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ABSTRACT

The outbreak of SARS-COV-2 has led to the COVID-19 pandemic in March 2020 and caused over 4.5 million deaths worldwide by September 2021. Besides the public health crisis, COVID-19 affected the global economy and development significantly. It also led to changes in people's mobility and lifestyle during the COVID-19 pandemic. In addition to short-term changes, the drastic transformation of the world may account for the potentially disruptive long-term impacts. Recognizing the adverse effects of the COVID-19 pandemic is crucial in mitigating the negative behavioral changes that directly relate to people's psychological and social well-being. It is important to stress that citizens and governments face an uncertain situation since nobody knows exactly how the viruses and cures will develop. Better understanding uncertainties and evaluating behavioral changes contribute to addressing the future of urban development, public transportation, and behavioral strategies to tackle COVID-19 negative consequences. The major sources of impacts on short-term (route, departure time, mode, teleshopping, and teleworking) and medium and long-term (car ownership, work location, choice of job, and residential location) mobility decisions are mostly reviewed and discussed in this paper.

Keywords: COVID-19 effects, mobility, lifestyle, teleworking, residential location

JEL: I14, R1, R4

1. Introduction

1.1 COVID-19 background

On March 11, 2020, COVID-19 has declared a global pandemic (Abreu, 2021). The first wave occurred in most countries during April and May 2020; soon after summer, most countries experienced a severe second wave compared to the first wave. For instance, France experienced extra mortality of 27,300 people in the first wave, while in the second wave from September 1 to December 31 there were 33,000 excess deaths (Staff, 2021), and Switzerland encountered 2.73 times more deaths in the second wave compared with the first wave (Etemad-Sajadi, 2021). Since then, the world has experienced several waves due to different variants of COVID-19 (for example, the Alpha, Beta, Gamma, or Delta variants), which have appeared selectively in different countries before they spread geographically. At this moment[1], although many countries have already got the vaccine, we are still struggling with the pandemic globally, since the vaccines are likely to be effective against specific variants of COVID-19, not all the mutations (Collier et al., 2021). Moreover, experts believe that 50 to 80% of the population must be vaccinated with double or even triple shots to achieve herd immunity (Erzurum, 2021).

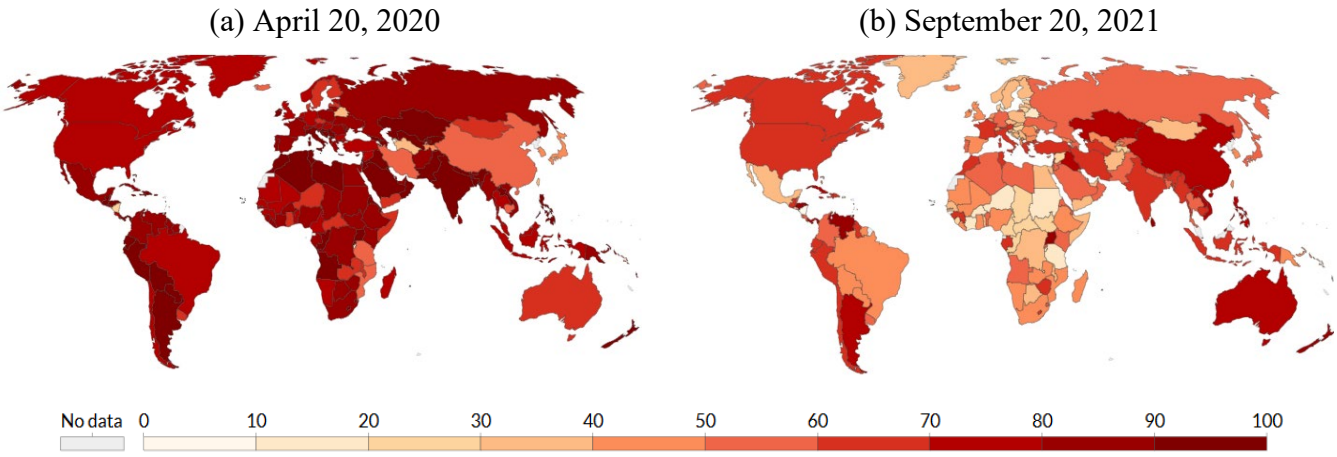
Since the main way of transmission of the virus has been close contact with infected people and contaminated surfaces (WHO, 2021), most governments have decided to minimize social contact. This led to calling for preventive actions against the spread of COVID-19 such as school closures, workplace closures, gathering restrictions, ban on public events, public transportation closures, stay-at-home rule, restrictions on internal movement, international travel bans, public information campaigns, and personal care including wearing masks, washing, and sanitizing hands frequently.

The wide range of governments' responses to the COVID-19 outbreak is measured by the Oxford COVID-19 Government Response Stringency Index[2], which aims to track and compare government responses worldwide (HDX, 2021). The Stringency Index is a number between 0 and 100, and a higher index score indicates a higher level of stringency (Civils Daily, 2020). Figure 1

[1] September 2021.

[2] This index is a composite measure of nine response indicators including school closures, workplace closures, gathering restrictions, public events ban, public transportation closures, stay-at-home requirements, restrictions on internal movement, international travel bans, and public information campaigns.

shows the stringency index, for example, on April 20, 2020 and September 20, 2021, indicating that most countries were strict about the restrictions but over time the stringency index dropped.

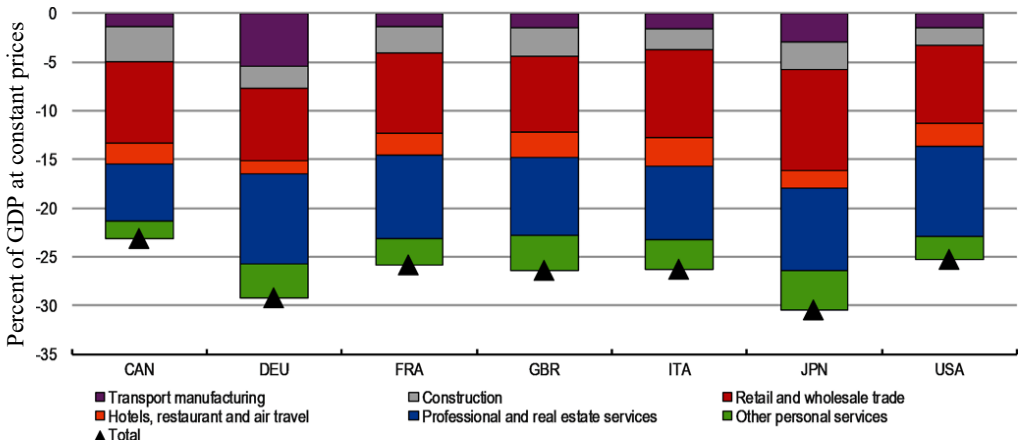


Source: Oxford COVID-19 Government Response Tracker, Blavatnik School of Government, University of Oxford

Figure 1 Government Response Stringency Index (HDX, 2021).

While governments' actions against the pandemic play a vital role in reducing the number of COVID-19 cases, they affect the global economy. The International Monetary Fund (IMF, 2020) report shows a negative correlation between the stringency of the lockdown and the real gross national product (GDP) growth forecast error[3], suggesting that countries with a tighter lockdown stringency experienced larger output losses. Another research (OECD, 2020a) presents that partial or complete shutdowns on activity in the G7 economies brought about a direct initial hit to the level of GDP typically between 25-30% in 2020, compared with 2019 (Figure 2). For instance, Germany had the largest reduction in transportation manufacturing, and Japan had the largest drop in retail and wholesale trade. Fortunately, the updated projection of GDP in G20 advanced economies countries in September 2021 shows that the recovery of GDP is faster than what was predicted in December 2020 (OECD, 2021).

[3] The forecast error is defined as the deviation of real GDP growth from the January 2020 World Economic Outlook projections, which are the latest ones before the COVID-19 outbreak.



Source: OECD Annual National Accounts and OECD calculations

Figure 2 Potential impact of shutdowns on activity in the G7 economies (OECD, 2020a).

1.2 Review strategy

This crisis had, has, and will have tremendous impacts on societies, including lowering physical activities, increasing working from home, and reducing public transportation usage, both in the short and long run. Such changes in people's behavior might result in enormous economic and transportation changes. Therefore, it is necessary to recognize the possible changes and raise awareness about the disruptive shocks to mitigate the adverse effects of the current crisis. A good understanding of the COVID-19 effects is essential for designing appropriate policies and investing in the preparedness of the probable future pandemics. This paper aims at providing an extensive overview of the effects of COVID-19 on various aspects of mobility and lifestyle.

The review strategy of this study is presented as follows. Before gathering materials for the proposed overview, we identified a conceptual framework concerning COVID-19-related causes of potential effects on passenger mobility and lifestyle, i.e., how people move and live. It is noticeable that compulsive interventions intended to prevent the spread of COVID-19, such as lockdown, social distancing, and quarantine, impose restrictions at varied levels on individuals' mobility and lifestyles. In addition, according to the theory of planned behavior, perceived concerns and social norms are contributing factors of modifying the intention and actual behavior of following the past habitual patterns (Ajzen, 1991). In terms of short-term effects, especially in the short time frame after the COVID-19 outbreaks, it is likely that virtual mobility (e.g., teleshopping and teleworking) dramatically increases to replace physical trips to activity destinations. The substitution effects may lead to adaptations in personal lifestyle and have broad environmental implications for congestions, air quality, etc. In places where travel is allowed,

people are unvolunteered to adjust mode choice preferences for both road and air transportation, resulting in the change of modal split. Besides the direct effects, COVID-19, as a substantial external force of resource reallocation, may also potentially causes medium and long-term indirect effects on car ownership, employment mobility, residential mobility, and the redesigning of urban spaces. Altogether, the conceptual framework is depicted in Figure 3. Since the long-term decisions impact short-term decisions and vice versa[4], the interactions between these two levels are denoted by a two-way link, different from the solid one-way links representing direct and indirect effects. Note that the review is not focused on the subtle interactions between the two levels and therefore the interactions are shown by a dashed link in Figure 3. Such interactions should be considered for future research.

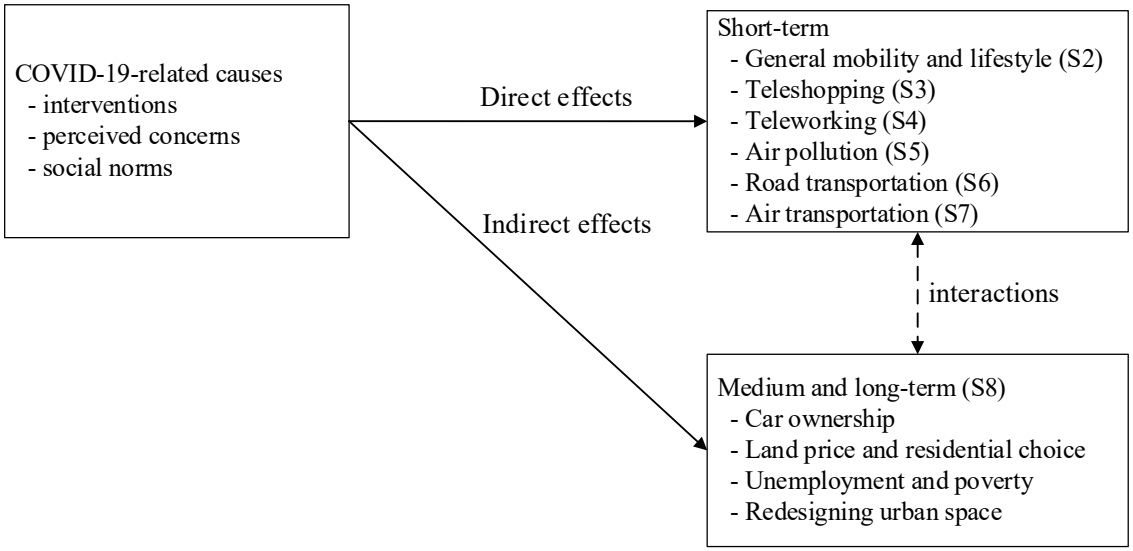


Figure 3 Sketch of a conceptual framework of COVID-19 effects (S: Section).

With the keywords identified in the framework, we identified peer-reviewed articles and reports from trustable organizations published till submission via search engines and bibliographic databases (e.g., Google Scholar, Web of Science, or Scopus). The search materials were assessed on whether they provide an explicit analysis of the effects of COVID-19, qualitatively or quantitatively, on mobility and lifestyle. We omitted those studies that only incorporated COVID-

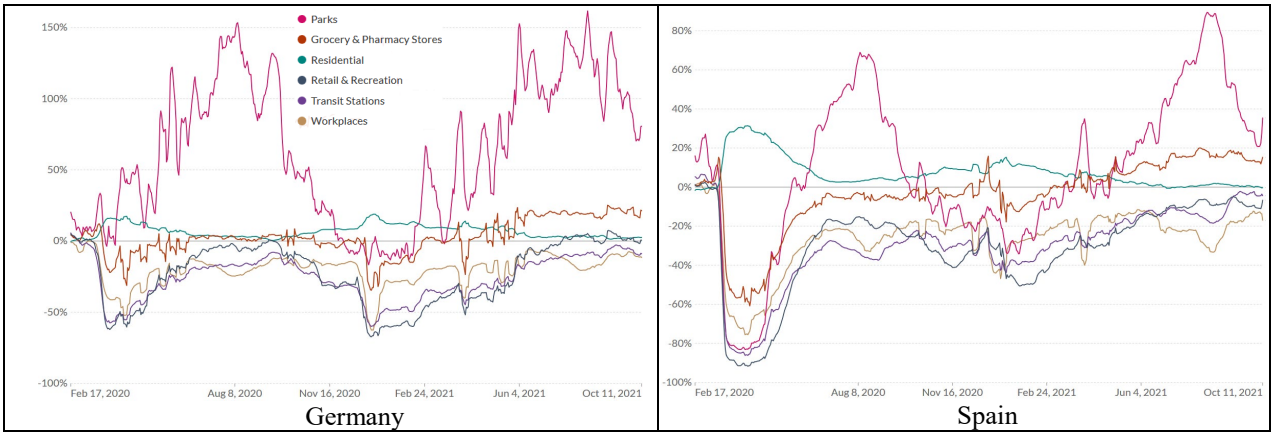
[4] For example, on the one hand, telework (as a short-term consequence) leads to change in residential location decisions (which is a long-term consequence) since people may need larger houses trading for living farther from work locations. On the other hand, relocation decided mainly by one member of the household might increase commuting costs for the spouse. This results in a higher tendency for telework by the spouse.

19 effects as a sideline analysis. After all, over 140 relevant papers, reports, and web pages were selected, which are by no means exhaustive (the literature is booming) but exhibit a fair coverage of the subjects. We also benefited from discussions with many academics and we attended various seminars to expand our opinions on COVID-19 effects. It should be emphasized that this current paper aims to provide a comprehensive overview of the literature (published by September 2021) of COVID-19 effects in a structured way. In that sense, it is not our major aim to critically reflect on the limitations or challenge the validity of the selected studies.

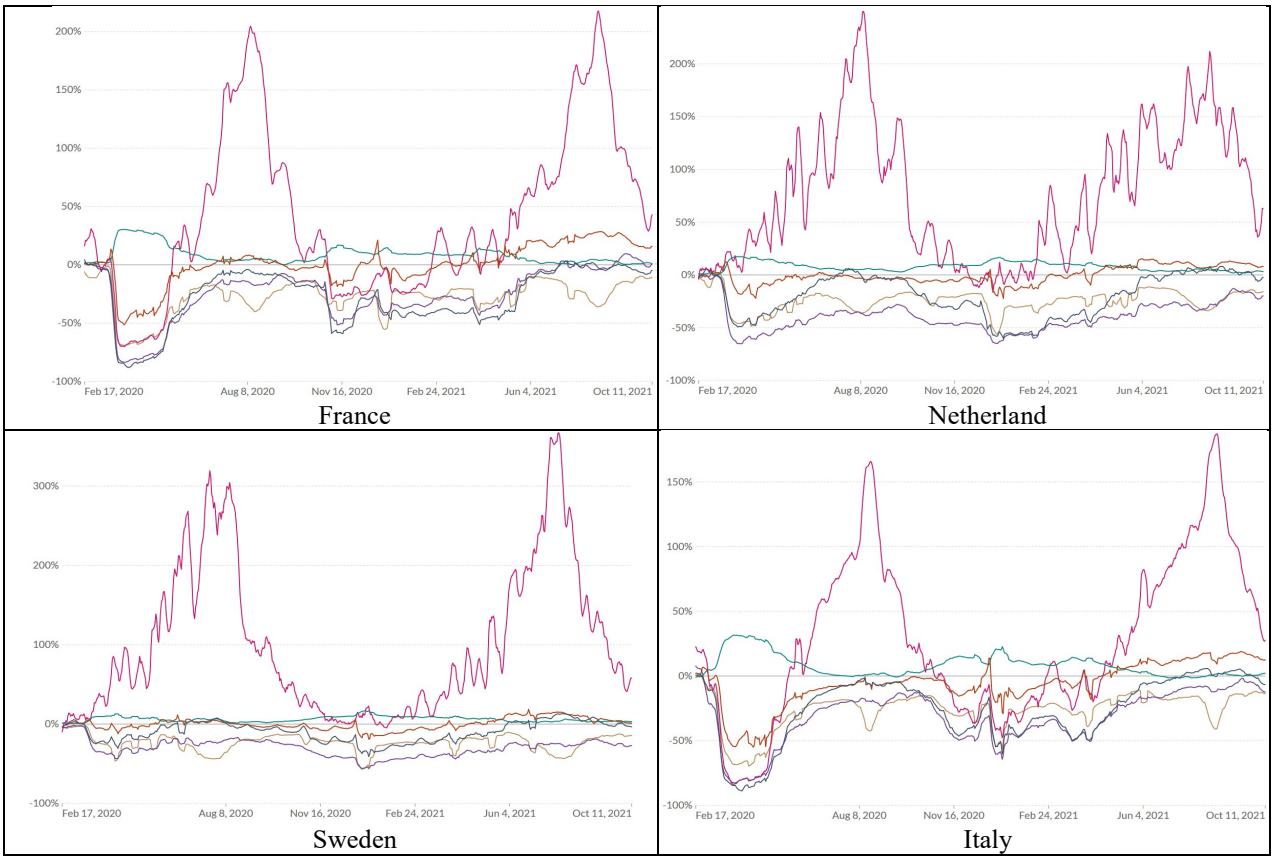
The remainder of this paper is structured as follows. We first review the effects of COVID-19 on mobility and lifestyle in general (Section 2). Then, we zoom in on the COVID-19 effects on teleshopping, teleworking, air pollution, road transportation, and air travel due to restricted mobility in Sections 3 to 7, respectively. Next, we shorty discuss the medium and long-term effects of COVID-19 including car ownership, employment rate, poverty, inequality, house price, relocation, and the necessity of re-designing urban spaces in Section 8. At last, Section 9 concludes this paper.

2. Effects of COVID-19 on mobility and lifestyle in general

As a result of forced social distancing and lockdown during COVID-19, daily mobility and lifestyle-related habits have changed in a significant manner. IMF (2020) estimates several regressions with data from 128 countries (early February to mid-July, 2020) and shows that a full lockdown declines mobility by almost 25% after a week, while releasing restrictions boosts mobility by about 18% over the same period. Changes in mobility demand in some European countries are shown in Figure 4 during waves 1 and 2 (February 2020 to October 2021). These changes continue as the pandemic progresses through different phases.



Germany Spain



Source: Google COVID-19 Community Mobility Trends

Figure 4 Different mobility demand changes in several European countries in the second wave during Feb.–Nov. 2020 (Our World in Data, 2021).

As it can be seen in Figure 4, in many countries, the demands for parks increased significantly, while the demands for recreation, work, and shopping dropped. However, the changes in mobility are not uniform across the world and depend on spatial factors. An analysis of the demand patterns at some points of interest (POI). In Munich, for example, it was demonstrated that the distance between a POI and public transportation stations intensifies the adverse effects of lockdowns (Mahajan et al., 2021). Accordingly, being close to the public transportation hubs induces more vulnerability for businesses (Mahajan et al., 2021).

Mobility as the potential of physical movements and the ability to travel between two separated locations has changed to virtual mobility via the internet during the pandemic. In Greece, for instance, online activities including teleconference (57%), online learning (53%), teleworking (49%), telehealth (11%), and teleshopping (5%) have increased significantly (Mouratidis and Papagiannakis, 2021). Bin et al. (2021) analyzed factors affecting the increased amount of daily

internet usage for various activities including work meetings, entertainment, and shopping. Their results show that internet usage has increased more for full-time workers with higher education than their counterparts. Also, they find that the perceived feeling of safety while being outside is negatively correlated with internet usage for entertainment and grocery shopping, but there is no significant correlation between perceived safety at work location and work-related internet usage.

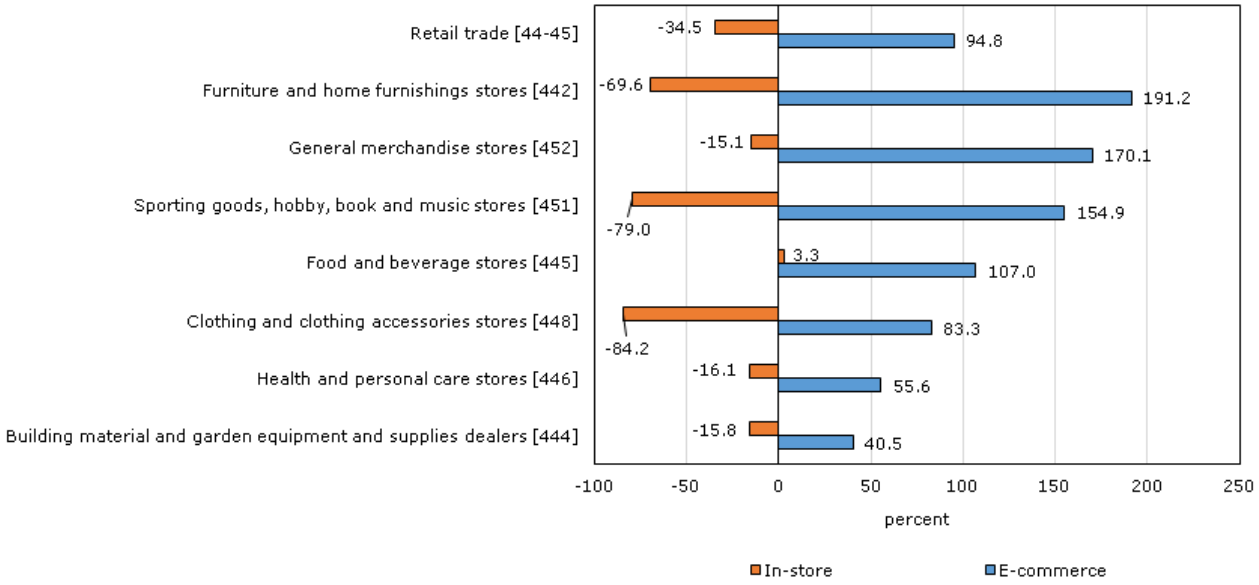
According to previous studies, quarantine, with various durations depending on the country, is associated with lifestyle. Much research has studied the psychological, physical, and economical values, interests, opinions, and behavioral changes, which are translated into lifestyle, among different groups of people. For instance, it is found that the pandemic brings about stress and depression (Chopra et al., 2020) (and sometimes even suicide) and leads to reduced physical exercises as well as leisure-related activities such as walking in parks and gardening (a detailed list of changes in several aspects of citizens' daily lives is presented in Appendix A). The changes in daily exercises and steps per day are inversely correlated with the changes in body weight (He et al., 2020). Hence, many studies prove that gaining weight during the pandemic carries some long-term effects on cardiovascular diseases. This is most probably related to the lack of physical exercise. Although one study (Chopra et al., 2020) confirms the improved eating behavior during COVID-19, other studies demonstrate food consumption and sugary drinks intake have increased significantly during the lockdown (Górnicka et al., 2020; Pietrobelli et al., 2020). An increase in screen time is another adverse impact of the COVID-19 outbreak proved in numerous studies. Górnicka et al. (2020) show that 49% of respondents reported an increase in screen time (time spend in front of the screen of a computer, TV, tablet, and/or telephone during working or non-working day), and Pietrobelli et al. (2020) show that screen time increased by 4.85 hours per day for children during the lockdown. The significantly increased screen time may affect the quality of life and result in mental health distress and anxiety in the long run. Anxiety, as studied experimentally by Fetzer et al. (2021), is not only concerned with health but also with the economic situation.

3. Effects of COVID-19 on teleshopping

Carvalho et al. (2020) investigated the purchasing behavior of individuals in the first two months of the COVID-19 outbreak in Portugal and found that during the pandemic people go less often to supermarkets and buy more each time, and visit local groceries more. Teleshopping has

also increased among customers during the pandemic. For instance, online shopping was nearly doubled in Canada from February to May 2020 (Aston et al., 2020). Figure 5 illustrates how in-store and online sales (e-commerce) vary among different products. According to this figure, all retail trade subsectors increase in online sales and decline sharply in in-store sales as a result of COVID-19. Only the food and beverage subsector experienced an increase in in-store sales (+3.3%).

In the U.S., online shopping increased by 78% in May 2020 compared with the same period in 2019 (Ali, 2021). There was a reported increase in South Korea's online food purchases and daily necessities by 92.5 and 44.5% due to the COVID-19 pandemic, respectively, in February 2020 relative to last year (Neo, 2020). Also, there was a surge in online shopping by 12–57% in countries like Vietnam, India, China, Italy, and Germany during the same period (Statista, 2021a).



Source: Statistics Canada; Monthly Retail Trade Survey.

Figure 5 Changes in in-store and online sales during COVID-19 in Canada (Aston et al., 2020).

France introduced a ban on the sale of all "non-essential" items in supermarkets in early November 2020, but online sales of all types of items - essential and non-essential - were still allowed from all types of retailers (France 24, 2020a). Also, a ban implemented on the sale of non-essential items during Wales' lockdown caused confusion and frustration among some shoppers but others did not complain (BBC News, 2020). The definition of essential and non-essential is debatable and public acceptability has played a role when setting those definitions.

The pandemic has changed the shopping habit from in-store to online, and this habit has the potential of persisting even after the pandemic. Hence, some studies have focused on the factors affecting the selection of online and in-store shopping after the stabilization of COVID-19. For instance, in Korea, Moon et al. (2021) reveal that the more that people care about government policies, the higher online shopping will be post-pandemic. As people's knowledge about COVID-19 increases, people are more likely to continue online shopping post-pandemic (Tien et al., 2021). These studies can help businesses to align their sale strategies to fit in the new customers' behaviors. For example, Tien et al. (2021) discussed the change in consumer behavior and the challenges that Vietnamese enterprises would face in the post-COVID world.

4. Effects of COVID-19 on teleworking

In addition to individual-based preventive efforts such as handwashing and wearing a mask, some preventive measures such as teleworking (or telecommuting or working from home) require social efforts. Teleworking is recommended as a means of preventing the propagation of COVID-19 in many countries. Kawashima et al. (2020) show that teleworking has a significant negative correlation with fever as a proxy symptom of COVID-19 among company employees aged 15 to 59. Also, Knittel and Ozaltun (2020) show that all commuting modes (e.g., public transportation, walking, and driving) except for biking are associated with higher death rates relative to teleworking. It is found that a 10% point increase in public transportation ridership, relative to teleworking, results in an increase of 1.21 per 1000 people in deaths.

It is worth mentioning that teleworking and school closure together had a significant impact on controlling the COVID-19 spread in France so that 8-week school closure coupled with 25% adult teleworking would cause nearly 2 months delay in the peak and 40% reduction in the case incidence at the peak, while school closure alone would have limited benefit in reducing the peak incidence (Di Domenico et al., 2020). Hence, due to COVID-19, teleworking has been increased among many organizations worldwide. A recent Deutsche Bank Research report (McKeever, 2020) even advocates a 5% tax rate on the average salary of remote workers to be redistributed to service-sector workers with incomes below a certain level who cannot work from home.

Since teleworking has strong impacts on lifestyle and commuting behavior, one of the main challenges is to determine if teleworking is going to stay even after the COVID-19 crisis. Often despite innovations, behaviors tend to stay resilient. To answer this question, one may need to know how working from home will change productivity. It should be noted that if workers are

more productive at home than in the workplace, employers would prefer to assign more remote work to the employees than before COVID-19. Accordingly, factors affecting the pervasiveness of working from home and productivity should be addressed, for which some preliminary analyses are provided below.

4.1 Factors affecting the tendency to teleworking

The use of teleworking as a response to the crisis is heterogeneous among activities and it depends on the activity of the organization. For instance, companies in the service sector present higher rates of teleworking (Belzunegui-Eraso and Erro-Garcés, 2020). In Japan, the highest increased rate of working from home belongs to communications and information services that had an increase of 10 days from February to March 2020, resulting in a total of 27 days of teleworking (Okubo, 2020).

Bartik et al. (2020) find that in the most educated quartile of industries, 64% of firms had some workers switch to remote work. In the least educated quartile of industries, only 36% of firms had any workers switch to remote work. This suggests that more educated workers are more likely to have the opportunity of working from home. Using a survey of owners and managers of small US businesses in May 2020, Bartik et al. (2020) show that as the share of female workers in the industry increases by 10% points, the share of remote workers increases by 1.7% points. A survey of 70 business economists who are members of the National Association of Business Economists (NABE) in April 2020, also shows that as the share of women in the industry increases by 10% points, the share of remote employees increases by 5% points.

4.2 How teleworking affects productivity

Teleworking occurs to affect employees' productivity. Although teleworking productivity varies by country, sector, firm size, occupational skill intensity, and so on, many studies strive to address the productivity of widespread teleworking during COVID-19. Baert et al. (2020) examined employees' perceptions of teleworking in various aspects of life and career and found that respondents mainly attribute positive characteristics to teleworking, such as increased efficiency and a lower risk of burnout. OECD (2020b) introduces a hypothetical relationship between teleworking and worker efficiency as an inverted U-shaped curve (Figure 6), in which by increasing teleworking, efficiency first increases, and then decreases. The location of the maximum depends on the sector, size, personal circumstances, etc. For instance, Raišienė et al.

(2020) show that respondents who worked remotely for up to two days a week emphasize the advantages of teleworking, and beyond that more teleworking results in some conflicts. This number can be heterogeneous among various samples. Behrens et al. (2021) also theoretically explained with a partial equilibrium model the bell-shaped curve representing the relationship between teleworking and productivity.

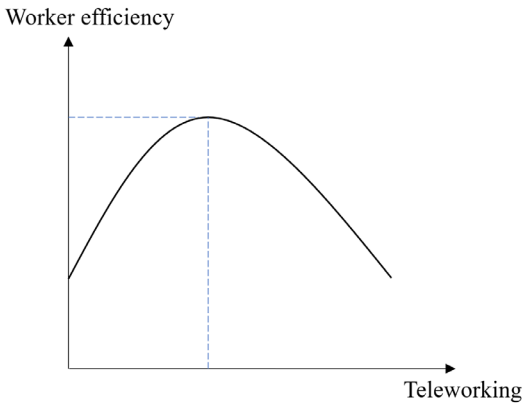


Figure 6 Hypothetical relationship between teleworking and worker efficiency (OECD, 2020b).

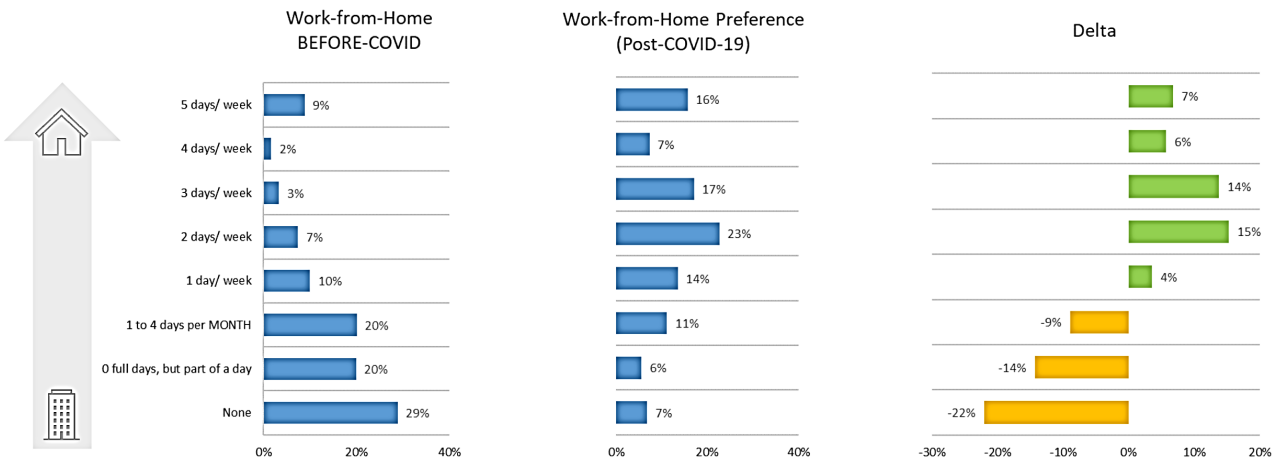
Bartik et al. (2020) show that the NABE respondents (leaders of large professional organizations for business economists) were generally positive about remote working productivity. About 28% thought that workers had become more productive through remote working and a majority believed that remote working has not involved any productivity loss. The Alignable respondents (leaders of the Small Business Owners in North America) were less optimistic, reporting an average productivity change of -0.198 (on a -1 to 1 scale, with 0 representing no change).

Employees' characteristics also play a vital role in the efficiency of teleworking. For instance, employees with children are less satisfied with the increased teleworking (Baert et al., 2020). Also, Raišienė et al. (2020) demonstrate that men evaluated working from home more negatively than women. Likewise, Bartik et al. (2020) show that as the share of female workers increases by 10% points, the probability that a respondent declares higher productivity than before increases by 11.4% points. Older generations tended to emphasize the disadvantages of teleworking (Raišienė et al., 2020). Bartik et al. (2020) also show that as the share of college-degree workers increases by 10% points, the perceived productivity of remote workers increases by 0.33% points. In Japan, high-educated and high-wage employees, as well as long-distance commuters, are more likely to

declare a relatively small reduction in working from home productivity (Morikawa, 2020). This suggests that some policies are needed to maximize the potential productivity. To achieve further productivity improvements, innovations in teleworking infrastructure and software that enable human interactions in a way similar to face-to-face communication are necessary.

4.3 Will teleworking persist once the crisis ends?

The worldwide medians of days per week for working from home are estimated to be 0.5, 5, and 2 for before-COVID-19, during COVID-19, and post-COVID-19, respectively (GWA, 2020). Therefore, widespread teleworking may remain a permanent feature of the working environment even after the crisis. A study in Belgium explains that employees believe that teleworking and digital conferencing will remain in the future with probabilities of 85 and 81%, respectively (Baert et al., 2020). Beck et al. (2020) also present that there is an attitude towards working from home even after the pandemic in Australia. Figure 7 depicts employees' preferences for days of working from home in post-COVID-19 compared to the teleworking before COVID-19, based on a survey of 2865 responses from all over the world.



Source: Global Work-from-Home Experience Survey, 2020

Figure 7 Global work from home post-COVID-19, May 2020 (GWA, 2020).

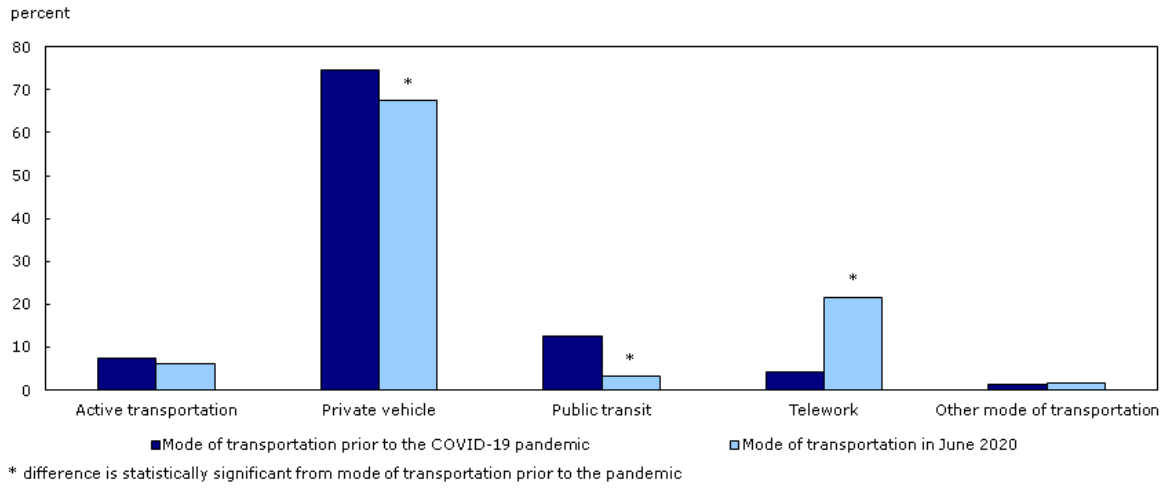
Bartik et al. (2020) indicate that 36% of NABE respondents believe that more than 40% of workers who switched to teleworking during COVID-19 would continue working remotely after the crisis ends. Also, the Alignable (leaders of the Small Business Owners in North America)

survey results were quite similar, and 40% of firms thought that 40% of their workers that switched to remote working during COVID-19 would continue so after the crisis ends.

Moreover, studies have shown that job satisfaction has increased due to the teleworking introduced during the COVID-19 pandemic, a better work-life balance has been obtained, and the relationship between managers and employees has improved (Karácsony, 2021). As a result, teleworking is very likely to remain more popular in the post-COVID era than before. If these projections prove true, this suggests a significant reduction in future demand for office space and commuting trips. This might have a rebound effect if firms start to pay less to workers who live far away and rarely come to the office.

4.4 Changes in transportation due to teleworking

Crowley et al. (2020) illustrate that commuters by car have a relatively high potential for remote working relative to those who commute by walking, bike, and motor but not more than public transportation users. As a result, during the COVID-19 outbreak, the number of work commuters by car will probably drop in the short term. Riggs (2020) presents that while total work-based trips and vehicle-miles-traveled (VMT) declined slightly due to teleworking in the COVID-19 era, an increase happens in total trips from 3.97 to 4.45. This means that while VMT and the share of driving may decline, the number of trips and engine cold starts may go up. Figure 8 also illustrates that although remote working among Canadian workers has increased five times more than before the pandemic, the share of private vehicles drops slightly. The drop in public transportation share is tangible and it decreases to a quarter of that before COVID-19.



Source: Canadian Perspectives Survey Series 3, 2020

Figure 8 Canadian commuting modes before and during COVID, June 2020 (Savage and Turcotte, 2020).

5. Effects of COVID-19 on air pollution

On the one hand, the introduction of stay-at-home restrictions to slow the spread of COVID-19 has greatly reduced transportation-related emissions. On the other hand, changes in commuting behavior, related to an increase in remote working, will affect transportation usage and bring about positive environmental outcomes. In the US, by mid-April 2020, vehicle travel dropped around 40% and electricity consumption fell around 6%, which was computed to lead to a 19% reduction in CO_2 emissions (Cicala et al., 2021). Although increased remote working can have immediate and direct environmental benefits, indirect costs associated with non-urban residential relocation increased non-work-related trips and car dependency may nullify any benefits in the longer run.

In early April 2020, lockdowns led to a 17% reduction worldwide in carbon pollution compared to the same period in 2019 (France 24, 2020b). Also, NO_2 has significantly reduced during lockdown (Crowley et al., 2020; Orro et al., 2020). Table 1 shows a summary of the studies that analyze pollutant concentrations in various parts of the world and compared the air pollution during COVID-19 to the pre-COVID-19 era. While many studies demonstrate a significant drop in air pollution, some studies explain that the decrease in pollutant concentrations is similar in magnitude to what has been observed during the same period of the previous years (Orro et al., 2020; Zangari et al., 2020). Even those who find a significant reduction in air pollution during the COVID-19 lockdown believe that the reduction did not solely depend on COVID-19, and other factors, such as weather conditions, industrial activities, and biomass burning, should be considered for further investigations. A study of 11 cities in Spain shows that lockdowns did not have a significant impact on emissions (CO, SO_2, PM_{10}, O_3, and NO_2) reduction when taking the key affecting meteorological parameters into account (Briz-Redón et al., 2021).

In addition to the effect of COVID-19 on air pollution, some studies seek the impact of pollutant concentration on COVID-19 propagation and mortality. Wu et al. (2020), for instance, find that a 1 $\mu g/m^3$ increase in $PM_{2.5}$ leads to an 8% increase in the COVID-19 mortality rate. Travaglio et al. (2021) also show positive relationships between air pollutants, especially NOx, and COVID-19 mortality in England. They find that an increase of 1 $\mu g/m^3$ in the long-term average of $PM_{2.5}$ results in a 12% increase in new cases (Travaglio et al., 2021). Another study in Italy investigates the impacts of $PM_{2.5}$ or PM_{10} on the fast diffusion of COVID-19 because these pollutants have significant adverse effects on the human immune system (Zoran et al., 2020).

Table 1 Change in air pollution during COVID-19 relative to pre-COVID-19

Study	Study Area	Time	Pollutant					
			NOx	$PM_{2.5}$	PM_{10}	O_3	CO	SO_2
Abdullah et al. (2020)	Malaysia	Mar 18 to Apr 14, 2020 compared to Mar 14-17, 2020		-50%				
Adams (2020)	Ontario, Canada	Mar 17 to Apr 14, 2020 compared to 2015-2019	-2 ppb (29%)	NS		-1 ppb (3%)		
Barua and Nath (2021)	Europe excluding the EU and the UK East Asia and the Pacific Middle East and Central America South America	Feb 15 to Apr 17, 2020					-8% -4% -3% -2%	
Berman & Ebisu (2020)	U.S.	Jan 8 to Apr 21, 2020 compared to 2017-2019	-25.5%	-4.8 ppb				
EEA (European Environment Agency) (2020)	Milan, Italy Bergamo, Italy Rome, Italy Barcelona, Spain Madrid, Spain Lisbon, Portugal	Mar 16-22, 2020 compared to 2019	-21% -47% -26 to 35% -55% -41% -51%					
Faridi et al. (2020)	Tehran, Iran	Feb 20 to Apr 2, 2020 compared to 2019		+20.5%	+16.5%			
Ghahremanloo et al. (2021)	Beijing-Tianjin-Hebei, China Wuhan, China Seoul, Korea Tokyo, Japan	Feb 2020 compared to Feb 2019	-54% -83% -33% -19%				-8% -4% -6% -1%	~0 -71% +38% +243%
Ju et al. (2021)	Korea	Mar 2020 compared to 2019	-20.4%	-45.5%	-35.6%		-17.3%	
Blumberg (2020)	Northeast U.S.	Mar 2020 compared to 2015-2019	-30%					
Orro et al. (2020)	A Coruña, Spain	Mar to Jun 2020 compared to 2017–2019	-2.7 g/m^3N		NS			
Rodríguez-Urrego (2020)	50 most polluted capital cities	During quarantine (depending on the city) compared to before		-12%				
Zangari et al. (2020)	New York City	Jan to May 2020 compared to 2015-2019	NS*	NS				

* Not significant

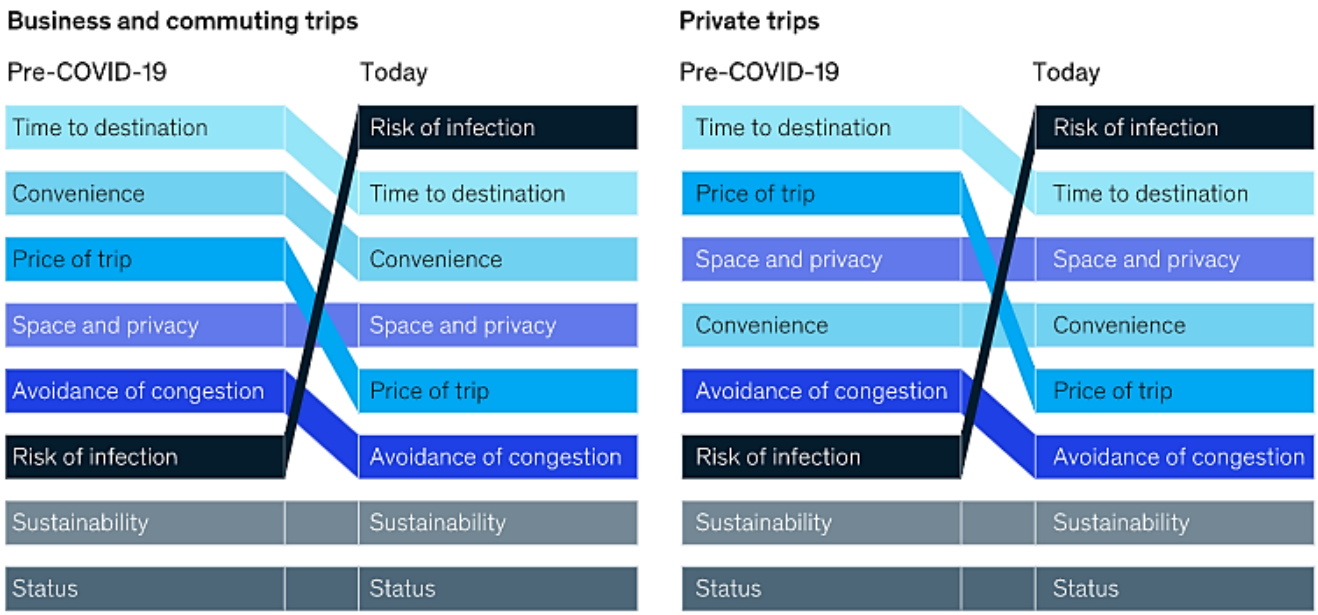
6. Effects of COVID-19 on road transportation

In this section, the impacts of COVID-19 on different aspects of transportation including mode preferences, public transportation usage, and peak spread are discussed.

6.1 How does mode choice change during the COVID-19 outbreak?

A McKinsey survey (in the United States, United Kingdom, Germany, France, Italy, Japan, and China) investigated the factors affecting mode choice before and during COVID-19 (Hattrup-Silberberg et al., 2020). Figure 9 illustrates how key factors in mode choice have changed compared to pre-COVID-19 for private and business trips. Cost and convenience have traditionally played key roles in travelers' mode choice decisions. However, reducing the "risk of infections" is the top reason for mode choice during COVID-19, even much more important than travel time, for both private and business trips. Interestingly, the price of a trip has lost importance, especially for private trips (ACT, 2020).

Since reducing the "risk of infections" is now a priority in mode choice decisions, the high risk of exposure to the virus in public transportation brings about a sharp reduction in its usage. In contrast, using auto vehicles is increasing, in part due to lower travel time, adequate free parking, and the absence of road pricing due to the pandemic. Using data from the first half of 2020 over data of 2017-2019 in A Coruña, Spain, Orro et al. (2020) find that the new normal share for bike, bus, and the total traffic volume is less than that before COVID-19, but the total traffic volume and the shared bike system recovered a higher percentage of their previous use than the bus (see Table 2).



Source: McKinsey Center for Future Mobility

Figure 9 Ranking of key reasons for transportation mode choice, September 2020 (Hattrup-Silberberg et al., 2020).

Table 2 Traffic volume and mode share changes during COVID-19 in A Coruña, Spain

	Before	Initial lockdown	Severe lockdown	Open up Phase 0	Open up Phase 1	Open up Phase 2	Open up Phase 3	New normal
Traffic Volume	100	30	17	32	55	70	75	85
Bus demand	100	15	9	12	20	35	45	60
Bicycle usage	100	0	0	40	50	70	50	70

Source: Extracted by authors from Figures 5, 6, and 7 in Orro et al. (2020)

A survey of 10,000 US workers, with 78% of full-time workers, compares commuting modes before and during COVID-19. Based on this information provided in Table 3, when respondents are asked which modes they might take to the workplace, 44% (51%) of respondents reported driving alone, and 12% (less than 2%) reported teleworking, as their main commuting mode during COVID-19 (before COVID-19) (ACT, 2020). Interestingly, the share of respondents who reported biking and scootering as their main commuting modes has increased to 11%, which is more than twice as before COVID-19 (ACT, 2020). Also, another study in Bangladesh finds that, in the new normal condition, 56% and 45% of the respondents are expected to increase their trips by walking and bike, respectively, compared to the pre-COVID era (Zafri et al., 2021). Similar results have been found in Toronto in July 2020, where walking increased to 23.5% (which was 15.3% before the pandemic), and cycling increased to 8.9% (which was 5.5% before the pandemic) (Loa et al., 2021).

Table 3 Share of American workers commuting by each mode before and during COVID-19 (ACT, 2020)

Time \ Mode	Drive alone	Public bus	Carpool	Bike/Scooter	Subway/Train	Walk	Commuter rail	Other	Telework	Vanpool	Private bus	Ferry	Taxi	Sum
Pre-COVID-19 (%)	51.1	19.4	9.4	4.9	4.1	2.8	2.6	1.9	1.8	0.9	0.7	0.2	0.2	100
During COVID-19 (%)	44.0	7.5	8.9	11.2	3.7	3.0	2.1	4.7	11.7	0.8	0.8	0.6	1.1	100

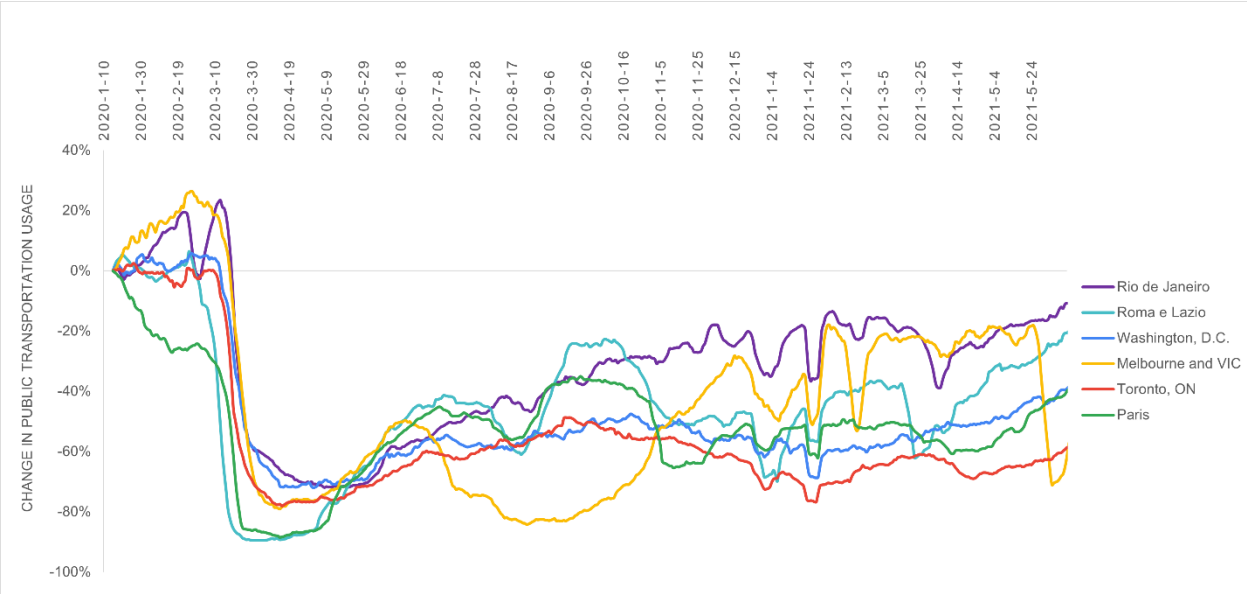
Source: Extracted by authors from figures in ACT (2020)

Since many studies show that the demand for active transportation modes including biking and walking has increased, the pandemic can lead to a more sustainable way of living if city planners seize the opportunity. A study, for instance, tested various scenarios in Italy about adding more

bicycle lanes and pedestrian areas into a city and concluded that the share of cycling can increase to 29-35% from 14-20% (Scorrano and Danielis, 2021). Since this extra demand for bikes can happen due to a decrease in other active modes such as walking, auxiliary policy implementations and interventions may bring about the enhancement of walking tips.

6.2 Reduction in public transportation usage and the financial issues

The congested public transportations, especially subways, have been recognized for propagating infection across the city since the beginning of the outbreak (Fathi-Kazerooni et al., 2020). To show the effectiveness of public transportation restrictions in limiting the spread of the COVID-19 pandemic, Harris (2020), using zip code data for New York City, estimate that for a 10% point reduction in subway ridership during the first three weeks of March 2020, the cumulative number of infected declined by around 12 cases per 10,000. In another study, a 17 to 27% reduction in the total COVID-19 cases per capita is estimated for every 10% point fall in mobility in Atlanta, Boston, Chicago, and New York City (Redding et al., 2020). A correlation of 0.44 is found between change in the numbers of trips and COVID-19 cases per capita (Redding et al., 2020). As a result, public transportation usage around the world decreased dramatically right after the initial lockdowns. It continued decreasing during March and April 2020, but it started increasing in June 2020 when some restrictions were released. However, all these studies agree on the fact that the demand for public transportation in the "new normal condition" is still less than that before COVID-19 and might never come back to the previous normal. Figure 10 demonstrates how public transportation usage around the world drops and does not reach the previous normal by May 2021. On Feb 10, 2021, for instance, Washington, Paris, Rome, Melbourne, and Rio's public transportation demands were 59.9, 50.8, 40.0, 22.0, and 17.6% lower than normal conditions before COVID-19 (Moovit, 2021).



Source: Moovit Public transport index

Figure 10 Use of public transportation around the world, Jan 2020 - May 2021 (Moovit, 2021).

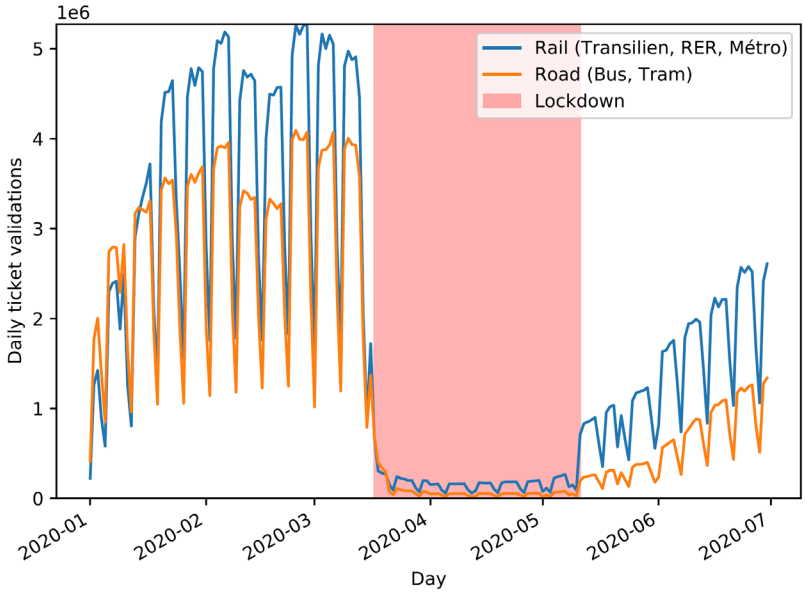


Figure 11 Daily ticket available for public transportation in Paris, Jan-Jul 2020[5].

Figure 11 also depicts the Paris public transportation usage before, during, and after the lockdown. Daily tickets available are higher for rail compared with bus and tram. These available

[5] Diagram is extracted by Lucas Javaudin, using data from https://data.iledefrance-mobilites.fr/explore/dataset/validations-sur-le-reseau-ferre-nombre-de-validations-par-jour-1er-sem/ and https://opendata.paris.fr/explore/dataset/comptages-routiers-permanents/.

tickets drop approximately to zero during the lockdown. Right after the lockdown, daily tickets available start to increase; however, rail transportation (Transilien, RER, Métro) appears to recover faster.

Recent research indicates that the awareness of the disease, the perception of the lockdown strictness, and the perception of safety in public transportation undoubtedly affect people's preferences toward using public transportation (Aaditya and Rahul, 2021). It is worth mentioning that age and gender are highly correlated with the perception of safety so that younger people and men feel safer using public transportation (Aaditya and Rahul, 2021).

The significant drop in public transportation rideshare raises the concern that the pandemic could pose a notable threat to social equity and sustainable mobility, and also could bring about financial challenges for public transportation operators around the world (Tirachini and Cats, 2020). The public transportation providers have encountered financial issues due to a significant decrease in fares revenues. In the data submitted by UITP (The International Association of Public Transport) members by May 2020, many European countries faced huge losses in the public transportation sector (Smith, 2020). For instance, Ile-de-France Mobility reported losses of €2 Bn since the beginning of lockdown restrictions in mid-March 2020, and public transportation operators in Spain, Finland, and Sweden are currently losing €250 m, €192 m, and €100 m per month, respectively, in fare revenues (Main Spring, 2020). As a result, city planners need to look for policy implementations to make public transportation safer and more efficient during and after the pandemic.

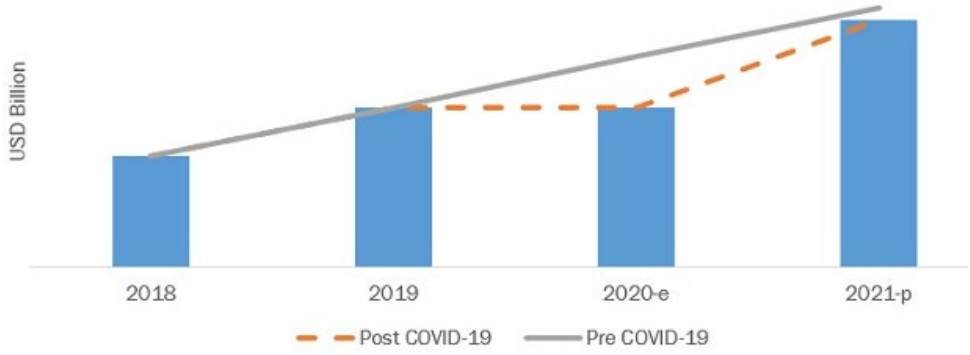
Among the studies that have analyzed the effects of various actions on public transportation safety, Schwarts (Schwarts, 2020) finds that based on 150 million rides on New York City Transit between June 1 and August 18, public transportation plays no significant part in the spread of COVID-19 as long as proper precautions such as making one seat available out of two, wearing a mask, and controlling travelers' temperature are taken. Another study (Zhou and Koutsopoulos, 2020) demonstrates that mask-wearing and ventilation are effective mitigation methods under various demand levels. When the demand levels are lower than 30% of the base case (pre-COVID), the risk is relatively low, and the differences among the various strategies are small. When the demand level exceeds 70%, the risk increases more rapidly. However, actual and perceived risks differ, as shown in behavioral economics. Also, Tirachini and Cats (2020) discuss the potential policy interventions to avoid crowded public transportation and boost public health considerations to reduce or eliminate the adverse effects of reduced public transportation demand in the future.

6.3 Taxi and ridesharing market and financial issues

The demand for taxis and ridesharing services, such as carpooling and ridehailing, has profoundly diminished due to both reduced service operations and users' concerns about being infected with the virus in shared vehicles. Nian et al. (2020) investigated the impact of COVID-19 on taxi travel behavior in Chongqing, China. The results show that the number of taxi trips dropped sharply during the pandemic, and travel speed, travel time, and spatial distribution of taxi trips have been significantly influenced. Another study in New York shows a 92% reduction in the demand for Yellow Cab during the early days of the pandemic compared to 2019 (Manley et al., 2021). This study also discusses that COVID-19 has changed the demand for taxis both spatially and temporally (Manley et al., 2021).

With the impact of COVID-19, the global ridesharing market, including different service types (e-hailing, rental car, carpooling, etc.) with different key players (Uber (US), Lyft (US), DiDi (China), Grab (Singapore), Gett (Israel), Ola (India), BlaBlaCar (France), Lime (US), and Herts (US)), lost its share by 50–60% during 2020 (Markets and Markets, 2020). The reduced market share has adverse effects not only on service providers but also on service receivers. Anxiety, cancellation, job loss, and income reduction are among the negative outcomes for service receivers (Kaur, 2021). From the service providers' perspective, the worst impact of reduced market share can be the loss in revenue which might be enormous. In the first three quarters of 2020, for instance, Uber announced a loss of US$ 5.8 Bn (O'Brien, 2020). A study in Egypt reveals that perceived infectability and fear of COVID-19, interestingly, are not found effective on users' intention to use the ridesharing services (Rasheed Gaber and Elsamadicy, 2021); however, performance expectancy (boosting users' productivity), economic benefits (saving time and money), facilitating conditions, and social influence are the factors that significantly encourage Uber customers to continue using the app during the pandemic (Rasheed Gaber and Elsamadicy, 2021).

It is predicted that, by 2021, the ridesharing market will gain its share by 70–80%. As a result, it is expected that the size of the ridesharing global market hits US$ 117 Bn, in 2021, which is almost 55% higher than 2020 (US$ 75 Bn) (Statista, 2021b). Figure 12 demonstrates how much ridesharing is projected for 2021.



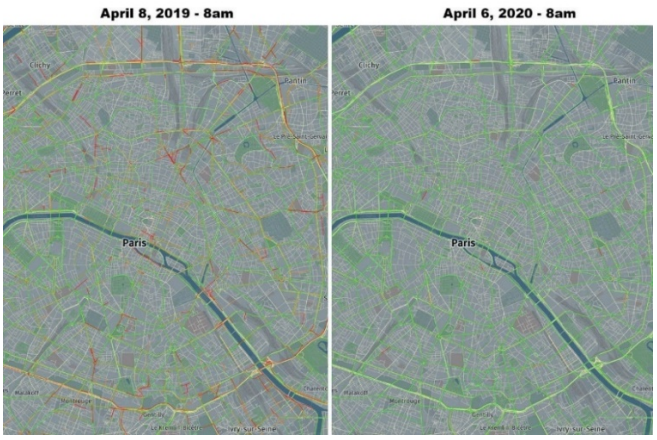
Source: Markets and Markets

Figure 12 Global ridesharing market pre- and post-COVID-19 (Markets and Markets, 2020).

A study in the U.S. examined the factors affecting the ridesharing services demand reduction and found that age and income are negatively correlated with using ridesharing services (Said et al., 2021). Also, the authors found that public transportation users are very likely to shift to ridesharing services due to COVID-19 (Said et al., 2021), indicating that taxies and ridesharing services play a vital role in social equity, especially during the pandemic. Thus, the governments need to take into account the evolving pandemic experiences and develop deliberate policies not only for this pandemic but also to deal with the possible future pandemics.

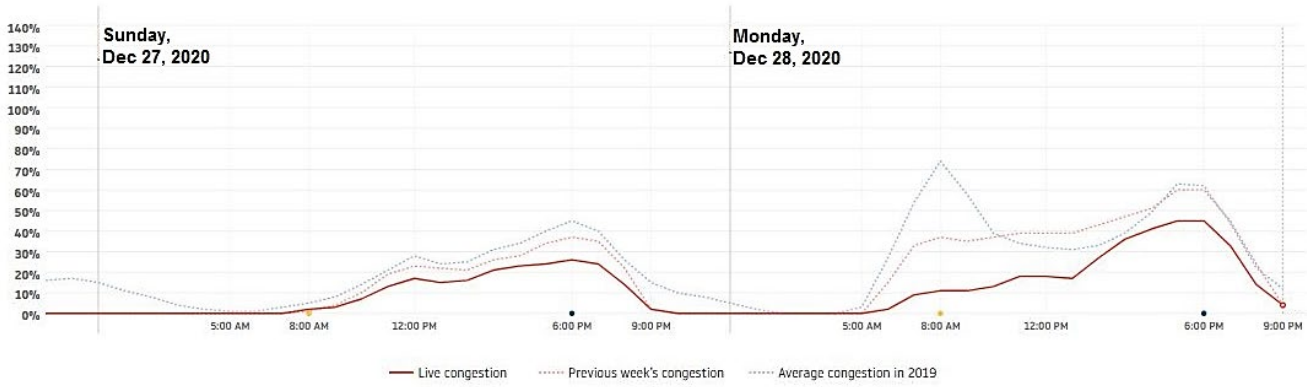
6.4 Peak spread

Traffic patterns have significantly changed during the first COVID-19 wave. The main change is that the morning rush hour has been almost eliminated. For instance, Figure 13 compares peak hour traffic volume at 8 am on April 8th, 2019 (pre-COVID-19) with the same time and roads on April 6, 2020 (during COVID-19), in Paris, where the state of confinement was: ban on all trips except for professional activity, buying essential goods, health or family reasons, or brief individual exercise. People outside the home were supposed to carry identification and a signed and dated declaration for any travel. Figure 14 depicts the daily patterns of traffic volume in Paris showing that morning and evening peak congestion levels (percentage of increase in travel time compared to free-flow travel time) were 63% and 18% lower, respectively, on Monday 28th Dec 2020 than the average Mondays in 2019. Figure 15 illustrates the demand for public transportation in Paris on Sunday 27th Dec 2020 and Monday 28th Dec 2020 which were 67% and 78% less than the normal, respectively.



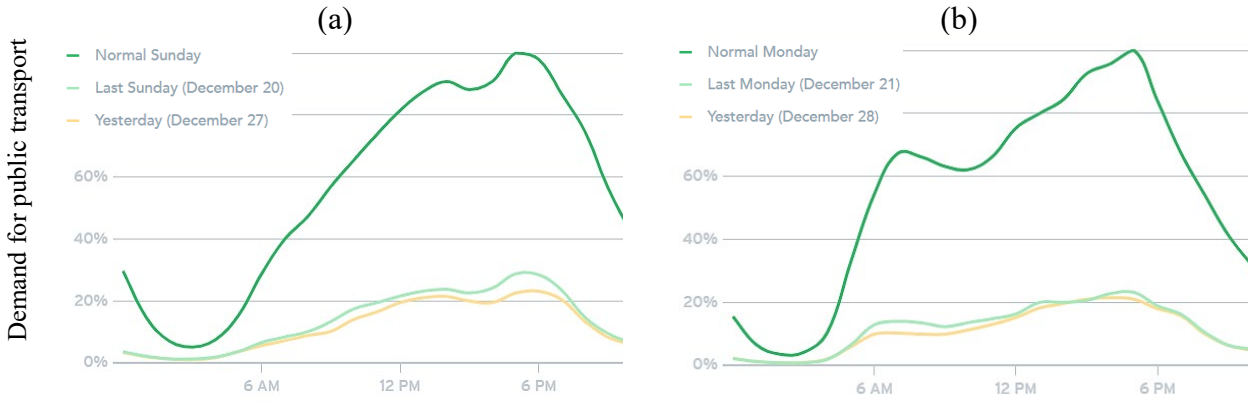
Source: 360.here.com

Figure 13 Paris peak spread – 96.8% reduction in traffic (Dickson, 2020) (red routes have heavy congestion, yellow is moderate, and green is clear).



Source: TomTom traffic index

Figure 14 Hourly congestion level in Paris, December 27 and 28, 2020 (TomTom, 2020).



Source: Transit.com

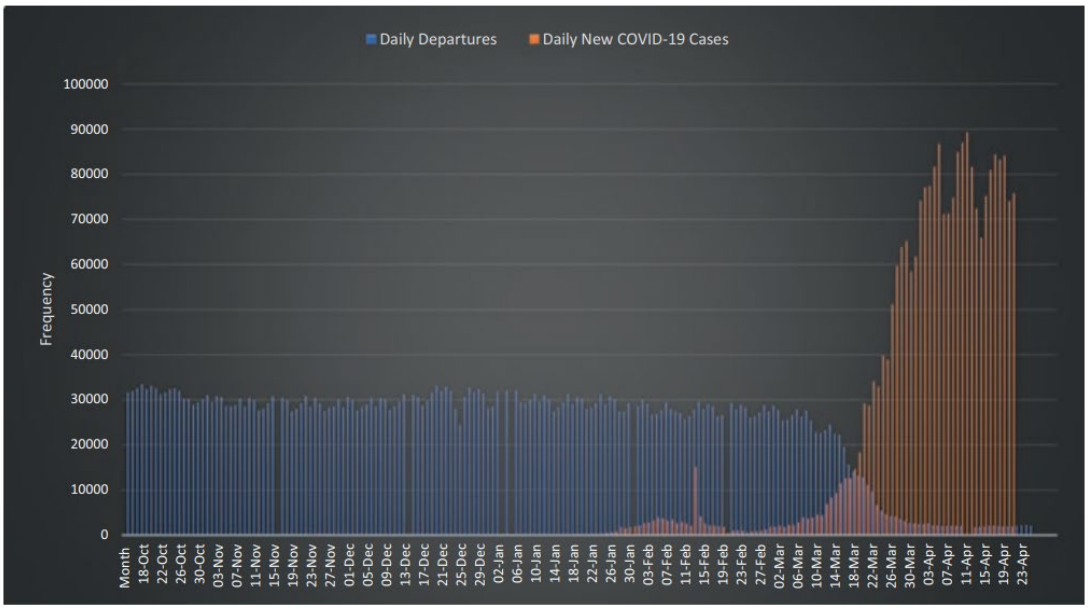
Figure 15 Demand for public transportation by the time of day in Paris (Transit, 2020): (a) Sunday 27th Dec 2020, compared with normal Sundays, and (b) Monday 28th Dec 2020, compared with normal Mondays. Note that peak demand on a normal day is considered as 100%

7. Effects of COVID-19 on air transportation and tourism industry

In this section, we discuss the profound effects of COVID-19 on air transportation and the international tourism sector.

7.1 Air transportation demand reduction and financial issues

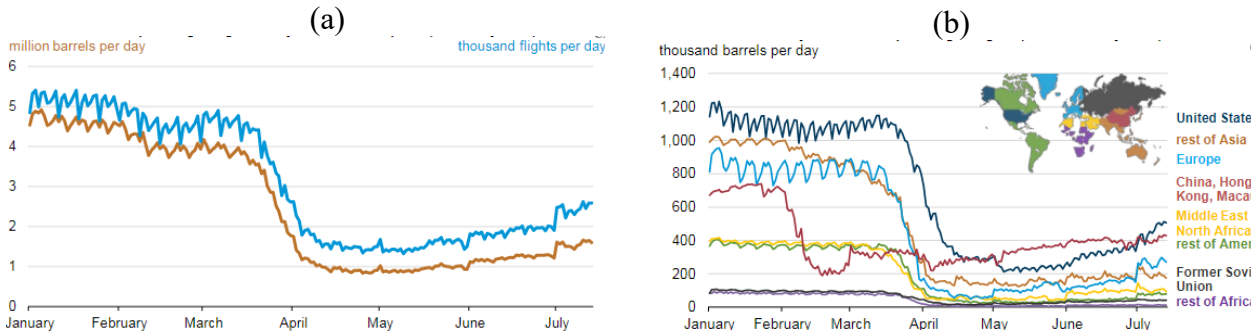
The COVID-19 outbreak resulted in a decline in global departures. As shown in Figure 16, global departures dropped to less than 10,000 aircraft, 10 days after the pandemic declaration. By the end of April 2020, there were fewer than 2,000 departures on average. Around 95% of the departures were lost globally, and flying hours declined by 56% and 76% in North America and Asia, respectively (Nhamo et al., 2020). Due to the decrease in air travel, aircraft were grounded across the world. Besides airport parking challenges, many economic and employment issues have occurred because of COVID-19 travel restrictions (de Palma and Vosough, 2020) for more details). The dramatic drop in demand for air transportation due to COVID-19 resulted in approximately US$ 371 Bn loss of gross passenger operating revenues of airlines in 2020 (ICAO, 2021). Since the decline in world total passengers in 2021 is estimated to be less than 2020, the loss of gross passenger operating revenues of airlines is estimated to be US$ 313-324 Bn (ICAO, 2021). Bankruptcies or mergers among air transportation companies due to the reduced passenger demand could have adverse impacts on competition in air transportation.



Source: Nhamo et al. (2020), using data from ICAO

Figure 16 Daily departures at all airports and daily new COVID-19 cases, Oct. 2019 –Apr. 2020 (Nhamo et al., 2020).

Given the collapse in air transportation demand, the fuel used by airlines declines sharply. As shown in Figure 17 (a), the air transportation sector's fuel consumption fell globally from an average of 4.3 million barrels per day in January and February 2020 to 1.0 million barrels per day in April 2020. Figure 17 (b) depicts the daily fuel consumption of the air transportation sector for different parts of the world.



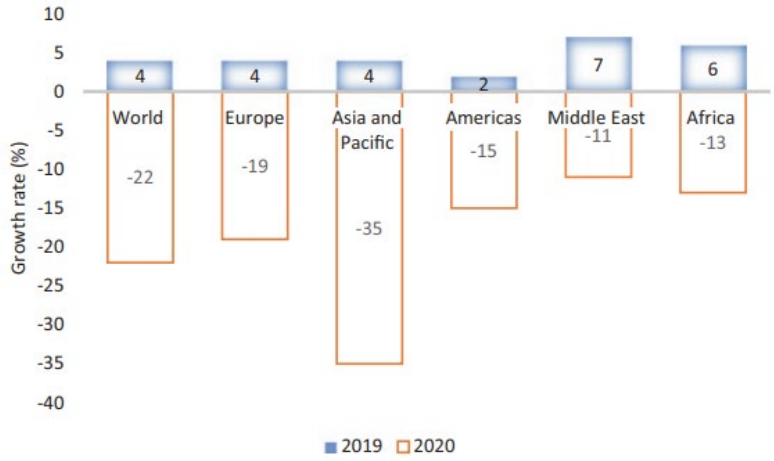
Source: U.S. Energy Information Administration (EIA), Cirium, EUROCONTROL

Figure 17 Global commercial passenger flights and jet fuel consumption, Jan.–Jul. 2020 (EIA, 2020): (a) The whole world; (b) By region.

As time goes by, the air transportation demand and the fuel consumption rebound to the level before the COVID-19 era. In China, for instance, fuel consumption in the first half of 2020 was calculated to be 0.38 of that in 2019 while in the second half of 2020, it increased to 0.85 (Xue et al., 2021). Aviation authorities need to forecast the demand to not only support their operational decisions but also evaluate aircraft emissions for the sake of environmental plans such as the European Green Deal (European Commission, 2019). The air passenger demand prediction is essential to make decisions and prevent financial damages. Hence, many studies strived to forecast air passenger demand. For example, de Palma and Vosough (2020) estimate that the number of Instrument Flight Rules (IFR) in 2024 will hit the number of IFR in 2019 if vaccination is done in 2021. If the vaccination is done in 2022, the number of IFR flights in 2028 will be the same as in 2019. Similarly, a study (Gudmundsson et al., 2021) reveals that the global air transportation demand will recover by mid-2022 under the most optimistic scenario, while the recovery will take until 2026 under the most pessimistic scenario. The recent increase in energy prices will somewhat reshuffle the cards.

7.2 International tourists arrivals

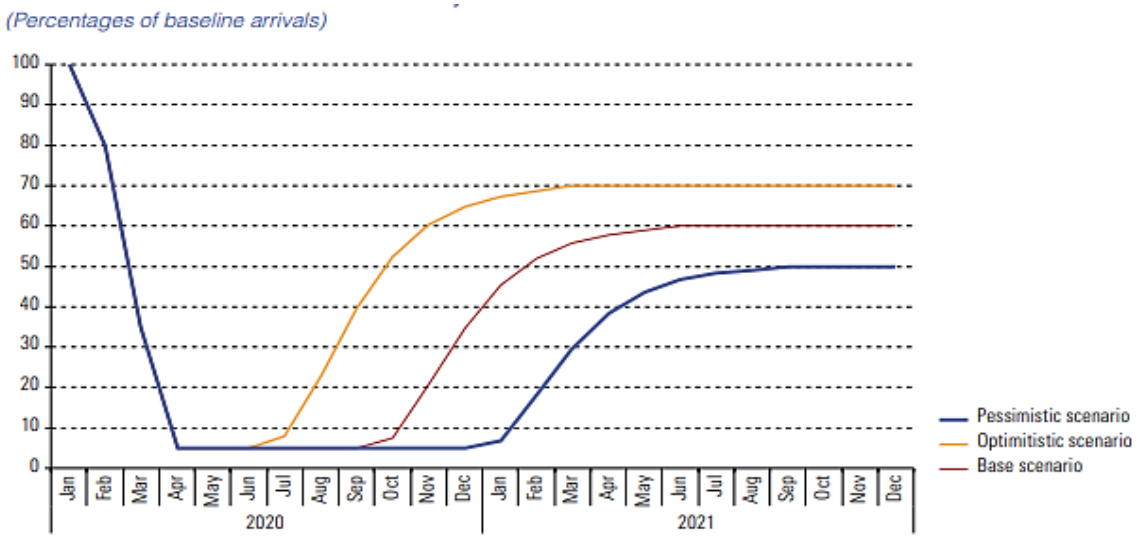
It is shown that the numbers of COVID-19 cases and deaths in a country are highly correlated with the number of inbound and outbound tourists; for instance, it is estimated that a 1% increase in tourists leads to 1.2% and 1.4% higher cases and deaths, respectively (Farzanegan et al., 2021). As a result, global tourist arrivals dropped significantly during the pandemic, as shown in Figure 18. Blue bars show the growth rate of tourist arrivals in 2019 relative to 2018 in various regions while orange bars demonstrate the drops in tourist arrivals in 2020 during the pandemic relative to 2019. The drop in tourist arrivals costs the world nearly US$80 Bn in export revenue in the first 3 months of 2020 (Nhamo et al., 2020). Data from the United Nations World Tourism Organization (UNWTO) shows that various global tourism regions have been severely affected, albeit variations can be observed across regions, with the least impact noted in the Middle East and Africa (Nhamo et al., 2020).



Source: Nhamo et al. (2020)

Figure 18 Global tourism growth rate for Q1 of 2020 compared to 2019 (Nhamo et al., 2020).

The expected time for tourism industry recovery was expected to be 10 months due to previous shocks; however, for COVID-19, the recovery time will be significantly longer (Škare et al., 2021). Figure 19 illustrates tourist arrivals in 2020 and 2021 for three scenarios (optimistic, base, and pessimistic scenarios) in Caribbean tourists' arrival. Given the optimistic scenario, tourist arrivals for 2021 are projected to be 70% of those before the pandemic (ECLAC, 2020). Accordingly, researchers strive to present a framework about how the tourism industry can be revived (Sharma et al., 2021).



Source: Economic Commission for Latin America and the Caribbean (ECLA)

Figure 19 The Caribbean three scenarios for recovery in tourist arrivals (ECLAC, 2020).

8. Medium and long-term effects of COVID-19

This crisis might have profound medium and long-term effects on car ownership, relocation, employment rate, poverty, and house price. Hence, the synthesized analysis provides policymakers with a cautionary lesson for addressing the importance of paying attention to the future of urban development, public transportation, and behavioral strategies to tackle COVID-19 negative consequences. In this section, we aim at reviewing some changes that will bring about changes in activity and travel behaviors in the long run.

8.1 Car ownership

Findings from the first wave of COVID-19 show that in May 2020 car purchase was 17% lower than pre-COVID-19 (Furcher et al., 2020) probably because consumers encountered financial issues and decided to spend less (Coibion et al., 2020). This reduction in the car market was not uniform geographically. In Europe, it was down 20-30%, while China had recovered to the pre-COVID-19 level (Furcher et al., 2020). In August 2021, McKinsey survey results (Furcher et al., 2021) indicate that global car purchase intention revived from the COVID-19 shock. A significant rise has been found in electric vehicle purchases, especially in Europe and China (Furcher et al., 2021). Since, nowadays, people are less likely to use ridesharing and public transportation, car ownership might still increase. If this holds, it may cause the largest long-term

effect of COVID-19. Because once people own a car, they tend not to get rid of it, and in parallel people who own a car tend to drive more.

8.2 Relocation

The results of a survey (Cohn, 2020) show that 3% of Americans moved permanently or temporarily due to COVID-19 by early June 2020. The most important reasons for moving among U.S. adults due to the pandemic are announced reducing the risk of infection (28%), closed college campus (23%), being with family (20%), financial issues (18%), job loss (8%), and other money-related reasons (10%).

The pandemic has also led to a great decline in the demand for housing in neighborhoods with higher population density due to the diminished need for living close to jobs (telework-compatible) and the declined access to amenities. Thus, home sales in central cities and dense neighborhoods dropped more than those in other locations since the outbreak. Based on a report by British property firm Savills, 71% of younger UK homebuyers said outdoor space and rural locations had become more important to them since COVID-19 (Wintle, 2020). This calls for a potential geographical decentralization of the country and its urban economies. It will be positive in terms of a better distribution of density and activity across many cities. However, the suburban lifestyle is more oil-intensive compared to its urban counterpart. For example, the increase in oil use because of pandemic-related moves from New York City (NYC), Los Angles, and Chicago into suburbs is estimated to be 11.6 million barrels per year with a migration rate of 5% in NYC and a 3% migration rate for other metropolitans (Young, 2020).

8.3 House price

As a result of the pandemic, house prices have changed. Based on the IMF report, global house prices were increasing during 2020, and the price indices were calculated to be 166.0, 167.4, 169.0, and 169.8 in 2019Q4, 2020Q1, 2020Q2, and 2020Q3, respectively (IMF, 2021). The increasing trend does not apply to a few countries around the world such as India, United Arab Emirates, Philippines, Colombia, Morocco, Hungary, Peru, etc., where the house price reduced compared with before COVID-19 (IMF, 2021).

In Metro Vancouver, apartment prices have been falling recently (Mortgage Sandbox, 2020). They appear to be falling out since people seek larger living spaces where they can work from home. In selected capital cities in Europe, the year on year house prices increased 0.7% points less

than the whole euro area. This reflects the increased possibilities for decentralization of countries due to working from home, which can be permanent (Roma, 2021).

Data suggests that the worldwide growth of rent, in the short run, is often negatively affected by the number of COVID-19 cases (Ouazad, 2021). Since working from home requires more home space, relocations happen and tend to affect the rent gradient. Data also suggests a more contrasted situation that despite the substantial short-run impact on the flow utility of housing in metropolitan areas, the pandemic does not significantly affect buyers' long-run expectations of the value of living in those areas with large numbers of COVID-19 cases.

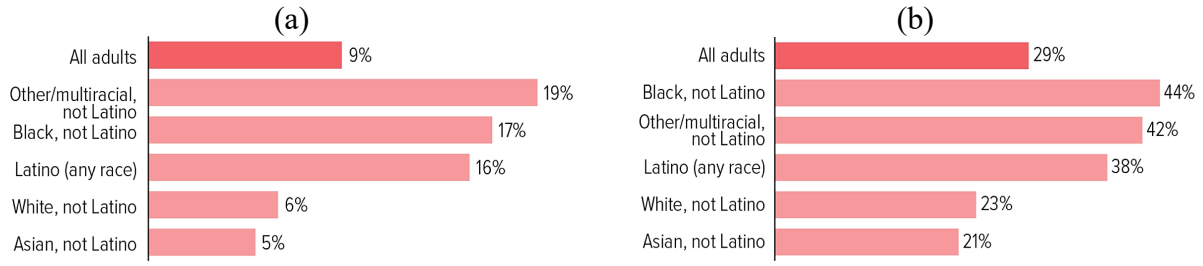
8.4 Poverty, job loss, and inequality

Poverty is of one the main barriers to accessibility and mobility to meet human basic needs. On the one hand, social restrictions during the pandemic lead to income loss and poverty. Based on the World Bank predictions, COVID-19 pushed about 49 million people into extreme poverty in 2020 (Sánchez-Páramo, 2020). IMF (2020) demonstrates that lockdowns have a significant adverse effect on job postings, and job postings are estimated to decline by 12% two weeks after the introduction of the lockdown. On the other hand, the poor are less likely to comply with the restrictions, so a faster spread of COVID-19 has occurred among poorer regions (Bargain and Aminjonov, 2021). This raises the concerns for policymakers that restrictions cannot be helpful if no consumption support is taken to account, especially in poor areas. The support can be conveyed in the form of cash or food (Bargain and Aminjonov, 2021).

Decerf et al. (2021), using data from 150 countries, estimate that more than 68 million additional years spent in poverty were imposed on the world due to the COVID-19 pandemic by early June 2020. Sumner et al. (2020), assuming a 5% contraction in per capita incomes, estimate that the world would experience an increase in the number of poor people of more than 80 million, 130 million, and almost 124 million for the US$1.9/day, US$3.2/day, and US$5.5/day poverty lines, respectively, relative to 2018.

As shown in Figure 20, based on the Bureau Household Pulse Survey in October 2020, American Black adults (18%) and Latino adults (17%) were more than twice as likely as white adults (7%) to report that their households did not get enough to eat (CBPP, 2021). Some people have not caught up on rent payments (10.3 million adults in the US), and have difficulty paying for household usual expenses (more than 80 million adults in the US) (CBPP, 2021).

COVID-19 has also increased inequalities (as measured by the Gini index (World Bank, 2020)) within countries and more importantly across countries (Shadmi et al., 2020). Even the impact of COVID-19 is likely to vary for the different spouses in a household because the balance of power within the family changes and most probably women will suffer (de Palma et al., 2021). Moreover, working from home most probably influences skilled workers less than unskilled workers, which may raise income inequality (Behrens et al., 2021). As a result, policymakers, based on new studies in this field, must make sure that the vulnerable segment of the population is provided with their basic needs including health services and food.



Source: Created by the Center on Budget and Policy Priorities (www.cbpp.org)

Figure 20 Share of adults reporting financial issues during COVID-19 in the US, October 2020 (CBPP, 2021):
(a) their households sometimes or often did not have enough to eat in the last 7 days.
(b) they have difficulty paying for household usual expenses.

8.5 Redesigning and respacing cities

As consumer behavior has shifted during the pandemic, decision-makers have increasingly put cities at the center of their concerns. The optimistic argument is that COVID-19 is an opportunity for city planners to assign more street space to pedestrians and cyclists, moving cities closer to becoming sustainable and resilient with a lower carbon economy. For instance, Milan (Italy) transformed 35 km of streets previously used by cars into walking and cycling lanes after the lockdown (May to December 2020); Paris (France) devoted 50 km of lanes usually reserved for cars to bicycles during the lockdown in summer 2020, and Brussels (Belgium) assigned 40 km of car lanes to bike paths in May 2020 (Vandy, 2020).

To place positive incentives for active transportation modes, cyclists can claim rebates for every kilometer cycled into work in several European countries. In the Netherlands with the highest cycling rates in the world, for instance, cyclists can claim €0.19 for every kilometer cycled

to work (Ministerie van Algemene Zaken, 2020). In response to COVID-19, French employees who can prove the use of sustainable transportation modes such as ridesharing and cycling are paid up to €400 tax-free funds per year from the Sustainable Mobility Package announced by the government (Sung & Monschauer, 2020).

Although cities are repurposing streets to meet higher demands for walking and cycling, not everyone can walk or ride a scooter or bike to their destinations. Thus, public transportation must remain at the heart of urban mobility. For this purpose, public transportation should be redesigned to cope with COVID-19's preventive actions both in vehicles and stations. The Berliner Verkehrsbetriebe (BVG), for example, altered the hours of operation for better alignment with medical shifts; it also limited all vehicles at 50% capacity to enable physical distancing (Cooperman, 2020).

Parking policies have been changed in some cities due to COVID-19 as well. For instance, in France, on-street parking was free in many places during the first lockdown in Spring 2020 (The connexion, 2020). Rotterdam (Netherlands) also allowed businesses to take over the parking spaces directly in front of their buildings, without a permit (Robertson, 2020).

Bereitschaft and Scheller (2020) address how cities might use planning and design strategies to improve resilience (the capability of recovering quickly from disruptions) confronting COVID-19 as well as future pandemics. Their recommendations include (1) designing, financing, constructing, and maintaining public green spaces and corridors near residences, (2) expanding outdoor walk spaces near businesses, (3) implementation of increased and innovative public transportation sanitation practices, and (4) planning municipal and intergovernmental strategies for future pandemics. Resiliency is favored by the high quality of education, good diversification in industry and services, high-quality local amenities, and, especially in the US, racially integrated neighborhoods. In this case, cities are capable of facing large shocks. This is neither a rule nor a theorem, but it is driven from lessons based on past studies which can serve as a guide.

9. Conclusions

9.1 Summary

The COVID-19 pandemic is not a minor event. No one can be quite sure about what the pandemic considers for our future. In this extremely complex time, the characterization of the range of impacts of the COVID-19 is crucial. The COVID-19 crisis is likely to bring major changes

to mobility, transportation, the environment, the tourism industry, and air transportation. Hence, the goal of this study is to provide an overview of the effects of COVID-19 on mobility and lifestyle in the transportation research field to recognize the changes, their adverse effects, and new opportunities. Since some of these changes will persist even after the COVID-19 crisis, identifying the behavioral changes and their consequences will help policymakers to mitigate the negative outcomes that directly relate to several economical, psychological, and social well-being consequences.

During COVID-19, confinements and restrictions (to varying degrees) lead to significant changes in household lifestyles (as workers or consumers). When individuals are forced to quarantine or see less of nature, their friends, acquaintances, and relatives, or even not to hug their beloved ones, they tend to accumulate stress, anxiety, and depression (Burke et al., 2020). Reducing physical activity and spending a lot of time using mobile phones and computers during the pandemic bring about cardiovascular disease, obesity, and other health problems (Mattioli et al., 2020). Such changes might have enormous economic and mobility consequences. In the short term, COVID-19 changes departure time choices, mode choices, activity destinations, and route choices. In the long run, car ownership will increase especially for car-insufficient households. Therefore, governments must be prepared to face these phenomena.

The decrease in socio-economic activities and the demand for transportation (urban, inter-urban, and air travel), negative per se, also has positive aspects: the reduction in global coal demand (8% compared to 2019 (IEA, 2020)), oil demand (5%), gas consumption (2%), electricity demand (20%), traffic accidents (74.3% in Spain (Saladié et al., 2020)), and emissions (Table 1). Total work-based trips and VMT also have declined due to expanded teleworking in the COVID-19 era, but an increase happened in the total number of trips. As a result, the number of engine cold starts may go up. This confirms that without any intervention, the trend could yield more short trips and vehicle cold starts particularly on local roads, especially in places where auto vehicles continue to rely on internal combustion engines, without having access to the necessary resources to facilitate clean energy transition.

Another key issue during the COVID-19 era is that equality has deteriorated and certainly poverty has increased worldwide (within and across countries). Because of lockdowns, job postings declined, and the unemployment rate experienced a surge (de Palma et al., 2020) for more information about economic assessments of lockdown). Accordingly, raising awareness about all aspects of this disruptive shock, designing appropriate spatial and transportation responses (such

as re-spacing cities and re-scheduling public transportation services), and investing in the preparedness of the probable future pandemics are necessary.

Cost and convenience, which traditionally played key roles in mode choice decisions, are (partially) replaced by reducing the risk of infections. Such behavior can shift travel demand back to private cars, biking (conventional or electric), micro-mobility, and even walking after COVID-19, as observed during the pandemic. Thus, the public transportation sector, ride-hailing, ride-sharing, and other emerging Mobility as a Service (MaaS) applications are therefore expected to face serious monetary problems as a result of the loss of income during the confinement period and decreased demand afterward. In this situation, governmental financial stimulus packages will not only save local jobs but also prevent the surge increase in car usage by adjusting public transportation to eliminate social inequality.

Although future planning models and scenario construction models are necessary to analyze all impacts of this pandemic, it is impossible to answer all questions raised by COVID-19 since many factors are involved and concerned with extreme events. We believe that, in this situation, the key is not to have a perfect forecast, but rather how to set goals and determine which policies should be put in place to better achieve these goals with much flexibility. Hence, the content presented in this overview has attempted to collect evidence and experiences to steer future policies.

9.2 Open discussion and lessons learned

This crisis adversely affects a vast number of people. We have all observed in Academia that students suffer from a lack of socialization, obesity is growing among children, and households encounter monetary problems. However, in all crises, there are winners and losers. Although most firms suffer from the crisis, the winners such as online businesses and digital companies are positively impacted by COVID-19. Nevertheless, gains are not equally distributed among the winners. Besides, new firms and services have emerged during the pandemic.

Measuring and monitoring the trends of changes during and after COVID-19 require appropriate data and methodology. In many ways, COVID-19 provides a natural experiment ideal to collect mobility data. Reviewing the selected studies that addressed the effects of COVID-19 on mobility and lifestyle, we identified three distinct types of datasets collected by researchers and organizations under various initiatives. For the first one, respondents were requested to recall what happened in certain periods before COVID-19 versus during COVID-19. These datasets provide

preliminary information about adapted individuals' behaviors. However, one noticeable limitation is that those findings were highly context-dependent, and thus had limited implications for policymaking in different contexts. For the second one, respondents were requested to state their attitudes and choices in synthesized scenarios. The analyses based on these datasets offered insights into the potential behaviors and adaptations. Besides the common limitations, such datasets are biased since respondents have the propensity to overreact at the beginning of a new situation of substantial changes. For the third one, respondents' mobilities were traced or registered specifically via the internet of things at the aggregate level. These datasets, unlike the former two types, could be used to track trends and changes. They can serve as the ground truths and be essential for investigating the dynamic effects of COVID-19. For any type of dataset and the accompanying study designs, it is argued that it is important to create common grounds for comparisons to reach broad relevance.

Besides the changes that occurred during COVID-19 and can be measured using data and statistical modeling, much uncertainty remains, and societies have to learn how to cope with these new structural dimensions. Many researchers (but not all) believe that the world will not be the same as before even after COVID-19. Over the long haul, people may find a new equilibrium. For instance, a part of the population in the post-pandemic era may avoid public transportation due to disease transmission concerns and opt for more individualistic forms of mobility. Moreover, the choice of occupation, residential location, and even job location might be influenced probably due to the restructuring of the service industries, long-lasting telework, and donut effect changes in housing prices (decrease within the city and increase outside).

During and after COVID-19, we are not only facing risk but also ambiguity. The attacks of different variants of COVID-19 show that the world's changes vary to some extent under each variant, and the long-run effects of COVID-19 are unknown. In this situation, governments are confused, and they cannot decide, for instance, whether schools and universities should remain open, or/and whether teleworking should be permanent. Once again, the key might be not to have perfect forecasts, but to learn how to cope with ambiguity, and how to deal with risky situations where even the probabilities are unknown (Wakker, 2010).

In an unknown and uncertain situation caused by a crisis, relying on previous crises to forecast demand and behavioral changes sometimes is a good strategy, yet sometimes is a misleading strategy. In general, public intervention, good pedagogy on COVID-19, and some directions as for how society should be reorganized are key elements to ensure quick recovery from shocks so that

some cities may go back to normal. This is the concept of urban resilience (Labaka et al., 2019). What we have learned from COVID-19 that can be used for dealing with the possible future crises are:

- preventive measures hinder mobility but are essential;
- innovations in passenger mobility are accelerated;
- virtual mobility becomes the new normal;
- everyone is not impacted/treated equally;
- lifestyle changes invoke attention to mental health;
- societies need to build up capacity for resilience.

Although this overview as a way of bringing the relevant materials, which are growing explosively, in a structural fashion is undeniably meaningful, researchers in this field are encouraged specific aspects to perform follow-up deep reviews for future research.

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Appendix A

Table A1 Observed changes in lifestyle due to the COVID-19 pandemic

Activity	Range of change	Impact on health	Study area	Sample	Reference
Physical activity	Decreased	–*		Concluding from other studies	[1]
	Decreased among 30% of sample (48% of sample does not change)	–	India	995 responses (58.5% male, mean age 33.3 years)	[2]
	Decreased to 8.6 min for women (61%) Decreased to 11.8 min for men (79%)	–	China	158 males with a mean age of 36.4 and 181 females with a mean age of 37.6 years	[3]
	Decreased among 43% of sample (38% of sample does not change)	–	Poland	2381 residents aged 18 years and older	[4]
	Share of people who spent more than an hour exercising drops from 26.6 to 14.7%	–	Spain	1065 Spanish above 16 years old (72.8% female)	[5]
	Decreased by 2.3 hour/week		Italy	41 children and adolescents with obesity	[6]
Cardiovascular risk	Increased	–		Concluding from other studies	[1]
Stress, anxiety, and depression	Increased	–		Concluding from other studies	[1]
	Increased among 33% of sample (52% of sample does not change)	–	India	995 responses (58.5% male, mean age 33.3 years)	[2]
Eating diet	Balance diet increased among 30% of sample (46% of sample does not change)	+	India	995 responses (58.5% male, mean age 33.3 years)	[2]
	Fast food intake decreased among 37% of sample (55% of sample does not change)	+	Poland	2381 residents aged 18 years and older	[4]
	Eating in restaurants declined to 1.08 times per week from 1.98	+	US, UK, Australia, and Canada	7753 responses	[7]
Bodyweight	Increased	–		Concluding from other studies	[1]
	Increased 2.2 kg for women with BMI < 24 Increased 1.7 kg for men with BMI < 24 Increased 0.9 kg for women with BMI ≥ 24 Decreased 0.9 kg for men with BMI ≥ 24	–	China	158 males with a mean age of 36.4 and 181 females with a mean age of 37.6 years	[3]
	37.3% of sample gained between 1 and 3 kg	–	Spain	1065 Spanish above 16 years old (72.8% female)	[5]
	Increased 2.8 kg among 34% of women who gain weight (18% of women reduced weight)	–	Poland	1769 women	[8]
	Increased among 11-72% of sample	–	32 countries	59,711 individuals above 16 years old	[9]

* + and – represent positive and negative effects, respectively.

Table A1 (continue): Observed changes in lifestyle due to COVID-19 pandemic

Activity	Range of change	Impact on health	Study area	Sample	Reference
Screen time	Increased among 43% of sample (49% of sample does not change)	–*	India	995 responses (58.5% male, mean age 33.3 years)	[2]
	Increased among 49% of sample (46% of sample does not change)	–	Poland	2381 residents aged 18 years and older	[4]
	Increased by 4.85	–	Italy	41 children and adolescents with obesity	[6]
Leisure (grocery, shopping, walking in parks, gardening)	Decreased among 46% of sample (39% of sample does not change)	–	India	995 responses (58.5% male, mean age 33.3 years)	[2]
Sleep time	Increased among 26% of sample (68% of sample does not change)	+	India	995 responses (58.5% male, mean age 33.3 years)	[2]
	Increased among 30% of sample (61% of sample does not change)	+	Poland	2381 residents aged 18 years and older	[4]
	Increased by 0.65 hour/day		Italy	41 children and adolescents with obesity	[6]
	Sleep onset and wake time shift 42 and 59 min later	–	US, UK, Australia, and Canada	7753 responses	[7]
	Sleep quality worsened among 44% of sample	–			
Smoking	Smoking prevalence decreased from 23.3% to 21.9%	+	Italy	6003 adults aged 18-74	[10]
	Number of cigarettes per day increased from 10.9 to 12.7	–			
	prevalence of e-cigarette increased from 8.1% to 9.1%	–			
Walking	Average steps per day decreased by 3297 for women (47%) Average steps per day decreased by 4593 for men (55%)	–	China	158 males with a mean age of 36.4 and 181 females with a mean age of 37.6 years	[3]

* + and – represent positive and negative effects, respectively.

References:

[1] Mattioli et al. (2020)
[2] Chopra et al. (2020)
[3] He et al. (2020)
[4] Górnicka et al. (2020)
[5] Sánchez-Sánchez et al. (2020)
[6] Pietrobelli et al. (2020)
[7] Flanagan et al. (2021)
[8] Drywień et al. (2020)
[9] Bakaloudi et al. (2021)
[10] Odone et al. (2020)