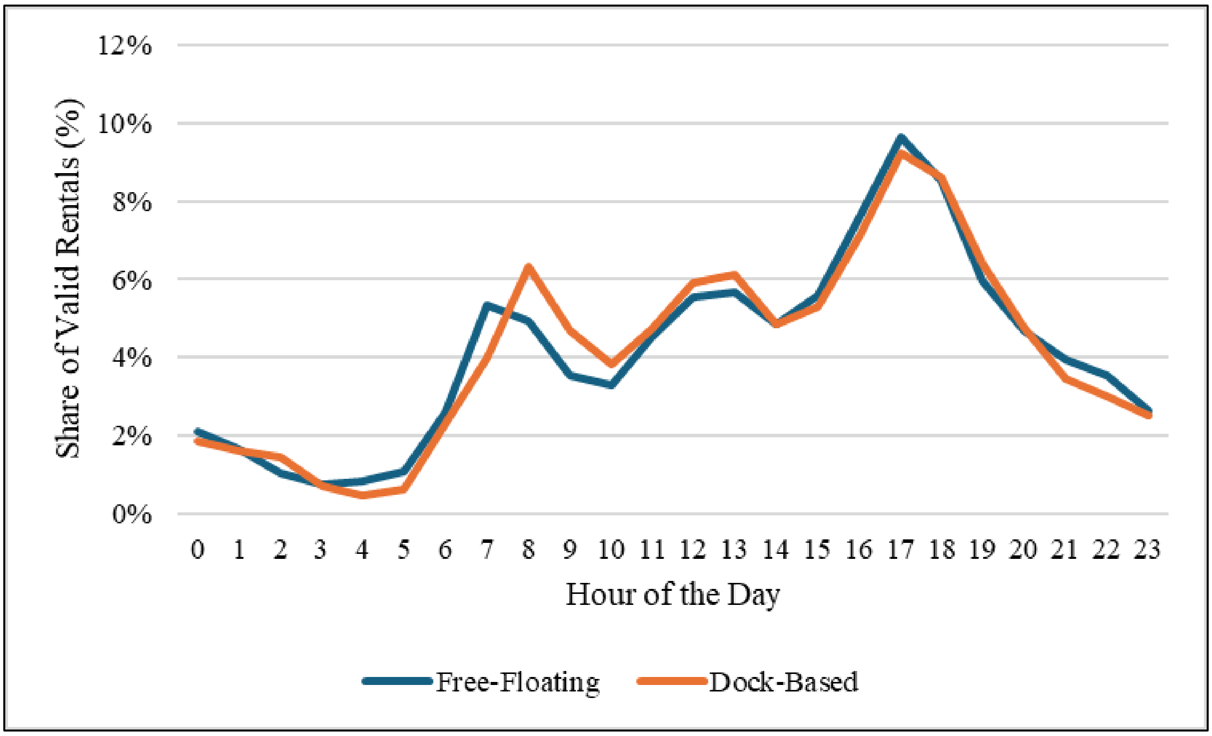

Figure 16 Rental Distribution Throughout the Day

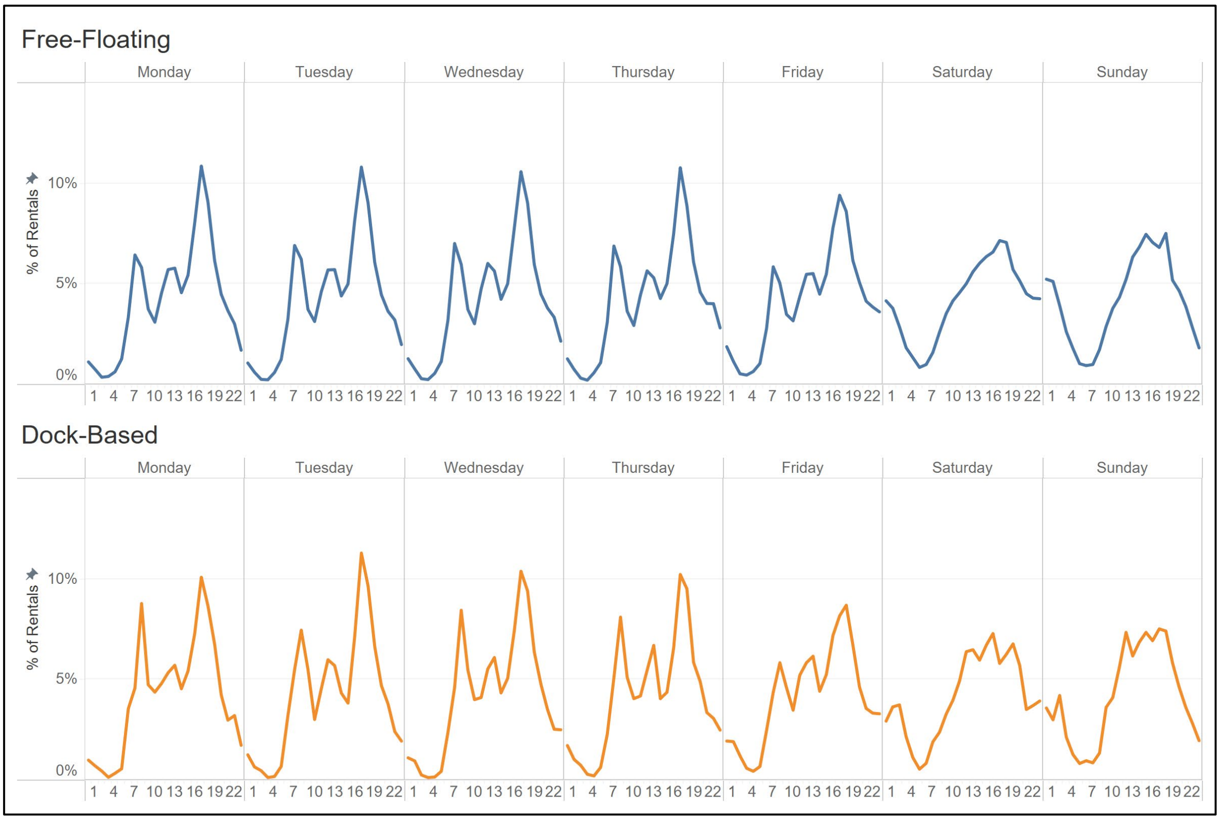

Figure 17 Rental Distributions Throughout the Days of the Week

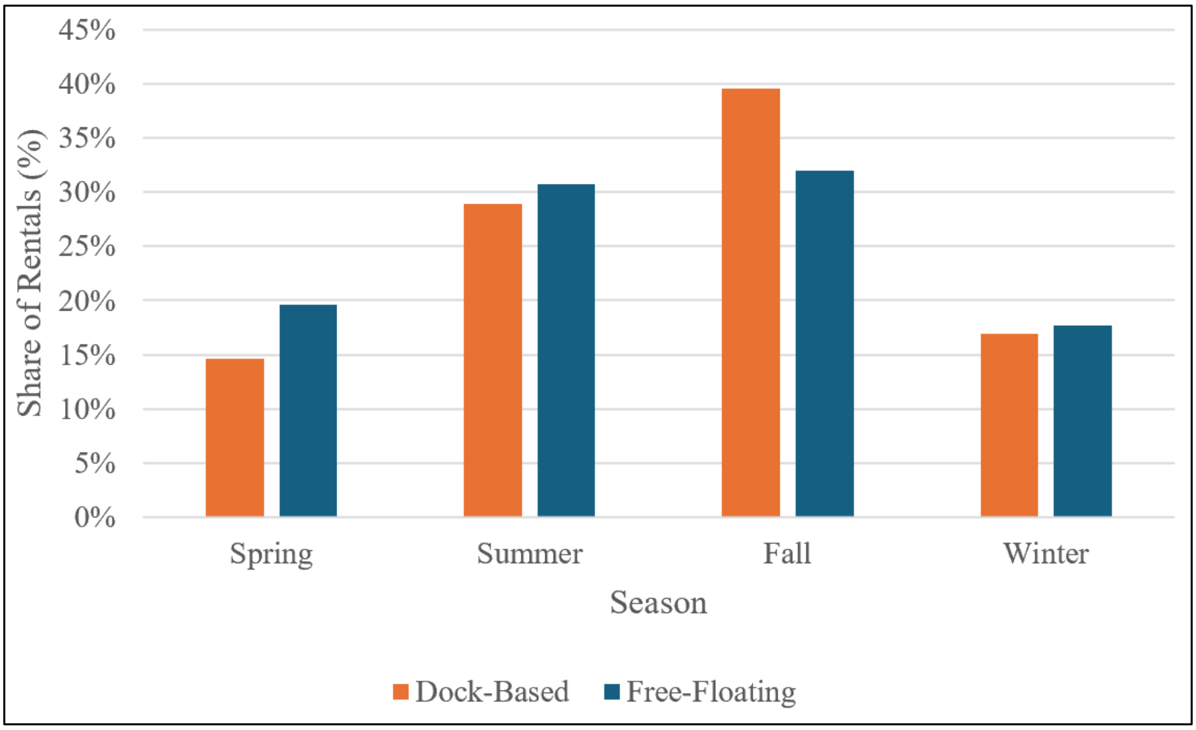

Figure 18 Distribution of Rentals by Season

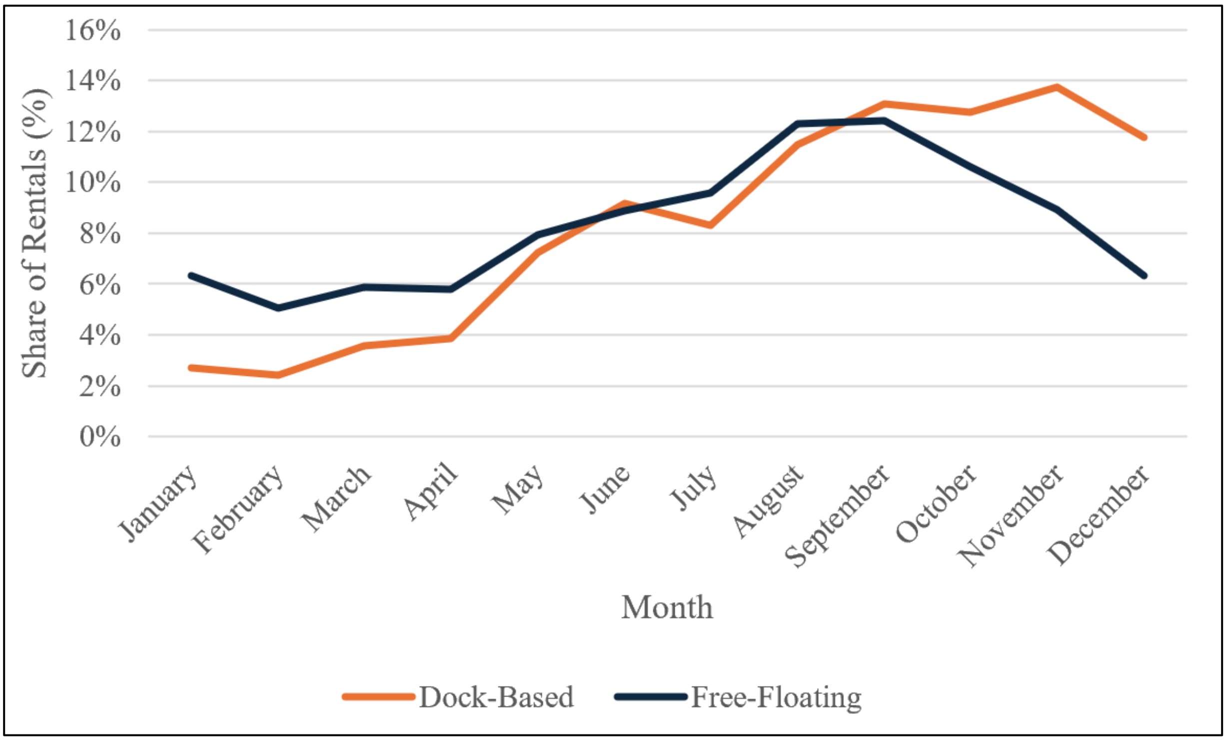

Figure 19 Distribution of Rentals by Month

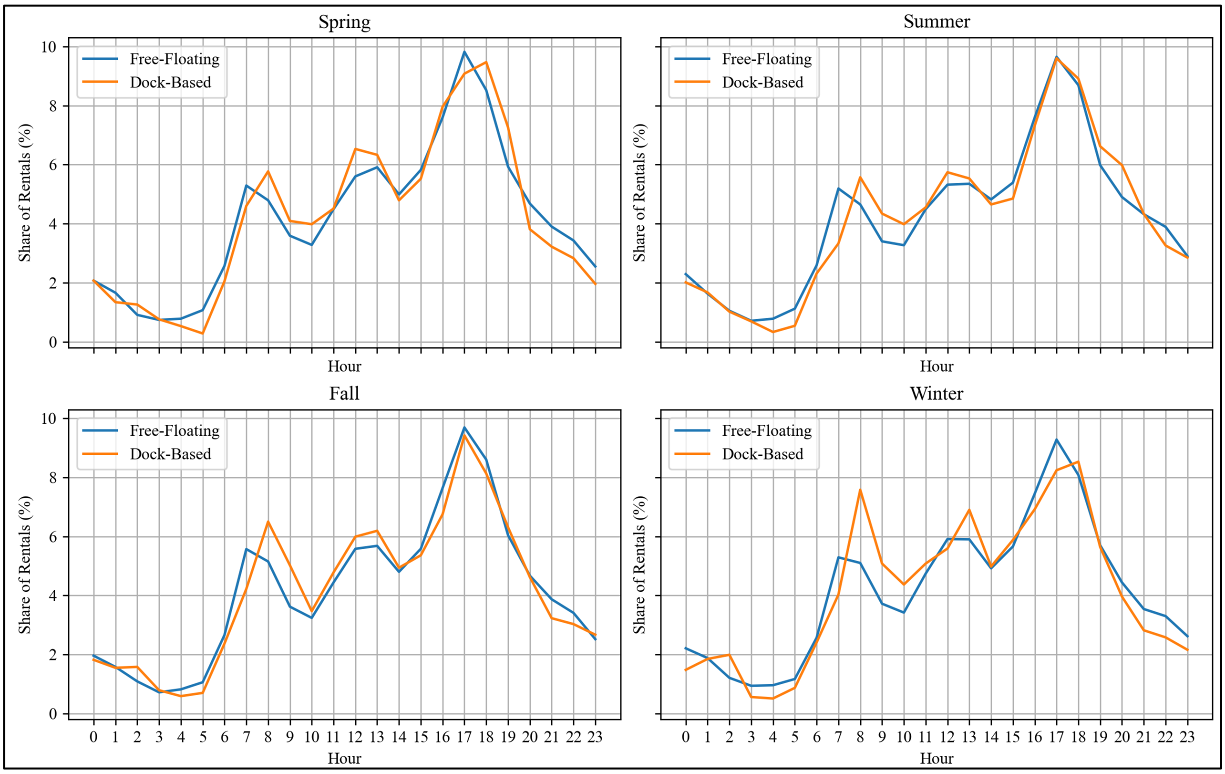

Figure 20 Usage Peaks by Season

4.2.4. Weather Impacts

The influence of weather on various forms of mobility, including mode and destination choice have been discussed in various publications. Noland (2021), for instance, bad[7] weather has less of an impact on e-scooter usage than on e-bicycle and docked bikeshare usage (except for duration of trips). The scholars de Kruijf et al. (2021) came to the result in their study that the effect of air temperature on cycling is non-linear so that weather at low air temperatures and also at high air temperatures has a negative impact on cycling. Li et al. (2019) found in their study that e-bike sharing usage is drastically reduced in number in rainy weather. In their analysis, Raposo and Silva (2022) also found a significant correlation between precipitation and usage: the higher the precipitation, the lower the number of trips. The following subsections will analyze both temperature and precipitation in relation to rental numbers.

4.2.4.1. Temperature

Based on the provided temperature data, which was binned in whole degrees Celsius and ensured to cover only full years, it is evident that both the free-floating and dock-based e-bike rental systems in Basel exhibit some level of sensitivity to temperature variations. For the free-floating system, there seems to be a relatively consistent pattern: as temperatures rise from negative values to around 20°C, the percentage of e-bike rentals increases steadily, peaking at 4.15% at 20°C, then gradually declining as temperatures continue to rise. This trend suggests that moderate temperatures around the 20°C mark are conducive to higher e-bike usage. However, it is notable that extreme temperatures (both hot and cold) seem to deter rentals, as evidenced by the lower percentages at both ends of the temperature spectrum. In contrast, the dock-based system displays a somewhat different pattern. While there is still an increase in e-bike rentals as temperatures rise, the peak usage occurs at a higher temperature, around 7°C, with a percentage of 11.73%. Additionally, the decline in usage as temperatures increase beyond this point is more gradual compared to the free-floating system. This indicates that the dock-based system may be less sensitive to temperature variations within the observed range. Both systems exhibit a positive correlation between temperature and e-bike rentals up to a certain point, suggesting that milder temperatures are generally favorable for increased usage. However, the specific temperature range at which peak usage occurs, as well as the magnitude of the effect, differs between the free-floating and dock-based systems, likely due to differences in user behavior, system accessibility, and other contextual factors. Further analysis would be required.

4.2.4.2. Precipitation

The analysis of precipitation and its impact on e-bike rentals reveals interesting patterns of user behavior under different weather conditions for both the free-floating and dock-based systems in Basel which can be seen in Figure 21.

In the case of the free-floating system, the majority of rentals (84.61%) occur during periods of no precipitation, indicating that dry weather is highly conducive to e-bike usage. As

[7] Bad is very subjective and most publications addressing climate and weather in the EBSS/micromobility context do unfortunately not elaborate or define concrete conditions for weather to classify as “good”, “bad” or “adverse”

precipitation levels increase, there is a gradual decline in rental percentages, with the lowest rentals observed during heavier rainfall events. This suggests that users are less inclined to rent e-bikes during wet conditions, likely due to concerns about safety, comfort, and convenience.

Similarly, for the dock-based system, the data shows a clear preference for dry weather, with 74.02% of rentals occurring during periods of no precipitation. However, interestingly, there is a notable increase in rentals during light precipitation events (0.1-0.3 mm), reaching a peak at 0.2 mm (10%). This could imply that users of the dock-based system may be more tolerant of light rain or drizzle compared to those using the free-floating system. However, as precipitation intensity increases beyond this point, rental percentages decline sharply, indicating a reluctance to use e-bikes in heavier rain.

These findings indicate the importance of weather conditions in influencing e-bike rental patterns. While dry weather is universally preferred, there are nuanced differences between systems and user behaviors regarding tolerance for light precipitation. Understanding these dynamics could inform operational strategies, such as adjusting pricing or implementing incentives during inclement weather to encourage e-bike usage and promote sustainable transportation options.

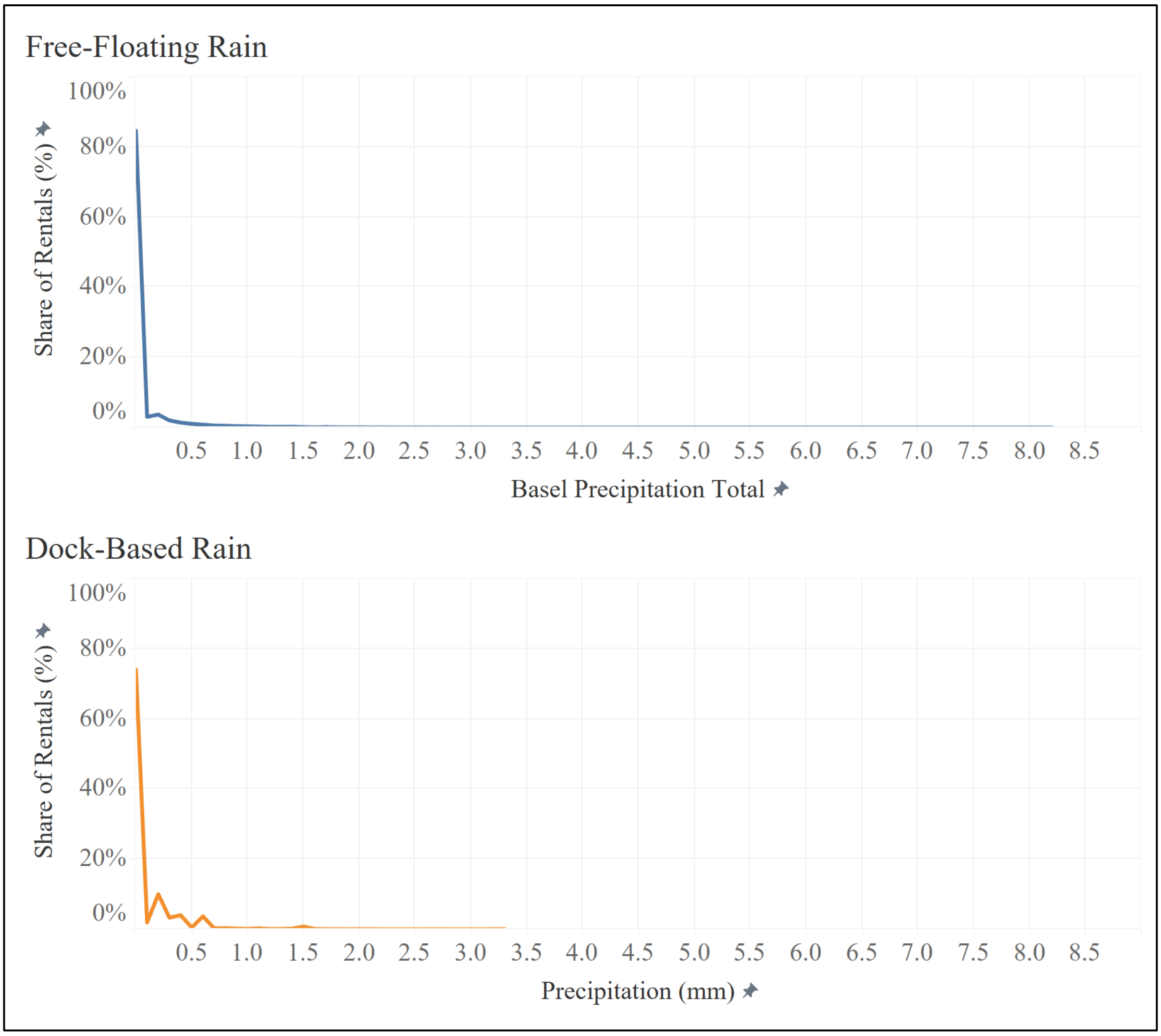

Figure 21 Rental Numbers in Relation to Precipitation

5. Discussion

The comparative analysis of user characteristics and use patterns in free-floating and station-based electric bike sharing systems (EBSS) in the Basel metropolitan area provides interesting insights into the adoption and operational dynamics of shared micro-mobility systems.

The demographic profiles and behavioral patterns of users demonstrate some but no substantially distinct differences between the two systems, which influence their respective usage patterns. For instance, the free-floating EBSS attracted a slightly older user base with a higher proportion of male users, whereas the station-based system showed a more balanced gender distribution and a younger average user age. These demographic variations are consistent with broader trends observed in similar studies, such as those by Reck and Axhausen (2021) and Bieliński and Ważna (2020), which reported that e-bike sharing systems generally appeal to younger urban populations.

Geographically, both analyzed systems are primarily utilized by Swiss residents. However, the free-floating system has a slightly higher national adoption (95%) compared to the station-based system (90.2%). Also, the share of users from the Basel area proved to be substantially higher in the free-floating system. This suggests that the free-floating system is more popular among local residents, while the station-based system attracts a broader user base, including a small but notable percentage of international users.

The spatiotemporal distribution of e-bike usage aligns with findings from international studies, indicating that urban centers exhibit higher usage due to the density of attractions and employment centers. This supports the theory that e-bike systems, particularly free-floating models, effectively support intra-urban connectivity, potentially bridging the first/last mile gaps in public transport networks, which is a potential noted in research like Guidon et al. (2019).

Our analysis of system productivity and idle times reveals that station-based systems, with their structured nature, tend to have shorter idle times and higher usage efficiency compared to free-floating systems. This observation aligns with findings from Bieliński et al. (2021), who noted the operational challenges associated with free-floating systems, including the need for frequent repositioning and higher maintenance demands. By contrast, our data suggest that dock-based systems could offer more sustainable operational efficiencies, which is critical for the environmental benefits of EBSS as discussed by McQueen et al. (2020), who highlighted the potential of EBSS to reduce urban carbon footprints.

6. Concluding Remarks

In examining the user base and behavior patterns of dock-based and free-floating electric bike sharing systems (EBSS) in Basel, our research has revealed insights into their adoption dynamics, identifying both commonalities and distinctive characteristics.

Both types of systems predominantly attract users within urban centers, consistent with global trends favoring micromobility solutions in densely populated areas. This preference is largely due to the convenience of proximity to amenities and workplaces. Additionally, user engagement across both systems is notably influenced by weather conditions, with increased usage during favorable weather and a decline in adverse conditions. The primary users tend to be younger, particularly those aged 20-39 years, suggesting a higher receptiveness among this demographic to integrate shared micromobility into their daily commutes.

Distinctively, the free-floating system appeals to an older user base due to its flexibility and convenience, which allows for spontaneous route selection and varied trip endpoints. In contrast, the dock-based system, with its fixed stations, tends to attract younger users who plan their routes around these set points. There is also a variation in gender distribution. The free-floating system has a higher proportion of male users, whereas the dock-based system shows a more balanced gender distribution. Moreover, the free-floating system has a larger proportion of dormant or silent users, while the dock-based system displays a higher percentage of active users, likely due to its reliability for regular commuting.

Operational flexibility in the free-floating system allows for a broad spatial distribution of bike pickups and drop-offs throughout the city. Conversely, usage of the dock-based system is more geographically concentrated around station locations, reflecting its structured nature typically associated with commuting.

The findings from this study suggest several implications for enhancing urban mobility. Enhancing cycling infrastructure, such as adding more docking stations, improving bike lanes, and ensuring secure storage, is paramount for increasing the appeal and accessibility of EBSS. Furthermore, integrating these systems into broader public transport strategies could help alleviate urban congestion and expand transportation options. Targeted marketing campaigns and community engagement initiatives are also crucial for attracting new users and reactivating dormant ones, emphasizing the practical benefits of EBSS. Additionally, embracing technological advancements like real-time updates or user feedback mechanisms could significantly enhance the user experience and operational efficiency. Lastly, implementing adaptive strategies, such as introducing weather-resistant bikes and seasonal or “bad weather” promotions/dynamic pricing, could help mitigate the impact of weather on usage and ensure consistent engagement throughout the year.

6.1. Limitations

This study is subject to many limitations related to both analytical methods as well as the scope and quality of the received datasets, as well as the early stage of the larger research project at which the analyses currently stand. Several limitations emerge, which also highlight areas where our understanding remains incomplete.

One significant limitation is the geographical focus on the Basel metropolitan area. While this provides specific insights into local usage patterns, these findings may not apply to other regions where cultural, economic, and urban planning contexts vary. Similarly, the data used in the study, primarily concerning registered users and their rental activities, might suffer from biases due to incomplete or inconsistently reported user profiles. Furthermore, the temporal scope of the study, capturing data from specific and only partly overlapping timeframes that also contain two years of Covid-19 influence data, may not reflect seasonal variations or evolving long-term trends in user behavior, which could be influenced by weather, cultural events, or shifts in mobility preferences.

Methodologically, the study faces challenges in comparing free-floating and station-based systems due to their inherent operational differences. For example, the impact of station placement on user behavior in station-based systems does not have a direct counterpart in the free-floating model, complicating direct comparisons. Moreover, the study's reliance on quantitative data means it lacks qualitative insights such as user satisfaction, reasons for choosing a particular system, and users' subjective perceptions of the service. These aspects are crucial for understanding the motivations behind and barriers to EBSS usage.

Several uncertainties and unanswered questions also persist. The study does not fully account for external factors like public policy changes, economic shifts, or technological advancements, all of which could significantly influence EBSS adoption and usage patterns. The specific behavioral dynamics of different demographic groups also remain unclear, for example, whether younger users are more likely to use bikes for leisure rather than commuting. Additionally, it is not well understood whether EBSS primarily serves as a substitute or complement to existing transportation options, an understanding vital for effectively integrating EBSS into urban mobility strategies.

To address these limitations and deepen our understanding of EBSS dynamics, future research should expand to include a broader geographical scope and integrate both qualitative and quantitative methods. Longitudinal studies that track changes in user behavior over time could reveal more about the shifting trends in mobility. Moreover, incorporating external data sources such as traffic patterns, urban development plans, and economic indices would provide a richer, more comprehensive analysis of the factors driving EBSS usage. Such expanded research could help tailor EBSS services more effectively to meet diverse user needs and better integrate them into the urban transport landscape.

6.2. Directions for Further Research

To build on the current study of electric bike sharing systems (EBSS) in the Basel metropolitan area and address its limitations, future research should take a more expansive and detailed approach. This involves conducting longitudinal studies to understand how user behaviors and system performance evolve over time, particularly in response to changes in urban infrastructure and mobility policies. Expanding the geographical scope of research beyond Basel to include diverse urban environments can also help generalize findings and tailor EBSS more effectively to different urban contexts.

Integrating qualitative and other empirical quantitative social science methods, such as interviews and surveys, would enrich the data with personal user experiences and insights into why certain demographics prefer specific EBSS types. These insights could help address barriers to adoption and improve system design and policy.

Exploring whether and how dock-based and free-floating e-bike co-exist or compete with each other would also make a substantial contribution to the current knowledge on EBSS. Strategies for this could include using causal methods, such as difference in differences (DID) in combination with empirical social research to see whether users are changing their preferred system based on factors such as price, speed, vehicle availability, network coverage, et cetera.

Adopting an interdisciplinary approach involving experts from urban planning, environmental science, and public health could provide a holistic view of the impacts of EBSS, from reducing traffic congestion and emissions to improving public health.

Additionally, exploring the impact of technological advancements on EBSS efficiency and user engagement could lead to more adaptive and responsive systems. Lastly, examining the effectiveness of specific policies on EBSS usage (e.g., corporate mobility management, speed limits/no-ride zones, further PT + EBSS fare discounts, etc.) could guide the development of targeted incentives and regulations to promote sustainable urban mobility.

By addressing these areas, future research could offer valuable insights into optimizing EBSS for broader adoption and greater urban sustainability.

Declarations

Ethical Considerations

No human subjects were actively involved in this research. The researchers followed common guidelines on academic rigor and integrity. The analyzed data was used in anonymized form making personal inference impossible. The research is not subject to any major ethical considerations.

Data Availability

Data are not freely available to the public but may be made available upon reasonable request, conditional on the agreement of the data providers.

Conflict of Interest

The authors declare no conflict of interest related to this research.

Funding

This research is part of the research project "POTEBS – Investigating the Potential of E-Bike-Sharing Systems for Sustainable Mobility in Different Spatial Types" funded by the Swiss Federal Office of Energy (SFOE, Research Grant No. SI/502720-01).

References

Arnegger, B. (2021). Die COVID-19-Krise als Katalysator des E-Commerce–Theoretische Einbettung für Akteure der Mikromobilität. *Mobilität nach COVID-19: Grenzen–Möglichkeiten–Chancen*, 111-119.

Azevedo, B. F., Metzger, K., & Pereira, A. I. (2023). A comprehensive data analysis of e-bike mobility and greenhouse gas emissions in a higher education community: IPBike study of case. *SN Applied Sciences*, *5*(11), 291.

Bau- und Verkehrsdepartement des Kantons Basel-Stadt. (2023). *Städtevergleich Mobilität*. Kanton Basel-Stadt. Retrieved April 24 from https://www.mobilitaet.bs.ch/gesamtverkehr/verkehrskennzahlen/staedtevergleich-mobilitaet0.html

Bieliński, T., Kwapisz, A., & Ważna, A. (2021). Electric bike-sharing services mode substitution for driving, public transit, and cycling. *Transportation research part D: transport and environment*, *96*, 102883.

Bieliński, T., & Ważna, A. (2020). Electric scooter sharing and bike sharing user behaviour and characteristics. *Sustainability*, *12*(22), 9640.

Cherry, C., Worley, S., & Jordan, D. (2010). *Electric Bike Sharing--System Requirements and Operational Concepts*.

de Kruijf, J., van der Waerden, P., Feng, T., Böcker, L., van Lierop, D., Ettema, D., & Dijst, M. (2021). Integrated weather effects on e-cycling in daily commuting: A longitudinal evaluation of weather effects on e-cycling in the Netherlands. *Transportation research part A: policy and practice*, *148*, 305-315.

Fistola, R., Gallo, M., & La Rocca, R. A. (2022). Micro-mobility in the "Virucity". The Effectiveness of E-scooter Sharing. *Transportation research procedia*, *60*, 464-471.

FOEN. (2024). *Climate: In brief*. Federal Office for the Environment FOEN,. Retrieved April 15 from https://www.bafu.admin.ch/bafu/en/home/topics/climate/in-brief.html

FSO. (2023a). *Mobilitätsverhalten der Bevölkerung: Ergebnisse des Mikrozensus Mobilität und Verkehr 2021*. Federal Office for Spatial Development. https://www.are.admin.ch/dam/are/en/dokumente/verkehr/dokumente/mikrozensus/mzmv-hauptbericht2021.pdf.download.pdf/Hauptbericht%20MZMV%202021%20DE.pdf

FSO. (2023b). *Switzerland and Basel*. Federal Statistical Office. Retrieved August 3 from https://www.media-stat.admin.ch/maps/profile/profile.html?226.2701.en.geoRefStandard

Fuchs, S., Duran-Rodas, D., Stöckle, M., & Pfertner, M. (2021). Who uses shared microbility? Exploring users' social characteristics beyond sociodemographics. 2021 7th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS),

Fukushige, T., Fitch, D. T., & Handy, S. (2021). Factors influencing dock-less E-bike-share mode substitution: Evidence from Sacramento, California. *Transportation research part D: transport and environment*, *99*, 102990.

Guidon, S., Becker, H., Dediu, H., & Axhausen, K. W. (2019). Electric bicycle-sharing: A new competitor in the urban transportation market? An empirical analysis of transaction data. *Transportation research record*, *2673*(4), 15-26.

Handy, S. L., & Fitch, D. T. (2022). Can an e-bike share system increase awareness and consideration of e-bikes as a commute mode? Results from a natural experiment. *International Journal of Sustainable Transportation*, *16*(1), 34-44.

Hess, A.-K., & Schubert, I. (2019). Functional perceptions, barriers, and demographics concerning e-cargo bike sharing in Switzerland. *Transportation research part D: transport and environment*, *71*, 153-168.

Kontar, W., Ahn, S., & Hicks, A. (2022). Electric bicycles sharing: opportunities and environmental impacts. *Environmental Research: Infrastructure and Sustainability*, *2*(3), 035006.

Li, Y., Dai, Z., Zhu, L., & Liu, X. (2019). Analysis of Spatial and Temporal Characteristics of Citizens' Mobility Based on E-Bike GPS Trajectory Data in Tengzhou City, China. *Sustainability*, *11*(18), 5003.

Martin, R., & Xu, Y. (2022). Is tech-enhanced bikeshare a substitute or complement for public transit? *Transportation research part A: policy and practice*, *155*, 63-78.

McQueen, M., MacArthur, J., & Cherry, C. (2020). The E-Bike Potential: Estimating regional e-bike impacts on greenhouse gas emissions. *Transportation research part D: transport and environment*, *87*, 102482.

Noland, R. B. (2021). Scootin'in the rain: Does weather affect micromobility? *Transportation research part A: policy and practice*, *149*, 114-123.

Oeschger, G., Caulfield, B., & Carroll, P. (2023). Investigating the role of micromobility for first-and last-mile connections to public transport. *Journal of Cycling and Micromobility Research*, *1*, 100001.

Ploeger, J., & Oldenziel, R. (2020). The sociotechnical roots of smart mobility: Bike sharing since 1965. *The Journal of Transport History*, *41*(2), 134-159.

Popovich, N., Gordon, E., Shao, Z., Xing, Y., Wang, Y., & Handy, S. (2014). Experiences of electric bicycle users in the Sacramento, California area. *Travel behaviour and society*, *1*(2), 37-44.

Raposo, M., & Silva, C. (2022). City-level E-bike sharing system impact on final energy consumption and GHG emissions. *Energies*, *15*(18), 6725.

Reck, D., & Axhausen, K. W. (2021). Who uses shared micro-mobility services? Empirical evidence from Zurich, Switzerland. *Transportation research part D: transport and environment*, *94*, 102803.

Rérat, P. (2021). The rise of the e-bike: Towards an extension of the practice of cycling? *Mobilities*, *16*(3), 423-439.

Shimano. (2022). *Perceived motivations to consider buying or hiring an e-bike in Europe in 2022*. https://www.statista.com/statistics/1353437/motivations-electric-bike-use-europe/

SKM. (2023). *Städtevergleich Mobilität: Vergleichende Betrachtung der Städte Basel, Bern, Luzern, St.Gallen, Winterthur und Zürich* (Städtevergleich Mobilität, Issue. https://skm-cvm.ch/cmsfiles/staedtevergleich_2021_231030.pdf

Tschubby. (2024). Lage des Kantons in der Schweiz. In Karte_Lage_Kanton_Basel_Stadt_2024.png (Ed.). wikipedia.

Wang, J., & Lindsey, G. (2019). Neighborhood socio-demographic characteristics and bike share member patterns of use. *Journal of Transport Geography*, *79*, 102475.

Ye, M., Chen, Y., Yang, G., Wang, B., & Hu, Q. (2020). Mixed logit models for travelers' mode shifting considering bike-sharing. *Sustainability*, *12*(5), 2081.

Zhou, K. N. (2022). *Shared electric bicycles: who are the potential users? An examination of survey results from urban and suburban neighbourhoods in the Greater Golden Horseshoe area* Toronto Metropolitan University]. https://doi.org/10.32920/19083410.v1

Zhou, Y., Yu, Y., Wang, Y., He, B., & Yang, L. (2023). Mode substitution and carbon emission impacts of electric bike sharing systems. *Sustainable Cities and Society*, *89*, 104312.

Zhou, Y., Zhang, M., Kou, G., & Li, Y. (2022). Travel preference of bicycle-sharing users: A multi-granularity sequential pattern mining approach. *INTERNATIONAL JOURNAL OF COMPUTERS COMMUNICATIONS & CONTROL*, *17*(1).

Zhu, Z., & Lu, C. (2023). Life cycle assessment of shared electric bicycle on greenhouse gas emissions in China. *Science of The Total Environment*, *860*, 160546.