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Tracing the effects of the Covid-19 pandemic on car usage in Germany - an analysis of the German Mobility Panel

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Being a vast external influence, the COVID-19 pandemic causes major changes in travel behavior on the individual level. This exceptional situation and the political measures such as the lockdown lead to decreased overall travel demand and shifts in mode choice. To understand these effects, the analysis of car usage in private households offers explanatory insights. To this aim, this study provides a differentiation of car usage before and during the COVID -19 pandemic in spring 2020. Furthermore, insights into structural changes of car usage in private households based on German Mobility Panel data are presented. The results show that during the COVID -19 pandemic car usage was affected, and overall mileage decreased. Especially newer cars with large cubic capacity show a large decrease in mileage by 39 % between 2019 and 2020. In addition, we see that the type of car usage (business/private) and the household characteristics are related to different magnitudes of change in car usage. Overall, it becomes evident that examining identical households and cars before and during the pandemic allows for a deeper understanding of the impacts of the COVID -19 pandemic.

Keywords: *Car mileage, car usage, COVID-19, panel data, German Mobility Panel (MOP), longitudinal travel data.*

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1. Introduction

In December 2019, infections with a novel coronavirus (COVID-19) were reported for the first time in Wuhan, China. From there, the virus spread all over the world, so that a pandemic was declared on March 11, 2020 (Jiang et al., 2020; Lipsitch et al., 2020; World Health Organization, 2020). In order to stop the spread of COVID-19, social distancing and thus the conscious renunciation of close contact with people was announced as an effective measure. For this purpose, a lockdown was enforced in Germany and many countries around the world. During the lockdown, public life was restricted to bare essentials. In the lockdown in spring 2020, among others, public institutions, schools, stores and restaurants had to close. In Germany, the lockdown was followed by a period of cautious easing of these measures at the beginning of summer 2020.

Usually, everyday travel behavior is relatively stable on an individual level, as schools, workplaces, places for the provision of daily goods and the activity frequencies are primarily set for prolonged periods of time (Gärling and Axhausen, 2003; Janke et al., 2021). However, it is known from the literature that certain events in the life cycle, such as a move to a new residence, can lead to changes in everyday travel (Schoenduwe et al., 2015; Verplanken et al., 2008). Analyses by De Haas et al. (2018) and Hilgert et al. (2018) show that travel patterns and activity choices can change due to such events. Shamshiripour et al. (2020) describe that a severe pandemic causes many people to rethink their habits and priorities, leading to changes in their former daily routines. Also, studies on changes in travel behavior during past pandemic or epidemic outbreaks showed that people adapt their everyday travel behavior during severe outbreaks. Kim et al. (2017) showed by analyzing the travel behavior during the Middle East Respiratory Syndrome (MERS), that the travel frequency of public transport trips was significantly reduced. Sadique et al. (2007) found in their study about regions affected by the Severe Acute Respiratory Syndrome (SARS) that around 75% of the people would avoid using public transport and 20-30% would try to stay at home as a precautionary action. In this respect, the COVID-19 pandemic can also be seen as a particular circumstance because the restrictions made it necessary for everybody to adapt their everyday travel. The measures implemented during the lockdown have drastic effects on everyday travel, which have been identified and investigated in numerous studies (Aloi et al., 2020; Askitas et al., 2020; Axhausen, 2020; De Haas et al., 2020; De Vos, 2020; Follmer and Schelewsky, 2020; Nobis et al., 2020).

1.1 Impact of the COVID-19 pandemic on travel behavior

Regardless of the COVID-19 pandemic, societies worldwide face the challenge of transforming their transport systems to run more sustainably and environmentally friendly to reach the goals set in the Paris Agreement (United Nations, 2015). An essential component is the shift from motorized transport (cars) to environmentally friendly means of transport (e.g. walking, cycling, public transport). The pandemic now led to far-reaching disruptions and changes in mobility, which should also be seen in the context of transforming mobility. Understanding the changes in everyday travel triggered by the pandemic is particularly important since it creates a time slot to encourage sustainable changes. Gärling and Axhausen (2003) describe that choosing other means of transport is accompanied by higher transaction costs because it means adopting new routines. Verplanken et al. (2008) point out that a context change disrupts individuals' habits, opening a window in which behavior is more likely to be reflected. Janke et al. (2021) describe a relocation to another town as a window of opportunity in which mode use may change. Hence, such incidents allow planners and policy makers to promote sustainable travel behavior. Since many people were put in a situation where they had to adapt their behavior during the pandemic, new routines may develop. The COVID-19 pandemic led to a reduction in the number of trips and a change in mode choice (Axhausen, 2020; De Haas et al., 2020; Follmer and Schelewsky, 2020; Nobis et al., 2020). The study of Shamshiripour et al. (2020) indicates a shift from shared mobility options including public transport to modes with less contact such as walking, cycling and using the private car. A study by De Haas et al. (2020) led to similar results and showed a significant reduction in public transport

trips during the lockdown in spring 2020. At the same time, the study shows that the proportion of walking has almost doubled and thus the radius of action decreased. The same effect is described by Axhausen et al. (2020) , who also show that these radii of action returned to normal due to the easing of measures in summer 2020. This indicates that changes in mobility induced by the pandemic will not necessarily remain in the medium or long term, at least not for all individuals. However, some behavioral changes, such as a higher number of people working from home, are considered to have a high potential to contribute to a more sustainable mobility in the future (Shamshiripour et al., 2020). Presuming that the pandemic is also a window of opportunity, policymakers and planners should focus on the changed mobility during the pandemic and use the results to implement measures promoting sustainable mobility.

1.2 Effects on Car Usage in Germany

The relevance of the car as a flexible means of transport is unquestioned. However, there are different types of car dependence (Behren et al., 2018). In 2019, people in Germany traveled 54% of their daily distances by car (Ecke et al., 2020). The car also plays a major role in long-distance travel: Zumkeller et al. (2005)showed that 74% of all long-distance travel journeys are made by car, whereby the proportion of car use is particularly high for private trips with a maximum of three overnights (81%) and business trips (76%). With regard to long-distance travel, households with high income or owning several cars (Eisenmann and Buehler, 2018; Reichert and Holz-Rau, 2015) or cars from the premium segment (Niklas et al., 2019) are more likely to use the car. Especially households with children are found to be car-affine (Buehler and Kunert, 2008). Therefore it can be expected that households with children also prefer the car for long-distance travel.

By means of official statistics, the decline in travel and especially in car travel can be measured directly and indirectly. The Federal Highway Research Institute in Germany collects data from permanent counting stations on German Highways. This data can be used to directly measure the effects of the COVID-19 pandemic on highways, particularly during the lockdown in spring 2020, and thus provide insights into the extent of which car mobility has declined (BASt, 2020). In the second half of March 2020, the start of the spring lockdown in Germany, the number of cars on German highways dropped by 40-47 % compared to the number of cars in February and early March 2020. Later the decline of counted cars was even higher at 50-57 %. The lowest traffic volume occurred in the second week of April 2020, which was the week of the Easter holidays, with a decline of 58 % of the cars on the highways compared to pre-pandemic situations. Since the Easter holidays, the traffic volume on German highways has been continuously recovering until mid-July 2020, when the number of cars from before the COVID-19 pandemic was reached again. However, it has to be considered that a large proportion of travel on the federal highway network is long-distance travel. Since the population has been explicitly instructed to avoid vacation trips and long-distance trips for leisure purposes, it can be assumed that this has led to a strong decline of travel demand on the federal highway network. It is likely that the decrease in car mobility on roads on which primarily everyday travel takes place, for example, around urban areas, is comparatively smaller.

Another data source which indirectly measures a decrease of car travel is the data on import, export and sales of mineral oil. Comparing the numbers of 2019 and 2020, a drop in sales of gasoline and diesel fuel can be seen in Germany (BAFA, 2020). Especially in April, May, and June, the differences are large. In April 2020, the differences for diesel were 2.53 million tons in comparison to 3.23 million tons in April 2019, which equivalents a decrease of 23 %. The differences for gasoline are even larger. In April 2020, 0.97 million tons of gasoline were sold compared to 1.47 million tons in April 2019 (-34 %). These numbers are all the more interesting, since at the same time the prices for mineral oil have declined strongly. The costs for gasoline dropped from 140,76 €-Cent/liter in February 2020 to 119,71 €-Cent/liter in May 2020. The costs for diesel at the same time dropped from 124,96 €-Cent/liter to 105,75 €-Cent/liter (MWV, 2020). The high level of car usage compared to other means of transport such as public transport, which was observed in Germany in spring 2020 (Follmer and Schelewsky, 2020), may have been favored by the lower fuel prices. As known

from literature, many car drivers make sure that they fill up their cars at low cost (Ritter et al., 2013). A study on car refueling behavior by Kitamura and Sperling (1987) shows that actual refueling behavior only weakly correlates with car users' socioeconomic and even demographic factors and their households. Accordingly, it is not so much the characteristics of the car users but the characteristics of the car itself that explain the refueling behavior. In addition, it was shown that refueling often takes place during commuting and that refueling as an activity itself is not unusual.

Further studies show that drivers are fairly sensitive to changes in fuel prices (Frondel et al., 2012; Frondel and Vance, 2013, 2018). According to these studies, a 10 % increase in fuel prices can reduce mileage by up to 7 %. It is reasonable to assume that under normal conditions this effect works similarly in the opposite direction, so that lower fuel prices lead to higher mileage. However, with the restrictions during the lockdown, this effect is assumed to be dampened.

During the COVID-19 pandemic, the car gained additional importance and usage (Bucsky, 2020). Several studies indicate a shift from public transport to private cars (Abdullah et al., 2020; Eisenmann et al., 2021; Kolarova et al., 2021; Shamshiripour et al., 2020). With the car it is possible to travel and at the same time to maintain social distance (De Vos, 2020), since it is primarily used within a household. Thus, it can be assumed that households use their cars more often than before the pandemic. However, the lockdown in spring 2020 reduced the travel demand in general (Follmer and Schelewsky, 2020). Therefore, it is of interest to gain insights into how car usage has changed and which types of cars were used more or less often in spring 2020. Furthermore, the relevance of different socioeconomic characteristics of car-owning households is of interest.

Our study aims to explore how the COVID-19 pandemic affects car usage and refueling behavior in spring 2020 compared to the situation of spring 2018 and 2019. The analysis is based on the longitudinal data of the German Mobility Panel. Using this source of data, we can identify identical cars (held by the same households) in consecutive years to study changes on an intra-individual and intra-car level, respectively. Furthermore, we develop a more detailed picture of how the COVID-19 pandemic affects car usage. Lastly, a conclusion is drawn and a reference for further research is given.

2. Description of the Data

Our study uses data from the German Mobility Panel (MOP), a national household travel survey, which collects data on travel behavior of the German population since 1994. It is designed as a rotating panel. Participants are asked to participate for three consecutive years. The MOP aims to gain deeper insights through a temporal longitudinal perspective on everyday travel and car mileage and fuel consumption. Therefore, the survey consists of two parts: A survey about everyday travel behavior (yearly in autumn) and a survey about car mileage and fuel consumption (spring the following year). The first part of the survey provides information about all trips during seven consecutive days (one week), i.e., distances, means of transport, trip purposes and departure and arrival times of trips, as well as sociodemographic information on household and individual level.

In addition to the survey on everyday travel behavior, a subsample which consists of households owning at least one car is asked to report the refueling of their cars as well as the respective odometer readings. This part of the survey takes place in spring and covers a survey period of eight weeks (April to June) outside the summer vacations. About 1,600 cars of 1,200 different households contribute to this part of the survey every year. The participants are asked to fill in a mileage diary reporting all refueling events (date, odometer reading, amount of gasoline dispensed, refueling cost). Furthermore, information on car characteristics (e.g. year of construction, cubic capacity) and car usage patterns (e.g. number of users, special events during the survey period) are reported. Analogously, households owning an electric car report when they charge the car.

For our analysis, we rely on three years of data. Two data sets that were collected in spring 2018 and 2019 serve as a pre-COVID-19 reference. A third data set was collected in spring 2020 during the lockdown and the easing period. Table 1 displays information about the sample along with information on cohort composition of every year. All columns equal 100 % or the total number of cars for the respective variable. Furthermore, information on the German car fleet is provided. As the households are asked to report for their cars up to three consecutive years, the respective data is collected between 2018 (cohort of 2018 first report) and 2020 (cohort of 2018 third and last report). For the year 2019, the sample contains 433 cars from cohort 2017, 574 cars from cohort 2018, and 659 cars from cohort 2019. The sample of 2020 consists of 729 cars that were reported for the first time, 531 cars (2nd report, cohort 2019) and 522 cars (3rd report, cohort 2018). 522 out of 692 cars that started in 2018 (first report of cohort 2018) remained after three years. In total, the data of all three years contains information from 5,050 car reports. When interpreting the following results, the large proportion of cars used only for private reasons (84.1 %, 2020) must be considered. Regarding the car characteristics (age of cars, cubic capacity, type of drive), the yearly samples of the MOP are fairly representative to the overall German car fleet (Kraftfahrt Bundesamt (KBA), 2020a, 2020b).

Table 1. Structure of the sample compared to the German car fleet (Kraftfahrt Bundesamt (KBA), 2020a)

Category	Year	German car fleet 2020	2018		2019		2020	
		%	N	%	N	%	N	%
Household			1,174	100.0	1,212	100.0	1,268	100.0
Cohort, households	2016		289	24.6				
	2017		367	31.3	309	25.5		
	2018		518	44.1	423	34.9	379	29.9
	2019				480	39.6	389	31.4
	2020						491	38.7
Car sample,			1,602	100.0	1,666	100.0	1,782	100.0
Cohort, cars	2016		396	24.7				
	2017		514	32.1	433	26.0		
	2018		692	43.2	574	34.5	522	29.3
	2019				659	39.6	531	29.8
	2020						729	40.9
Cubic capacity [cm³]	≤ 1,399	36.7	540	33.9	579	34.9	633	35.8
	1,400 – 1,599	19.6	336	21.1	370	22.3	385	21.8
	1,600 – 1,999	29.4	444	27.9	435	26.2	460	26.0
	≥ 2,000	14.3	273	17.1	274	16.5	289	16.4
	Electric car		9		8		15	
Age of car [years]	0-3	20.3	373	23.3	389	23.4	408	22.9
	4-6	17.4	308	19.2	324	19.5	336	18.9
	7-9	15.8	320	20.0	321	19.3	327	18.4
	≥ 10	46.5	601	37.5	632	37.9	711	39.9
Type of drive	Diesel	31.7	493	30.8	515	30.9	561	31.5
	Gasoline	65.9	1,052	65.7	1,092	65.6	1,145	64.3
	Other	2.4	57	3.6	59	3.5	76	4.3
Usage	Private usage		1,319	83.1	1,361	82.7	1,481	84.1
	Other (e.g.		268	16.9	284	17.3	281	16.0

3. Car usage affected by the COVID-19 pandemic

This section presents insights into the changes in mileage and fuel consumption during the COVID-19 pandemic in spring 2020 in Germany. With the MOP, we can compare car usage during the pandemic with the previous year, which is unaffected by the pandemic. We begin by comparing

the overall samples of 2019 and 2020 in a cross-sectional perspective in section 3.1(Kunert et al., 2012). For initial insight, the data are evaluated without regards to whether a car participated in only one or multiple years. It is followed by an analysis of the individual household and car level between years in section 3.2. For both parts, we mainly focus on changes in mileage. Finally, we analyze the structure of car refueling events and how they changed.

3.1 Dynamics between spring 2019 and 2020 on an aggregate level

The data contains information on the mileage of cars in private households over a two-month period in spring. For the analysis, we normalize the reported mileage to one month and describe it in the following as spring monthly mileage (SMM). The normalization is necessary to ensure better comparability of the mileage data, as survey participants may report over a shortened survey period. This is the case, for example, if participants replace or give up cars during the survey period. However, the reported SMM does not correspond to one-twelfth of the car's annual mileage, as relevant parts of the annual mileage of a car are caused by long-distance travel, e.g., vacation or visits to relatives. Long-distance travel does not usually occur with the same intensity every month but is concentrated in specific periods, such as school holidays. The MOP is designed so that the data is explicitly collected outside the long school holidays (e.g. summer holidays) to better capture everyday travel. Except for 2020, SMM has been stable over the last 10 years with only minor fluctuations (Ecke et al., 2020).

Comparison of mileage between years

In order to understand the dynamics in car usage that resulted from the COVID-19 pandemic, it is of interest how the SMM has changed between 2019 and 2020. Table 2 shows the mean change of SMM between 2019 and 2020 and between 2018 and 2019 as a reference. The results are differentiated by cubic capacity as a proxy for size, and age of car. A Kruskal-Wallis test is performed to further characterize the relationship between these variables and the changes in SMM.

Table 2. Change of spring monthly mileage 2019/2018 compared to 2020/2019

Change of spring monthly mileage 2019 compared to 2018 [km/month (%)]

	Age of car [years]				Total
Cubic capacity [cm³]	0-3	4-6	7-9	≥ 10	
≤ 1,399	0 (0)	-42 (-5)	35 (4)	-12 (-2)	-12 (-1)
1,400 - 1,599	156 (13)	-160(-14)	30 (3)	-119 (-16)	-47 (-5)
1,600 - 1,999	15 (1)	-72 (-6)	72 (5)	-91 (-10)	-38 (-3)
≥ 2,000	-102 (-5)	216 (14)	-104 (-9)	75 (3)	36 (3)
Total	23 (2)	-48 (-4)	42 (4)	-47 (-6)	21 (2)

Change of spring monthly mileage 2020 compared to 2019 [km/month (%)]

	Age of car [years]				Total
Cubic capacity [cm³]	0-3	4-6	7-9	≥ 10	
≤ 1,399	-290 (-28)	-247 (-27)	-188 (-21)	-185 (-25)	-222 (-26)
1,400 - 1,599	-515 (-37)	-159 (-14)	-404 (-36)	-141 (-18)	-259 (-25)
1,600 - 1,999	-365 (-22)	-388 (-30)	-360 (-27)	-213 (-23)	-291 (-24)
≥ 2,000	-746 (-39)	-463 (-30)	-346 (-29)	-429 (-41)	-477 (-37)
Total	-404 (-29)	-292 (-26)	-305 (-27)	-230 (-27)	-287 (-27)

Kruskal-Wallis tests were performed to check for differences in SMM at 95 % confidence level

When analyzing the change in SMM between 2018 and 2019 we see that the SMM fluctuates between years. We see the most substantial relative decrease (16 %) for cars aged 10 years and older and cubic capacity of 1,400-1,599 cm³. Smaller cars do not show a notable in- or decrease between 2018 and 2019. However, in 2019/2020 we see a decrease in SMM for all 16 groups/cells. On average, the SMM is reduced by more than a quarter (27 %) compared to the previous year. The

association between changes in SMM and age of car was found to be significant, whereas cubic capacity is no significant factor. When comparing the change of SMM between 2019/2020 and 2018/2019, strong differences in the mean values become apparent.

To evaluate the significance of the results given in Table 2, we performed a t-test. For comparison, we applied the same t-test for the SMM values of 2018 and 2019. Furthermore, paired t-tests for the subsample of those who reported for the second/third time were performed. The results of the paired t-test are not provided in Table 3 because the the structure of the results (significant/not significant) is the same. We conclude that the paired subsample does not negatively influence the given results. We assume that cars that report more than one year (repeaters) show a smaller variance. Given the size of the standard errors, we interpret the changes between 2018/2019 and 2019/2020 with great caution.

The results in Table 3 show that there are no significant changes in the mean SMM between 2018 and 2019, whereas significant changes can be seen between 2019 and 2020. The deviations between 2019 and 2020 are of such size that they cannot be random. We conclude that the COVID-19 pandemic significantly affects the mileage of cars, regardless of their engine capacity. It should be noted that the SMM has been rather stable for the whole sample between any two years within the last two decades, with a slight trend towards declining SMMs because the fleet is growing.

Table 3. Significance of changes in SMM for 2019/2020 and 2018/2019 at 95 % confidence level

Category	Years	t-Value	Pr>|t|
	2019/2020	4.23	<0.0001
	2018/2019	0.79	0.4295
Cubic capacity [cm³]			
≤ 1,399	2019/2020	7.18	<0.0001
	2018/2019	0.35	0.7278
1,400 - 1,599	2019/2020	5.23	<0.0001
	2018/2019	1.08	0.3849
1,600 - 1,999	2019/2020	5.63	<0.0001
	2018/2019	0.68	0.4962
≥ 2,000	2019/2020	6.4	<0.0001
	2018/2019	-0.42	0.6745

Distribution of reported mileage

To deepen the understanding of car usage during the COVID-19 pandemic, we also consider sociodemographic characteristics and travel patterns of the households. We use the everyday travel data of all household members who own a driver's license and the household characteristics as reported in the previous year (e.g., travel behavior data of autumn 2018 for the refueling data of spring 2019). One drawback of the MOP data sets is that we do not know which car is used by which member of the household. As a consequence, the data only allows for conclusions on the household level. We calculate the share of car trips for leisure-, shopping- and work-related trips for each household. Further, we identify households whose household members travel exclusively by car (monomodal households) and households with household members that use different means of transport (multimodal households). To verify whether the mean values of SMM in 2019 and 2020 are significantly different depending on sociodemographic characteristics and travel patterns of the households, t-tests were performed ($\alpha = 0.05$).

Figure 1 displays statistical measures for the SMM by type of car usage, household type, community size, the intensity of car usage in general and work-related car usage. The smallest group in the analysis is cars from communities with less than 20,000 inhabitants (N=217 in 2019), whereas the largest group (N=1,481 in 2020) includes cars with private usage only. The box plots show the ranges and distribution of the SMM. We cut the upper antennas at 3,000 km/month because we see extreme outliers for all groups in 2019 and 2020.

First, we see that the median (line in the middle of the box) and the mean (black dot) decrease between 2019 and 2020 for all groups. All results are significant at a 95 % confidence level. It is important to consider that cars which are registered as private are used differently than other cars. For example, business cars are often provided for business trips and registered in the name of a company but can also be used for private trips and are more likely to undertake long-distance trips. This becomes clear as the average SMM is higher for cars which are not only used for private purposes. Nevertheless, the SMM decreases for both types of cars between 2019 and 2020. The absolute difference of the mean SMM is higher for cars of other usages: 354 km/month for cars of other usage and 267 km/month for cars of private usage. We assume the primary explanation to be the reduction of long-distance travel since most business travel has been eliminated.

We also see that cars are used differently for commuting and business purposes. For cars where no work-related trips were taken in 2018 and 2019, the average SMM is on a lower level compared to cars with work-related trips. The highest share of cars without work-related trips consists of cars from small households without working people. Only a small share of car-owning households does not use the car for commuting. Furthermore, we see strong decreases in SMM for cars in households where all commuting trips were made by car in 2019. In 2020, many employees were asked to work from home. Consequently, the car was not used for commuting and likely contributed to the strong decline of 369 km in the average SMM.

In addition, we see that cars are also used differently according to the type of household. Generally, the level of SMM is lower for cars of small households compared to cars of larger i.e. family households, in which cars are shared and therefore used by different persons for several purposes. We see strong decreases for small households between 2019 and 2020. For small households without working people (e.g. pensioners) the decrease of SMM is very strong (-28 %). This can be explained by the fact that this group comprises pensioners who were urged to stay at home to minimize exposition. Further, their share of leisure trips (e.g. visits, excursions) is larger compared to employed people, whose car usage and travel are shaped by commuting.

Looking at the dependence of SMM on the community size, we see that cars are used more intensively outside of urban areas. Many alternative mobility options are provided in urban areas so that a car is not explicitly needed. In contrast, cars in rural areas/smaller cities are used more intensively because of long distances between points of interest and limited mobility alternatives. Following our other findings, the mean values of SMM decreased during the COVID-19 pandemic for all community sizes. The relative usage remained unchanged: Cars in cities with less than 20,000 inhabitants show the highest SMM.

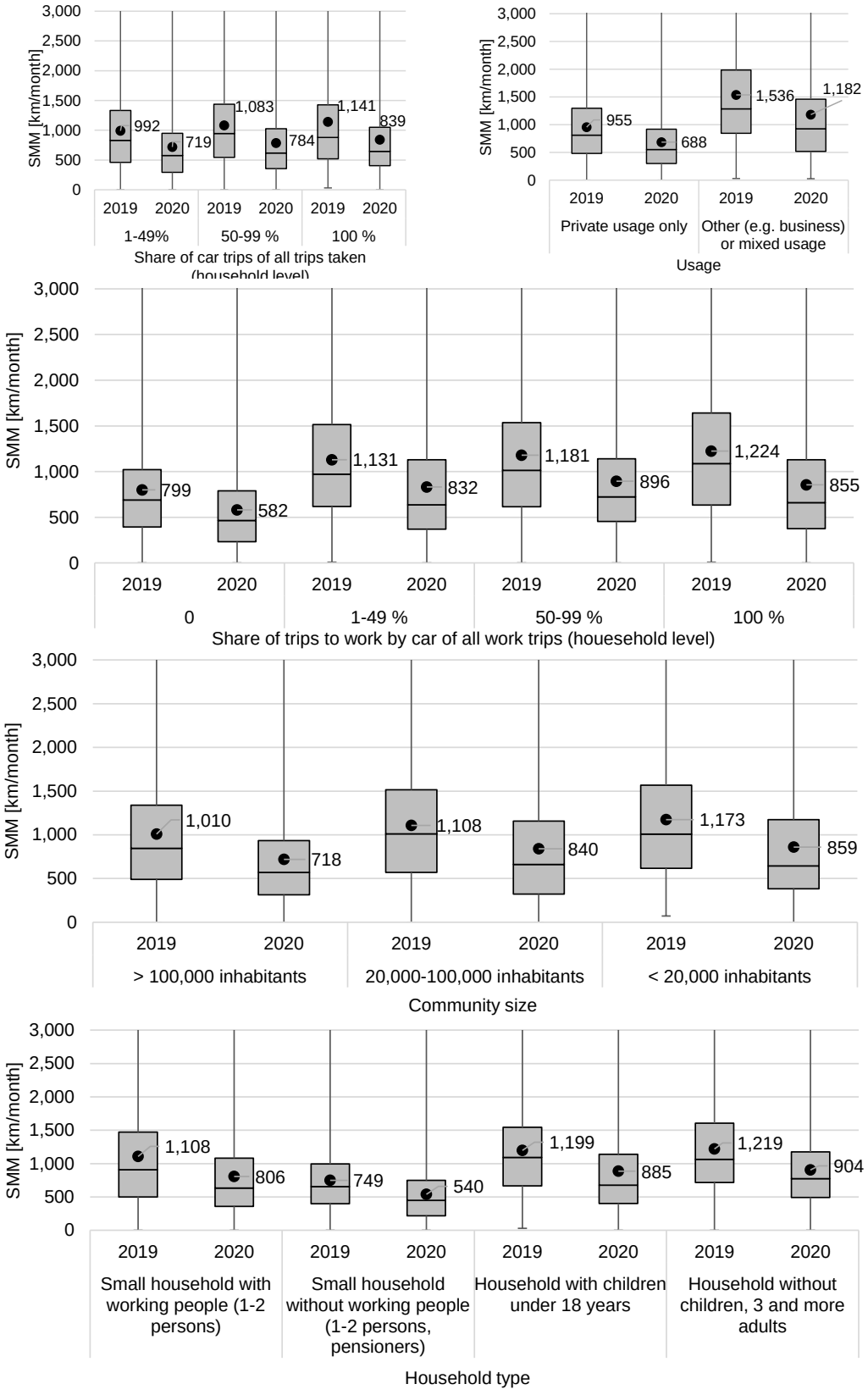

Figure 1. Comparison of SMM in 2020 to 2019 differentiated by sociodemographic characteristics of households and travel patterns of the households; all results are significant at 95 % confidence level.

When comparing the 2019 and 2020 surveys, we can see vast differences in car usage. The magnitude of difference in mileage depends on car characteristics and sociodemographic characteristics of the households. However, the results only provide an overview on an aggregate level from which no conclusions concerning changes in intra-individual car usage can be drawn.

3.2 Changes in Car Usage of Consecutively Participating Cars

Analyzing longitudinal data allows quantifying changes in car usage both for the same households and for the same cars. Due to the study design of the MOP, it is possible to identify identical cars in consecutive years and thus to track them for up to three years.

Based on the collected data, we have no direct information if a car in one year of the survey is the same car in the following year. To overcome this lack of information, we identify consecutive participating cars by a heuristic based on certain car characteristics (e.g. age, cubic capacity, year of procurement). We select consecutively participating cars of 2019 and 2020 (N=735, cohort 2019 and 2018) with this method. In the following sections, we examine changes in car usage patterns. Additionally, we analyze the SMM and differences in refueling behavior.

Shift of Spring Monthly Mileage

First, we investigate the decline of the SMM on the individual car level and whether we see shifts in certain SMM classes. Table 4 displays the changes of SMM for consecutively participating cars from 2019 to 2020. The SMM of the cars is divided into 400-kilometer classes. The table and the results of the McNemar tests show that the distribution within the SMM classes before the COVID-19 pandemic significantly differs from the distribution during the pandemic. Further, the table shows the extent of change between years. Above the diagonal, the proportions of cars are shown for which the SMM has increased (9 %). Below the diagonal, the proportions of cars with reduced SMM are shown (53 %). The reasons for the decrease in car usage include the COVID-19-related restrictions imposed by the Federal and State Governments (e.g. travel restrictions) and an increase in working from home, which has decreased everyday commuting. Furthermore, visits of relatives or friends and recreational trips during public holidays were deliberately reduced to minimize exposure. Under normal conditions, however, such visits and trips contribute to the SMM.

The diagonal cells (gray) show the proportion of cars where no change in SMM is measured. For more than every third car, no change in SMM class is identified between 2019 and 2020. We assume that these cars are used similarly in 2019 and 2020 and the COVID-19 pandemic did not result in a change.

The proportion of cars in the SMM class of over 2,000 km is 12.9 % in 2019, compared to 5.0 % in 2020. This SMM group largely consists of premium segment cars, which are likely to be used as business cars. During the lockdown in spring 2020, business trips, long-distance or weekend commuting were vastly reduced, which would explain the shift towards lower SMM classes.

Table 4. SMM of identical cars in 2019 and 2020 (N=735)

Cars [%]		2020						
Spring monthly mileage [km/month]		**0**	**400**	**800**	**1,200**	**1,600**	**≥ 2,000[1]**	**Total**
2019	**0**	4.0	0.5	0.1	0.0	0.0	0.0	4.6
	400	5.0	15.7	2.5	0.8	0.0	0.3	24.2
	800	2.6	13.2	9.4	1.6	0.4	0.1	27.4
	1,200	1.2	6.0	5.9	3.8	1.6	0.3	18.8
	1,600	0.1	2.6	3.7	3.8	1.2	0.7	12.1
	≥ 2,000[1]	0.4	1.1	2.0	3.6	2.2	3.6	12.9
	Total	13.3	39.1	23.5	13.6	5.4	5.0	100.0

[1]Values added up

p <.001 for all McNemar tests

Increase
Decrease
No change

Moreover, it can be assumed that cars have a specific role in a household (e.g. commuting vehicle, family car) and are used accordingly. In order to make a statement about the changed usage of cars at the household level, we aggregate the SMM of all cars within each household and calculate the difference between 2019 and 2020. For the analysis, we use the data of households who reported for all the household cars in consecutive years. A chi-square test of independence was performed to examine the relationship between household characteristics and the total change of SMM. Table 5 displays the share of households in which the total SMM has decreased, increased or remained the same.

Further analysis shows that small households without working people were significantly more likely to reduce car usage than small households with working people. The decrease of SMM in small households without working people is 79.7 % and 70.3 % for households with working people. A household without working people consists mostly of people being categorized as high-risk patients for COVID-19 due to their age. Avoiding exposure may explain their decreased mobility. Looking at households with children under 18 years and households without children but three and more adults, we also observe large decreases.

We see no major differences for SMM changes depending on the community size. Our analysis also shows no significant relationship between the number of cars in the household and the change in total SMM.

Summing up, all tests are not significant, meaning that the changes in SMM on the household level cannot be brought together with the characteristics of the household. Furthermore, we tested if we can find significant effects for other household characteristics: the share of drivers' licenses (as a proxy for the probability of using the car), the share of working from home, and household income, but no significant effects were found.

Table 5. Differences in SMM change on household-level between 2019 and 2020

Variable	N	Increase %	Stable %	Decrease %	P-value
All households	468	17.7	6.2	76.1	
Type of household					
Small household with working people (1-2 persons)	175	19.4	10.3	70.3	
Small household without working people (1-2 persons, pensioners)	187	16.6	3.7	79.7	9.24 (0.05)
Household with children under 18 years & household without children, 3 and more adults	104	16.3	3.9	79.8	
Community size					
100,000 inhabitants or more	323	17.7	6.5	75.8	0.17 (0.92)
Less than 100,000 inhabitants	145	17.9	5.5	76.6	
Number of cars in the household					
1 car	347	19.5	6.6	73.9	3.95 (0.13)
More than 1 car	121	12.4	5.0	82.6	

$p<0.05$

The analyses indicate that the COVID-19 pandemic has a high impact on individual car travel, because households have changed their car usage between 2019 and 2020. Nonetheless, we also need to know the level of the changes between the years affected by the pandemic and compare these with changes between the years before the pandemic. To this end, we analyze the differences of SMM of consecutively participating cars between the years 2018 to 2020. For this purpose, consecutively participating cars of the cohort of 2018 that took part in the survey in 2018, 2019 and 2020 were identified (N=266).

First, as a result of a t-test, the mean differences in SMM are significantly different between 2018/2019 and 2019/2020. The distribution of changes in SMM between 2018/2019 as well as between 2019/2020 are shown in Figure 2. For the analysis, the SMM of the previous year is subtracted from the SMM of the reference year for each car. The median change of SMM between 2018 and 2019 is -74 km/month, which means that the cars are used to the same extent in both years. This is reflected in the distribution of differences. In 2018/2019, the largest proportion of cars changed their SMM only marginally. The differences in SMM for 2019/2020 are distributed differently: Most cars reduced their SMM in 2020 compared to 2019. The median change of SMM between 2019/2020 is -181 km/month. The resulting distribution is shifted towards negative values (decrease in SMM). Besides the mainly negative shift, we also see an increase in SMM for a small share of cars. A possible explanation for the increase may be the replacement of trips that were previously undertaken by other means of transport, e.g. public transport to minimize contacts and avoid exposure.

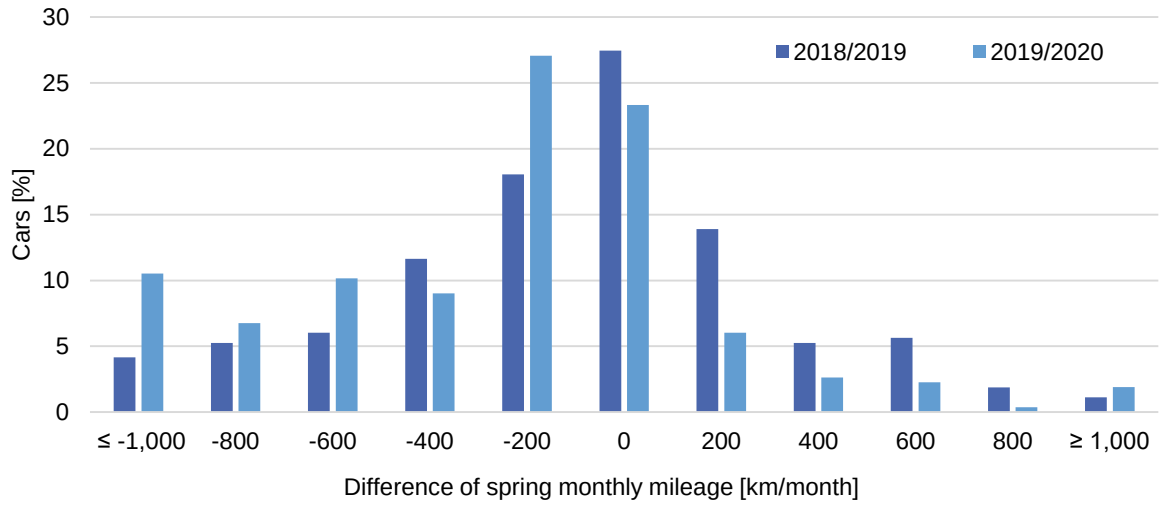

Figure 2. Distribution of the difference of SMM of identical cars between the years 2018/2019 and 2019/2020 (N=266)

In conclusion, we observe major differences between 2019 and 2020 for SMM and also on the individual level of usage. Unlike SMM, the average fuel consumption [l/100 km and car] is unaffected by these changes (Ecke et al., 2020). However, we expect that refueling was influenced by the COVID-19 pandemic, which is subsequently analyzed.

Distribution of Refueling Events

The survey does not only provide mileage information but also data on the refueling events. It can thus be examined whether there are differences in refueling behavior between 2019 and 2020. For further analysis, the calendar weeks (CW) of the reporting periods were identified in which both 2019 and 2020 were surveyed (CW 18-25). Labor Day (1st of May) was in week 18 in both years and the public holidays in spring (Ascension Day, Whitsun and Corpus Christi) were in CW 22-25 in 2019 and in CW 21-24 in 2020.

First, we see a decrease in the total amount of fuel consumed during the survey period of eight weeks from 159 liters/car in 2019 to 110 liters/car in 2020, reflecting the decline in total mileage traveled. Figure 3 shows the refueling events of consecutively participating cars from both years for CW 18-25. For 2019 we see the highest amount of refueling events in CW 23. We assume that this is due to the fact that this week was particularly suitable for vacations (combination of public holidays) and many cars were used for vacation trips. In 2020, cars were refueled less in CW 18 and 19 (April/May) compared to 2019. In 2020, the number of refueling events increased towards

the end of the reporting period. There is no indication of an accumulation of refueling events during the holiday period, as we saw in 2019. This indicates that less activities were undertaken around the public holidays in 2020. The column for 2020 also shows the slow development towards normality as the number of refuelings increase towards the level shown in previous years, without however reaching the normality level.

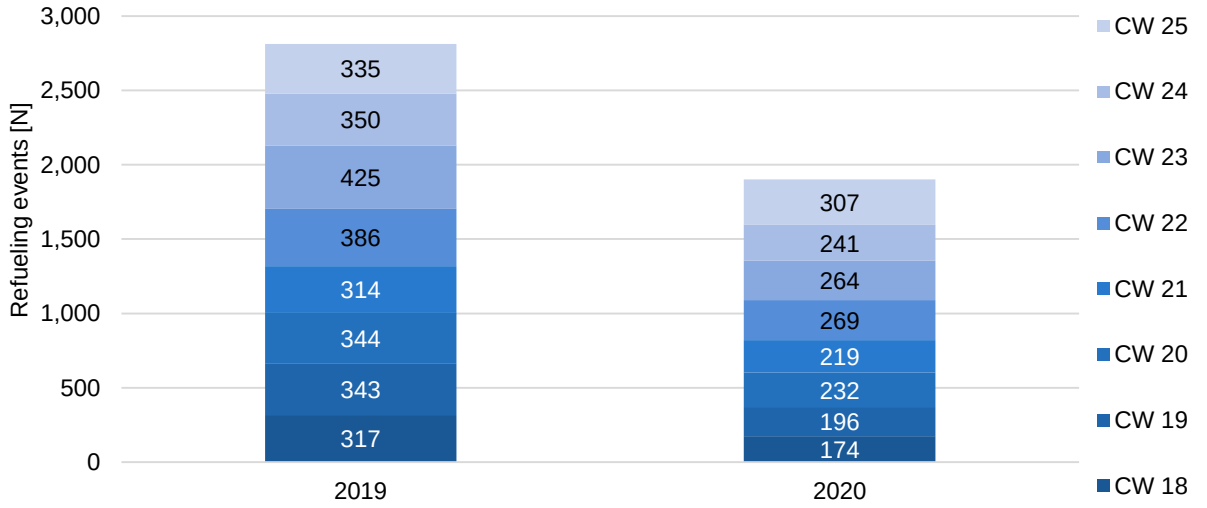

Figure 3. Number of refueling events of consecutive participating cars in 2019 and 2020 according to calendar week (CW) (N=735)

The observation that refueling events around special events such as vacations or leisure activities did not take place in 2020 is underlined by the distribution of refueling events on weekdays in 2019 and 2020 (Figure 4). For 2020, we see that the cars are refueled less on Sundays than in 2019. Because refueling is often combined with other activities, this indicates that (day) trips were omitted, especially on Sundays.

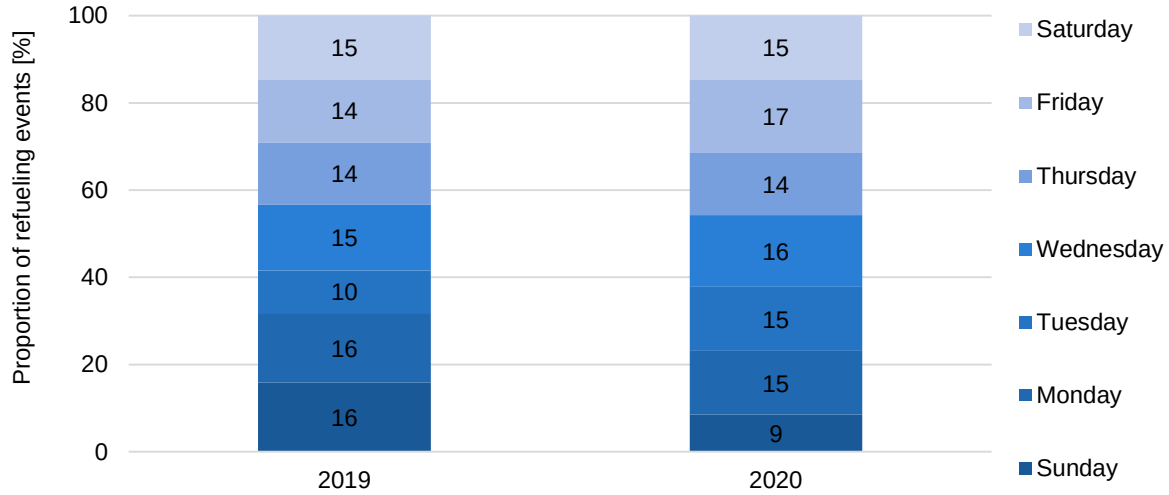

Figure 4. Refueling events of consecutive participating cars in 2019 and 2020 according to weekday (N=735)

4. Discussion and Further Research

It is undisputed that the COVID-19 pandemic has an impact on many areas of social life and habits. The lockdown in spring 2020 had a significant impact on individual travel behavior as the number of trips and the distances traveled have been reduced. In this situation, the car gained additional

importance. Still, the relatively higher share of car usage has not resulted in more kilometers traveled since the overall travel demand declined disproportionally.

The presented study explores the car usage and refueling behavior of cars in German households. The use of the unique dataset from the MOP allows for comparisons between 2020 and previous years. In the first step, we analyze the overall values of the spring monthly mileage (SMM) of the car sample in 2019 and 2020. The results show substantial decreases in car usage in 2020. The outcome indicates that car mobility has been reduced to necessary travel. A reduction in SMM is particularly noticeable for newer cars with large cubic capacity. Cars with such characteristics are predominantly business cars and held in households with high net income. Business cars are usually registered to companies but commonly also allow private usage. Furthermore, this type of car is often used for long-distance travel under normal conditions. We assume that since the start of the pandemic, the car users of business cars started to work mainly from home. However, the decrease in SMM is also noticeable for other types of cars/car users.

The COVID-19 pandemic has led to a strong decrease in business trips. Consequently, car usage was limited to necessary trips. In addition, we see a strong decline of SMM for cars held in small households (1-2 persons), which we explain by the sociodemographic characteristic of the corresponding group, which mainly consists of pensioners who are more likely to stay at home to avoid exposure.

The identification of consecutively participating cars made it possible to study changes on an individual car level. Overall, car usage is generally quite variable: We usually see a variation of increases and decreases, compensating each other in normal years. In contrast to usual behavior, our analyses show that most cars were used less in 2020 than in 2019 and fewer refueling events took place. However, the effects of the decline on distances traveled by car vary greatly at the individual level. In any case, a decline in SMM is evidence of a general reduction in car usage. This does not take into account to which extent individual behavioral patterns have been restricted. We assume that long-distance events in particular have been eliminated due to the travel restrictions for leisure activities and business trips. Nevertheless, a small part of cars was used more intensively during the COVID-19 pandemic in spring 2020. This change indicates that for some trips cars were used instead of other means of transport (e.g., public transport), as found in several studies (Eisenmann et al., 2021; Kolarova et al., 2021; Shamshiripour et al., 2020).

A shortcoming of our study is that the data does not provide information about the individual trips between refueling events such as trip purposes and information about car users. Thus, we do not gain accurate insights into changes in individual travel behavior. Unfortunately, our study cannot narrow down which car trips are actually deemed necessary during the COVID-19 pandemic in spring 2020. We see that for the complete capturing of car usage even eight weeks are not sufficient. Therefore, a modeling approach as described by Eisenmann and Plötz (2019), who model car usage by the distinction of everyday travel (e.g., commuting) as well as long-distance travel events (e.g. holidays) over one year, may be an approach to overcome these restrictions. In the approach by Eisenmann and Plötz the data on car mileage and fuel consumption was linked with travel survey data. Since we lack the data on everyday travel in 2020, we could not implement this approach. However, once the data is available, this can be a fruitful approach to continue our studies.

The COVID-19 pandemic has shown that people are able to reduce car usage and to adapt behavior. Although the exogenous influence of the pandemic cannot be assessed as a political measure, the pandemic has shown that strong measures can be brought about quickly when the occasion arises. The fact that society supported the sometimes strong policy measures during the COVID-19 pandemic shows that there is a possibility to promote the reduction of car usage through strong policy measures in the future. We see the effect of such policy measures mainly in digitalization and substitution of physical by virtual mobility. Therefore, we see potential in strengthening working from home as well as in delivery services and local recreation. The pandemic has also

shown that transport policies need to be designed in a flexible way to react to spontaneous events such as epidemics, pandemics or extreme weather events.

In our view, two questions are of particular importance for further research. One is the investigation of the everyday travel data of individuals which were collected in autumn 2020. Their reported mobility can be linked with the usage of cars during spring 2020 presented in this paper. In this context, it will be interesting to analyse whether the number of car trips made by household members decreases and whether commuting to work is replaced by working from home. Further, it is of interest whether car usage has increased for certain people because the car replaces other means of transport, and in particular trips by public transport. The longitudinal design of the MOP can be used to track people's travel behavior over several years and therefore assess the effects of the COVID-19 pandemic. Another question is to examine the permanence of the effects of the COVID-19 pandemic on travel behavior and car usage. By repeatedly surveying individuals, the MOP allows analyzing how people behave in 2021 compared to previous years.

From our point of view, the COVID-19 pandemic is an event that triggers sustainable changes in travel behavior and car usage of individuals. However, it remains to be seen to which extent these changes turn out to be structural. For the future, this change can be both a curse and a blessing: The curse being the drastic reduction of public transport usage due to the substitution by car trips, making it more challenging to achieve the goals set in the Paris agreement. The blessing is that the COVID-19 pandemic positively influenced parts of everyday travel behavior, for example reducing business trips. This contradictory development makes it difficult to predict the lasting effect on travel behavior.

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