Evolution of urban mobility behaviour in Brussels as a result of the COVID-19 pandemic

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Abstract
The goal of this research is to understand the impact of COVID-19 restriction measures on the change in urban mobility in Brussels, Belgium. With daily data over the past 2 years depicting both the affluence to different places and the level and type of restrictions, we investigate through regression analysis their impacts on the changes in driving, public transport and cycling use. We find that cycling increased significantly (+63%), and that driving levels have returned to pre-COVID levels after a significant reduction in spring 2020, while the return to public transport has been slower. We also find that the change in cycling use was not influenced by COVID-19 restrictions, although telework and closing of retail establishments strongly affected the other modes.

KEYWORDS
behavioural change, COVID-19, disruptions, mobility behaviour analysis, sustainable mobility

JEL CLASSIFICATION
R4, R40

1 | INTRODUCTION

On 11 March 2020, the World Health Organization (WHO) declared coronavirus disease 2019 (COVID-19) a global pandemic. In spring of 2020, most of the world went into (semi-)lockdowns, restricting people's ability to move in time, type, distance and duration. The aim of these lockdowns was to prevent the spread of the coronavirus.
Following this, the past 2 years have been regulated by successive measures, varying in type (closure, containment, economic or health) and stringency (e.g., from full lockdown to partial openings), which have impacted most aspects of human life, changing the traditional organization of school, work, shopping and leisure (Hale et al., 2021).

Gondauri and Batiashvili (2020) showed, for nine different countries, that the number of pedestrians and amount of traffic and transit had an impact on the spread of the virus. Similar findings are reported by Schlosser et al. (2020), who argue that the global mobility restrictions likely slowed down the spread of COVID-19. To limit the spread of COVID-19 through transport, and to increase resilience for future pandemics, Zhang (2020) proposes the nine-step PASS approach to transport policymaking: Prepare, Protect, Provide, Avoid, Adjust, Shift, Share, Substitute and Stop. This framework shows the importance of re-thinking mobility policies when it comes to virus contagion.

The unprecedented lockdowns have shown how fragile cities currently are (Tricarico & De Vidovich, 2021) and have had severe impacts on mobility worldwide (Benita, 2021). Aloï et al. (2020), for example, analyse the effects of the lockdown in spring of 2020 for the City of Santander, Spain, reporting significant overall mobility decreases that were most severe for public transport. Macharis et al. (2021) show this reduction of traffic during and right after the spring 2020 lockdown in Brussels, Belgium. Galeazzi et al. (2021) show similar findings for France, Italy and the UK. In the Slovak Republic, the decrease in mobility was stronger during the first pandemic wave in spring of 2020 than in the second wave later that year (Konecny et al., 2021). In a systematic literature review, Benita (2021) analysed 194 articles in the rapidly growing body of literature of COVID-19 in the transport sector, and found that the main research themes are land transport, traffic demand, air transport and environment.

There is currently no agreement on when the pandemic will end (Zhang, 2020), and the question arises as to what long-term behavioural changes will result from it, and therefore what role COVID-19 can play in the transition towards sustainable urban mobility. Despite the fact that strict lockdowns around the world caused a sharp increase in mobility measures, like the implementation of new bike lanes or the pedestrianization of streets (EIT Urban Mobility, 2020), the rushed implementation has caused some stakeholders to push back (Macharis et al., 2021). Right after the strict lockdowns, a slow return to pre-COVID mobility levels could be seen (Konecny et al., 2021).

At the onset of the pandemic, there was a belief that it would be short-lived, and that there might be a fast return to ‘normal’. After almost 2 years and no clear timing on when the COVID-19 crisis will end, it is becoming clear that it is having a profound impact on urban centres and urban mobility systems, challenging their resilience (Sharifi & Khavarian-Garmsir, 2020). In that sense, the pandemic is a major disruption that can potentially provide an opportunity for transition. Gaining insights into the mobility behavioural changes brought on by the crisis can serve as a learning point to tackle future disruptions and crises. This is especially true considering that the outbreaks of infectious diseases have, throughout the centuries, shaped societies and cultures (Huremović, 2019). As urban mobility is changing quickly in terms of technology, business models and behaviours, an analogy with the COVID-19 disruption can provide a useful framework for policymakers, especially keeping in mind that crises can provide opportunities for transformation, as they require quick and agile actions (Kakderi et al., 2021). However, there seems to be little literature that analyses the longer-term changes in the mobility sector following the varying levels of COVID-19 restrictions. The focus lies mostly on the effects of only the strict lockdowns on mobility patterns, or what the effects of mobility have been on the spread of the coronavirus. In terms of impact on urban mobility, two opposite trends have emerged so far: the first, in line with COVID-19 containment measures, is that there has been an abandonment of public transport in favour of individual motorized mobility (Tirachini & Cats, 2020). The other trend is a decreasing need for commuting due to teleworking, and a rise of sustainable mobility modes such as walking and cycling (Lozzi et al., 2020). Understanding what impacts changes in daily routines have on urban mobility is useful to understand the factors that influence urban mobility most (Vitello et al., 2021). In this paper, we therefore analyse, for the city of Brussels, Belgium, how mobility behaviours have evolved over the past 2 years following the different COVID-19 policy measures. We also reflect on what we can learn from the changes for the future of urban mobility. We focus on Brussels as it is one of the regions hardest hit by COVID-19 in Belgium (Dupondt, 2021).
The following section provides a brief overview of the literature on COVID-19 and mobility, and the role of crises in transitions. Section 3 presents our methodology, and Section 4 our results. This is followed by a discussion in Section 5. Lastly, we provide some concluding remarks and indications for further research.

2 | BRIEF LITERATURE REVIEW

Although the onset of the global COVID-19 pandemic is rather recent, it has already given rise to a rapidly emerging body of literature in the transport sector (Benita, 2021). In the next two sections, we analyse the bi-directional effects of mobility on the spread of the coronavirus, and of COVID-19 governmental restrictions on mobility. The third section examines the role of crises and disruptions in shaping urban mobility.

2.1 | Effects of mobility on the spread of COVID-19

The drastic worldwide lockdown measures enacted in spring of 2020 were aimed at containing and delaying the spread of the novel coronavirus, as human mobility is a major factor in the spread of vector-borne diseases (i.e., human diseases caused by parasites, viruses and bacteria) (Gondauri & Batashvili, 2020; World Health Organization, 2020). The measures included specific mobility restrictions with regard to domestic travel in distance, type, time and duration, but also included restrictions on international travel. It is estimated that, in China, without lockdown measures in Wuhan, COVID-19 cases would have been 105% higher in other Chinese cities outside Hubei Province (Fang et al., 2020). In Italy, an average 42% reduction of trips was observed between 8 March and 4 May 2020, and the mobility habits of the population are directly linked to the number of certified coronavirus cases (Carteni et al., 2020). For France, Italy and Spain, Iacus et al. (2020) showed that mobility can explain up to 92% of the initial spread of COVID-19. Gondauri and Batashvili (2020) showed, through an analysis of Apple Maps data and confirmed COVID-19 cases between 22 January and 14 April 2020, that mobility levels (number of pedestrians, amount of traffic and transit traffic) affected the spread of the virus in nine different countries (United States, Spain, Italy, France, Germany, UK, Belgium, New Zealand and Turkey). From this selected overview of studies conducted throughout the strict lockdown periods, it becomes clear that there is an effect of mobility on the spread of COVID-19.

2.2 | Effects of COVID-19 measures on mobility

The various measures taken to contain the spread of the virus have had a clear effect on mobility, with drastic mobility reductions seen throughout the (semi-)lockdowns, and up to the time of writing. Indeed, Europe, in autumn and winter 2021, is undergoing a fifth wave of the virus, leading to various new measures being implemented across the continent (Henley & Oltermann, 2021). These measures have had an important impact on mobility. In an analysis of US cities in March 2020, Klein et al. (2020) note that commuting volumes are close to those experienced on federal holidays. In Santander, Spain, a strict lockdown led to an average 76% decrease in mobility, with the strongest decrease witnessed in public transport occupancy rates (~93%) (Aloi et al., 2020). In Germany, rural area mobility decreased by a third, while a modal shift was observed towards the use of bicycles (König & Dreßler, 2021). In Brussels, the severe lockdown led to a 55% decrease in road traffic, a 29% decrease in weekday cyclists, and a public transport occupancy rate 87% below pre-COVID levels. Weekend cycling, on the other hand, surged, increasing by 197%. After the lockdown, the strong increase in cycling continued, and road traffic started to return to pre-COVID levels, while public transport occupancy rates increased more slowly (Macharis et al., 2021). Similarly, in July 2020, Apple Maps data showed a 16% increase in travel by car in the United States, and a 14% increase in...
Germany (Kakderi et al., 2021). There has seemingly been a shift towards the use of active modes, with bike sales in the UK increasing 63% in spring of 2020 (Reid, 2020), and an average uptake in cycling of 29% in France (Cosnard, 2020). For 12 European countries, Kahanec et al. (2020) analysed the impact of four COVID-19 restriction measures (prohibition of public events, school closing, closing of non-essential shops and restrictions on internal movement) on mobility between 16 February and 11 April 2020. Their findings suggest that all four types of restrictions are associated with a sharp decline in mobility, but that the cancellation of public events has a smaller impact. The closing of schools has a strong negative impact, as well as the restrictions on internal movement. However, the closing of schools and the closing of non-essential shops are strongly correlated, making it difficult to isolate their effects.

Importantly, these various analyses mostly concentrate on lockdown periods, or the months that followed. At the time of writing, the pandemic is in its fifth wave in Brussels (Thijs, 2021), while often the focus has been put on the effects of the first and second waves. In the short term, there are two opposing trends in the effects of COVID-19 containment measures, where, on the one hand, an increase in individual motorized vehicles is noticed (Tirachini & Cats, 2020) and, on the other, increases in walking, cycling and other micromobility are observed (Lozzi et al., 2020). As the COVID-19 pandemic has been ongoing for almost 2 years, it is important to gain longer-term insight into the changes in mobility behaviour due to the (new or ongoing) measures aimed at stopping the spread of COVID-19. This becomes especially important in discussing the potential role COVID-19 can play in the transition towards a more sustainable urban mobility system.

2.3 The role of crises and disruptions in the transition towards urban mobility

The ongoing COVID-19 pandemic has severely challenged the resilience of cities across the globe. It has changed priorities, put lifestyles into question and raised awareness about alternative ways cities could be designed (Kakderi et al., 2021; Macharis et al., 2021). The long timeframe of the crisis means that human behaviours and routines are starting to change (Kakderi et al., 2021), as can be seen, for example, in the uptake of biking (König & Dreßler, 2021). It has also highlighted the importance of taking public health threats into account in transport policymaking (Zhang, 2020). However, it can be assumed that COVID-19 is not the last disruption that urban mobility will face. The advent of autonomous vehicles, the emergence of drones or the sharing economy can be named, and these disruptions can be seen as a unique opportunity to influence future outcomes (Kane & Whitehead, 2017). The COVID-19 crisis is a wild-card event, that is, a low-probability but high-impact occurrence that is often overlooked in decision-making (Mendonça et al., 2004). It offers an opportunity for transition towards sustainability, but it is important to learn from it in terms of policymaking, to anticipate future challenges and disruptions. Transitions, as defined by Rotman et al. (2012, p. 16) are ‘transformation processes in which society changes in a fundamental way over a generation or more. Although the goals of a transition are ultimately chosen by society, governments can play a role in bringing about structural change in a stepwise manner. Their management involves sensitivity to existing dynamics and regular adjustments of goals to overcome the conflict between long-term ambition and short-term concerns.’ Within transition, crises and disruptions can help accelerate ongoing changes, and they offer a potential for paradigm shift (Kern et al., 2014). This makes it important to analyse the potential for sustainability transition the COVID-19 crisis brings. Understanding what happened as a result of previous crises in transport can help us understand the lessons to be learned for policy (What Works Centre for Local & Economic Growth, 2020). Manelici (2017), for example, found that, while transit ridership decreased in the year following the 2005 London bombings, the effects of the attack on transit vanished after 3 years. In Brussels, after the metro and airport terror attacks in 2016, transit ridership was close to pre-attack levels 3 months later (STIB-MIVB, 2017). Although the pandemic is still ongoing, it is necessary to understand the role it is playing in urban mobility behaviour changes.
3 | MATERIALS AND METHODS

The goal of our study is to understand the changing urban mobility behaviours in the past 2 years, since the start of the COVID-19 pandemic. To this end, we analyse how the use of three major transport modes – car, metro and bicycle – evolved in the city of Brussels and which factors influenced these changes. The next section will briefly describe the context of the city of Brussels, and the following section will describe the datasets used and the analysis conducted.

3.1 | Description of the city of Brussels

Brussels, the capital of Belgium, was chosen for our analysis, as it was one of the hardest-hit regions during the first waves of the pandemic (Dupondt, 2021). The city is home to 1.2 million residents (Statbel, 2022), dispersed over 19 communes. The city has an extensive network of public transport, including trains, trams, buses and metros, offering passengers in 2019 a total of 47.3 million driven kilometres (IBSA, 2021). At the time of the last federal mobility survey, 46% of trips were made by car, 24% on foot, 25% by public transport, 4% by bike and 2% by other modes of transport (FOD Mobiliteit en Vervoer, 2019). However, over recent years, biking has been gaining in popularity in the city (Henry et al., 2020). Recent analyses also show that 53% of households in Brussels do not own a car (Statbel, 2019).

3.2 | Data analysis

To understand the urban mobility behavioural changes due to COVID-19, we conduct three regression analyses, with three transport modes as successive dependent variables: the changes in driving, in cycling and in public transport use. For each transport mode, we present two linear regression models. In the first, we look at the change in activity behaviours by analysing Google’s ‘Community Mobility Report’, which records data on visits to different places (Google, 2020). For the second, we analyse categories of restriction measures that have been put in place to reduce the spread of COVID-19 (Hale et al., 2021).

All datasets have observations that are measured daily or aggregated on a daily level. As such, variables were measured as percental changes against a pre-COVID baseline, which accounts for weekly seasonality, meaning that we compare the variables with the same days of the week in the pre-COVID baseline. The trend was dealt with by adding the ordered variable of time in the analysis. The baseline for the different variables is selected in January or February 2020, depending on the available format of the provided data (i.e., percental change or raw daily volume). To reduce outliers, public holidays were removed from the analysis along with the ‘car-free Sundays’ (organized once a year in September), and 3 days when national strikes were organized (i.e., 28 September 2020 along with 24 September and 6 December 2021). The next section presents the measurements for the different mobility modes and how these data were cleaned. Then, we present the datasets used to retrieve our independent variables, how these datasets were processed and how the variables were selected.

3.2.1 | Dependent variables

The measures for the three transport modes come from three different secondary data sources. Descriptive statistics for these dependent variables after data cleaning are available in Table 1, and Figure 1 depicts their evolution in the past 2 years. First, the driven kilometre percental change data from Waze as of 1 March 2020 is used as a measure of driving change in Brussels (Waze, n.d.). The 2-week period from 11 February to 25 February 2020 is the baseline. After an initial average decrease of –79.67% during the 2020 lockdown, driving use slowly recovered, reaching
average levels of −21.85% at the start of the school year in 2020 and +5.38% a year later. As we will see in the next section, these last periods are the closest to the pre-COVID situation, with almost no restrictive measures in place.

Metro was chosen to represent public transport as it was the mode that was the most strongly impacted by the crisis (Macharis et al., 2021). The data for metro are also more reliable than for ground transportation because metro occupancy is measured directly through the mandatory validation to enter the metro stations. The data were made available by the local urban public transport operator (STIB-MIVB, n.d.). The baseline here is measured as the average for each weekday during the 3 weeks preceding the February school holidays (from 3 February to 22 February 2020). Ridership encountered a drastic drop during the first lockdown (−86.39%). It then increased gradually across the summer and reached an average change of −36.39% in September to October 2020. In November 2021, it approached pre-COVID levels before decreasing again in December owing to the implementation of new measures (Figure 1).

Finally, from the bike counters across Brussels, average daily number of cyclists was calculated (Brussels Mobility, n.d.). Change in the number of cyclists was then computed by comparing this number with a baseline of 7 weeks between two school holidays, from 6 January to 21 February 2020. Because of the excessive increase in cycling over the weekends (Figure 2), and because the mobility behaviour is different from that during the week, only the weekdays are considered in the analysis. Contrary to the other transport modes, cycling decreased, during the strict lockdown in 2020, by only 28.03% on average on weekdays, while it rose during the weekends (+189.06%). This was an exceptionally sunny period, but the trend remained in the following year and resulted in a weekday increase as well (+48.65% between the summer and autumn holidays 2020, +86.72% for the same period in 2021). In Figure 1, we notice three drops: the strict lockdown (18 March to 18 May 2020), a lighter lockdown (19 October

| TABLE 1 | Descriptive statistics of the dependent variables |
|---------|-----------------------------------------------|
| Transport modes | Driving | Metro | Cycling\(^a\) |
| Date | 1 March 2020 to 31 December 2021 | 2 March 2020 to 31 December 2021 | 1 January 2020 to 31 December 2021 |
| Mean (SD) | −0.30 (0.27) | −0.49 (0.18) | 0.20 (0.41) |
| Range | −0.95, 0.50 | −0.91, −0.01 | −0.86, 1.32 |
| N | 642 | 639 | 505 |

\(^a\)Weekends are not considered.
to 20 December 2020) and, finally, December 2021 when school holidays started earlier and work from home was enforced again.

3.2.2 | Independent variables

To understand which activities or measures influenced the drastic changes in mobility behaviour, we have selected two groups of independent variables for which two different linear regression are run. To avoid excessive multicollinearity, a selection of these variables was made beforehand on the basis of strong theory and correlation analysis. The absence of excessive multicollinearity was then verified with the generalized variance inflation factor (Fox & Monette, 1992). Statistics of selected variables along with their definitions are presented in Table 2.

First, we look at the impact of the change and the frequency of conducting different types of trips. To this end, we use the daily indicators from Google (2020) which measure the change in visits to places. They classified places into six categories: workplace, grocery & pharmacies, parks, retail & recreation, transit station, and residential. Retail & recreation, transit stations and residential will not be used in our analysis. From the Pearson correlation analysis (Table 3), we saw that retail, transit and recreation are highly correlated with the other variables. In addition, transit is too close in meaning to our dependent variable, while the retail category represents places such as restaurants, shops or libraries that have been affected differently by containment measures during this crisis.

In a second model, we include the impacts of the government measures taken in Brussels to fight the spread of COVID-19. The reactions of governments around the world with regard to the spread of the coronavirus have been systematically catalogued into the Oxford COVID-19 Government Response Tracker (Hale et al., 2021). This worldwide dataset captures, from 1 January 2020 onwards, governmental policies and interventions in five main action categories. We will consider here the category ‘containment and closure’. The catalogue gives a code to each indicator for each day and on a national level depicting its stringency. If measures differ across the country, the more restrictive case is considered. To ensure that this indicator reflects the Brussels case, all codes mentioning a targeted geographical scope were checked and manually adapted. Similarly, indicators that were not relevant for Brussels were disregarded, while others were transformed to fit the local context or the mobility scope of the analysis. The indicator for school closing was redefined to better reflect Brussels school measures and the impact on

FIGURE 2  Evolution of cyclists compared with the pre-COVID baseline
| Visits to place categories | Definition (N = 682)                                                                 | Mean (SD)               | References                                                                 |
|----------------------------|------------------------------------------------------------------------------------|-------------------------|----------------------------------------------------------------------------|
| Grocery                    | Mobility trends for places like grocery markets, food warehouses, farmers markets, | −0.11 (0.15)            | Google, from 12 February 2020 to 31 January 2021                           |
|                            | specialty food shops, drug stores and pharmacies                                     |                         |                                                                            |
| Park                       | Mobility trends for places like local parks, national parks, public beaches, marinas | 0.27 (0.41)             | Google, from 12 February 2020 to 31 January 2021                           |
|                            | dog parks, plazas and public gardens                                               |                         |                                                                            |
| Workplace                  | Mobility trends for places of work                                                  | −0.37 (0.21)            | Google, from 12 February 2020 to 31 January 2021                           |

| COVID-19 restrictions      | Categories (N = 731)                                                               | Frequency (%)           | References                                                                 |
|----------------------------|------------------------------------------------------------------------------------|-------------------------|----------------------------------------------------------------------------|
| School closing             | 0 - School is open (reference level)                                               | 332 (54%)              | Adapted from Hale et al. (2021), from 1 January 2020 to 31 January 2021    |
|                            | 1 - School is partially closed: Students are not allowed every day, or measures    | 109 (18%)              |                                                                            |
|                            | differ depending on their ages                                                      | 175 (28%)              |                                                                            |
|                            | 2 - School is closed: Due to school holidays or COVID restriction measures           |                         |                                                                            |
| Work from home             | 0 - No measures in place (before COVID)                                            | 27 (4.4%)              | Adapted from Hale et al. (2021), from 1 January 2020 to 31 January 2021    |
|                            | 1 - Working from home is recommended                                               | 300 (49%)              |                                                                            |
|                            | 2 - Working from home is mandatory                                                 | 289 (47%)              |                                                                            |
| Retail closing             | 0 - Retail and restaurants are open                                                | 348 (56%)              | Adapted from Hale et al. (2021), from 1 January 2020 to 31 January 2021    |
|                            | 1 - Retail is open, but not restaurants                                            | 160 (26%)              |                                                                            |
|                            | 2 - Both retail and restaurants are closed                                         | 108 (18%)              |                                                                            |
| Cancel public events       | 0 - No measures                                                                    | 24 (3.9%)              | Adapted from Hale et al. (2021), from 1 January 2020 to 31 January 2021    |
|                            | 1 - Recommend cancelling                                                           | 197 (32%)              |                                                                            |
|                            | 2 - Require cancelling                                                             | 395 (64%)              |                                                                            |
| Weather                    | Definition (N = 731)                                                               | Mean (min, max)         | References                                                                 |
| Temperature                | Daily average temperature in Brussels (in °C)                                      | 11.44 (−5.92, 28.53)    | IRM, from 1 January 2020 to 31 December 2021                              |
| Precipitation              | Sum of daily precipitation in Brussels (in mm)                                      | 2.43 (0, 59.1)          | IRM, from 1 January 2020 to 31 December 2021                              |
mobility. Similarly, ‘workplace closing’ was recoded into two variables to account separately for both teleworking and the closing of the different types of retail and hospitality activities. The final definition and coding along with descriptive statistics for the selected indicators are given in Table 2. Figure 3 shows their evolution throughout the considered period. All measures were at their highest in March to April 2020 during the strict lockdown. Then, measures were gradually lifted, with new peaks every few months. Schools, for example, opened only partially after this period, with not all students going back every day, and encountered several early closings around the school holidays. Only during the weeks after both summers were most measures relaxed. The correlation analysis shows that driving and public transport are correlated with the measures while cycling is not. Because the retail indicator is strongly correlated with stay-at-home measures, only the former has been kept (see Spearman ranked correlations in Table 4).

Finally, as active modes have been found to be influenced by weather, while this is not strongly the case for driving (Rudloff et al., 2015), we added the daily average temperature and the daily precipitation for cycling in both models. These data were measured at the weather station of Uccle (Brussels, Belgium) and were requested at the IRM-KMI (Royal Meteorological Institute, n.d.).
### TABLE 4  Spearman correlation for the stringency measure indicators

| Variable               | School closing | Retail closing | Work from home | Stay at home | Cancel public events |
|------------------------|----------------|----------------|----------------|-------------|----------------------|
| School closing         | 1.000          |                |                |             |                      |
| Retail closing         | 0.244***       | 1.000          |                |             |                      |
| Work from home         | 0.160***       | 0.304***       | 1.000          |             |                      |
| Stay at home           | 0.212***       | 0.875***       | 0.374***       | 1.000       |                      |
| Cancel public events   | 0.255***       | 0.516***       | 0.404***       | 0.497***    | 1.000                |
| Driving                | −0.351***      | −0.692***      | −0.326***      | −0.727***   | −0.445***            |
| Metro                  | −0.537***      | −0.683***      | −0.393***      | −0.726***   | −0.491***            |
| Cycling                | −0.285***      | −0.034         | 0.080*         | −0.041      | 0.092*               |

### TABLE 5  Summary of the regression results

| Characteristic       | Driving                  | Metro                  | Cyclinga                 |
|----------------------|--------------------------|------------------------|--------------------------|
|                      | Model 1 Model 2          | Model 1 Model 2 Model 1 Model 2 | Model 1 Model 2 |
| Time trend           | 0.40*** 0.59***          | 0.19*** 0.51***        | 0.19*** 0.42***          |
| Grocery              | 0.26*** –                | 0.40*** –              | – –                     |
| Park                 | 0.04 –                   | –0.13*** –             | 0.36*** –               |
| Workplace            | 0.39*** –                | 0.66*** –              | 0.37*** –               |
| School closing       |                          |                        |                          |
| 1                    | – –0.17**                | – –0.26*** –           | – –0.22**               |
| 2                    | – –0.34***               | – –0.73*** –           | – –1.1***               |
| Retail closing       |                          |                        |                          |
| 1                    | – –0.71***               | – –0.50*** –           | – 0.05                  |
| 2                    | – –1.1***                | – –1.1*** –            | 0.48***                 |
| Work from home       |                          |                        |                          |
| 1                    | – –1.1***                | – –2.1*** –            | – –0.18                 |
| 2                    | – –1.4***                | – –2.5*** –            | – –0.60                 |
| Cancel public events |                          |                        |                          |
| 1                    | – –0.44                 | – –0.53                | – –0.15                 |
| 2                    | – –0.22                 | – –0.38                | – –0.06                 |
| Temperature          | – –                     | – –                    | 0.28*** 0.59***         |
| Precipitation        | – –                     | – –                    | –0.22*** –0.28***       |
| $R^2$                | 0.641 0.740             | 0.808 0.842            | 0.609 0.660             |
| Adjusted $R^2$       | 0.639 0.736             | 0.807 0.839            | 0.604 0.653             |
| Observationsb        | 638 642                  | 635 639                | 469 505                 |

Notes:

* $p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

aOnly weekdays are considered.

bThe changing number of observations is due to different available date ranges between the different modes and between the three groups of dependent variables.
4 | RESULTS

The results of the regression analysis are presented in Table 5. In all models, the use of the mobility modes increases again with time, although to a differing degree.

In terms of mobility, driving increased the most when visits to workplace were high (\( b = 0.39 \)) or when visiting grocery places (\( b = 0.26 \)). As expected, the decrease is the strongest when measures enforced the closure of workplaces (\( b = -1.4 \)) and retail (\( b = -1.1 \)). However, the decrease was still important on days when working from home was no longer mandatory (\( b = -1.1 \)) or when only restaurants were closed (\( b = -0.71 \)). The impact of school closing is less important, and the cancellation of public events is not significant. The upward trend also highlights that, although the crisis is still underway and the restriction measures are accounted for in the model, driving is increasing again.

The elements that affected the change in metro ridership are not that different than the ones that impacted driving. The days with high workplace affluence (\( b = 0.66 \)) are here again days when transit use is high, but visits to parks negatively affect metro use (\( b = -0.13 \)). In terms of measures, the impacts of work from home and the closing of schools are stronger for metro than for driving. Although the time trend still influences metro ridership, the rise is slower than for driving uptake.

In both models, temperature and precipitation are important factors explaining cycling changes. Despite considering this weather component, cycling has been similarly influenced by visits to parks (\( b = 0.36 \)) and workplaces (\( b = 0.37 \)) while grocery shopping is not significant. Contrary to the other modes, cycling has not been strongly influenced by the restriction measures; the model not accounting for weather explained only 19.59% of the variance. Next to the weather variables, time is an important predictor: cycling increased whatever the measures were. Only the closure of schools (especially full closure) led to a significant decrease in cycling, while days with closed retail saw an increase in cycling. Because of collinearity and the low variance explained by the measurement indicators, this second model cannot be used to explain the separate impact of each measure on cycling behavioural changes.

5 | DISCUSSION

This paper analyses how mobility behaviours have evolved over 2 years following the COVID-19 policy measures. Not surprisingly, the restrictive measures have had an important impact on mobility in Brussels. The variations in mobility levels follow the levels of restrictions put in place, although the cancellation of public events does not seem to play a major role in mobility behaviour. These findings are similar to those of Kahanec et al. (2020), who saw that restrictions all resulted in a sharp decline in mobility, although the cancellation of public events played a smaller role. It is important, however, to note that their analysis focuses only on the first months of the pandemic.

More interestingly, we see that, while driving was strongly impacted in the first and second waves, car use levels in this fifth wave are back to pre-pandemic levels, although telework measures are still quite strict (Figure 3). Within the fifth wave, 4 days of telework per week are mandatory. One explanation for this may be that the initial shock of the pandemic prompted a swift behavioural change, but that people are reverting to initial behavioural patterns once they are used to the crisis. The sense of urgency and need to change is gone. However, we also saw in the regression that telework measures are a strong factor affecting changes in driving. This remains true even if there is a slight decrease in adherence to the rules with time. This could indicate that a structural reform with regard to telework can have a significant role to play in the transition to sustainable mobility.

Another interesting finding is that cycling is strongly predicted by the variables ‘park’ and ‘workplace’, but it very clearly increased over time. This can indicate that, while during the first lockdown people started cycling for leisure, they have continued to do so, and that it has increasingly become a commuting mode. However, it currently does not yet appear to have become a habit when it comes to shopping, since the visits to grocery places do not lead to a significant change in cycling. Overall, over the last 2 years, it is important to highlight the strong increase (63%)
in cyclists around Brussels, which is a trend confirmed in multiple cities around the world (Lozzi et al., 2020). A steady increase had been ongoing over the last few years, but it has remained relatively low compared with other Belgian cities (Henry et al., 2020). Vandenbulcke et al. (2011) highlight that the development of dedicated cycling infrastructure is an important factor for growth in cycling. The dedicated bike lanes implemented during the crisis, as well as the traffic calming solutions implemented in most parts of the city, can then help explain this extra uptake. We also see that the levels of COVID-19 measures did not significantly influence the number of cyclists, meaning that cycling increased even though restrictions were put in place. As expected, we see that the weather plays a significant role in cycling. One explanation for this could be that there are a lot of ‘new’ cyclists, who might still more easily shift transport modes in case of bad weather as they still have access to a private vehicle or a public transport subscription. They might also not yet have the right equipment to deal with bad weather.

The difference that we can see in behaviour with regard to cycling and driving can partially be explained in how they were acted upon differently at the policy level. Both the cycling and telework trends existed before the pandemic, and they were strongly intensified by it, but structural changes must be made to make them last. New bike lanes were implemented, and Brussels became one of Europe’s largest 30 km/h zones (although the timing of this last measure was planned before the COVID-19 crisis). However, even though these measures can have a dissuasive effect for driving, no explicit policy measures have been implemented to discourage the use of private cars.

When it comes to public transport, we see that it is slowly recovering after the strong initial decrease, with metro occupancy rates rising back to pre-COVID levels. However, public transport recovery has been slower than car traffic. One possible explanation for this is that the perceived risk of contagion on public transport is greater than in private transport. Qi et al. (2021), for example, found that fear of COVID-19 significantly reduces public transport ridership. Measurements done in December 2021 showed that the CO2 level on public transport in Brussels regularly exceeded the safety threshold of 900 ppm (BRUZZ, 2021). Reinstating trust in the safety of public transport could therefore help increase its occupancy levels. The revealed trend gives confidence that people will ultimately return to public transport, although the installation of more hybrid forms of working will have a lasting impact on transport use and make it necessary for transit operators to adapt to the post-COVID situation.

6 | CONCLUDING REMARKS

The goal of our research was to analyse the behavioural changes COVID-19 brought about on mobility in Brussels, Belgium. From our analyses, we see that the most important impact of the crisis is on biking and telework. We also see that, despite measures still in place, mobility levels are returning to pre-pandemic levels. This can be seen especially in road traffic data, while public transport ridership is rising to pre-corona levels more slowly. Cycling levels have not decreased back to pre-COVID levels and have instead continued to rise despite the different levels of restrictions. What can we now learn from these developments in terms of transition towards sustainable urban mobility?

One explanation for the return to normal that can be seen for car traffic may be the lack of preparation for the crisis. In the first months of 2020, there was no choice but to implement restrictive measures with regard to internal movement, telework or social distancing. This has led to the evolution of mobility behaviour described in the previous sections. However, despite this first ‘positive’ impulse, there is a risk of inertia when it comes to further transitioning towards a sustainable urban mobility system, as can be seen from the recovering car traffic levels. Without lasting policy changes, the possibility of transition is being diluted, because actors remain tied to old patterns of behaviour even in the face of disruption (Inayatullah, 2008). In Brussels, the initial measures taken during the strict lockdown and in the months that followed accelerated a transition that was already underway in terms of cycling. The city had the regional Good Move mobility framework that could guide the implementation of bike lanes and the pedestrianization of neighbourhoods in the city (Brussel Mobiliteit, 2021). However, the city did not have a scenario in place for the wide implementation of telework, or for measures regarding public transportation. From our
analyses, we see that telework measures are the most important predictor of mobility levels for car driving and public transport. It is therefore important to institutionalize these measures when they are no longer needed for the containment of COVID-19, as they could help reduce congestion. However, it is also important to consider the rebound effects of telework, since its benefits are dependent on commuting patterns (O’Brien & Yazdani Alabadi, 2020). It is also crucial to ensure that travellers return to public transport by ensuring their safety, since public transport has an important role in the transition towards sustainable urban mobility.

Our results show the importance of preparedness for flexible planning to capitalize on a crisis. If different scenarios have been worked out, decision-making becomes easier in the case of a disruption, as it shows the direction in which to accelerate. These guiding frameworks can be crucial in times of crisis: transitions can take multiple generations to happen, but crises allow for a rapid acceleration. Without appropriate preparation, people lose the sense of urgency and can revert to their initial behaviour.

While our analyses covered most of the COVID-19 period in relation to the restrictive measures, our study also has some limitations. One limitation is that the COVID-19 crisis seems to be far from over, making it difficult to give a complete picture of the impacts it has on potential changes in mobility behaviour. A second limitation concerns the inherent limit of the data used in our research to represent the different behaviours. The cycling data, for example, may contain some inaccuracies since counters can encounter technical issues and are less reliable with congestion, and Waze data are limited to the users of the application. In addition, the data used for the different transport modes are computed differently, meaning that comparison across modes can be challenging. It is therefore necessary for cities to collect better benchmark data to facilitate the comparison within and across cities. A last limitation linked to the collected data is that the data analysed here do not give an indication of the people behind it, for example, in terms of socio-demographic information. Further research into this topic could replicate our analyses for other cities in Europe or around the world, to analyse how and if mobility reacted differently to the restrictive measures. This could serve as a basis to adapt policy measures aimed at sustainable urban mobility transition.

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