Issue 21(1), 2021, pp. 70-93
https://doi.org/10.18757/ejtir.2021.21.1.5135

TU Delft OPEN

EJTIR

ISSN: 1567-7141
http://ejtir.tudelft.nl/

Impact of COVID-19 lockdown on commuting: a multi-country perspective

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We carried out an international online survey about changes in everyday mobility during the COVID-19 outbreak in 21 languages, collecting more than 11,000 responses from more than 100 countries. In this paper, we present our analysis about commuting travels of the responses between 23 March and 12 May 2020 from the fourteen countries with 100 or more responses, namely Austria, Brazil, Bulgaria, Czechia, Germany, Hungary, Iran, Italy, Japan, Malaysia, Slovakia, Slovenia, Thailand, and the UK. Home office is used typically by between 40% and 60% of working respondents. Among people with workplaces with possibility for home office, the percentage is between 60% and 80%. Among people with workplaces where presence is essential, the percentage does not typically go beyond 30%. This result potentially implies an ultimate magnitude of a strong home office measure. Among those who continued to commute but switched commuting transport modes from public transport to others, the COVID-19 infection risk in public transport is the reason that is most often referred to, but many of those who changed to private cars and to bicycles report reduced travel time, too. Measures to encourage the use of active travel modes where possible are strongly recommended, as this would potentially mitigate undesirable modal shift towards private motorized modes triggered by perception of infection risks while travelling with public transport.

Keywords: *COVID-19, home office, lockdown, mobility, travel behaviour, international comparison.*

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1. Introduction

The worldwide outbreak of the coronavirus disease 2019 (COVID-19) starting in February 2020 resulted in a wide range of socio-economic countermeasures in many countries, such as closure of schools and universities, restrictions in commercial activities such as closure of stores and restaurants, closure of workplaces and introduction of home office where possible. Such countermeasures as well as their timing of implementation were different from one country to another, but commonly many governments imposed or recommended people to stay home to reduce physical contact among people (e.g. Hale, Webster et al. 2020). Unlike other causes such as natural disasters that potentially lead to disruptions of transport infrastructures and services and eventually to sudden and unexpected impacts on travel behaviour of the people, functionality of transport services and infrastructures were not directly affected because of the COVID-19 outbreak itself. Rather, behavioural changes recommended or imposed by governments led to impacts on everyday mobility.

For many people, the lockdown led to sudden and direct impacts on their everyday mobility. In particular, closure of workplaces and imposed home office have led to significant changes in commuting behaviours: some workplaces were completely closed during the lockdown, such as the ones in restaurants and in the retail sector. Certain types of workplaces such as office and lecture rooms could be transferred to home office more easily, but other types of workplaces could not be transferred easily, such as production sites and healthcare facilities.

Research on interactions between spread of diseases and transport is not a completely new topic. For example, Condon and Sinha (2010) conducted an analysis about the use of face masks during outbreak of influenza in Mexico City, comparing voluntary and mandatory public health measures. Horna-Campos, Consiglio et al. (2011) published a short report about tuberculosis infections among workers in Lima's informal public transport sector. Andrews, Morrow et al. (2013) and Bóta, Gardner et al. (2016) both modelled spread of diseases in public transport networks. Grenfell, Bjørnstad et al. (2001) analysed infection waves in measles epidemics with spatial hierarchies taken into consideration, and Hufnagel, Brockmann et al. (2004) modelled the global spread of respiratory diseases with globalised transport network taken into consideration, applying a stochastic approach. A Japanese ministerial research institute carried out an analysis about potential responses of public transport operators in case of an epidemic of respiratory diseases, coupled with a series of recommendations by expert panels (Hase, Nakao et al. 2015). The World Health Organization (WHO) made a risk assessment among travellers in response to the Ebola outbreak in West Africa, and published a guidance for public health authorities and transport sectors (WHO 2014).

In response to the COVID-19 outbreak, WHO (2020) published a guideline about hand hygiene at transport nodes such as "major bus and train stations, airports, and seaports." The International Association of Public Transport (UITP) published a guideline for public transport operators, highlighting the high-risk environment of public transport systems for the COVID-19 outbreak, namely "high number of people in a confined space with limited ventilation", "no access control to identify potentially sick persons", and "a variety of common surfaces to touch (ticket machines, handrails, door knobs, etc.)" (UITP 2020). The International Union of Railways (UIC) published a catalogue of potential measures "to increase customer confidence in rail transport" to "limit the risk of infection and also communicate" about relevant measures (UIC 2020). Tirachini and Cats (2020) present a roundup of the current knowledge related to public transport and COVID-19 infections, and identified research topics in need of immediate attention.

As such, the outbreak of COVID-19 brought about impacts on passenger transport and everyday mobility in two different senses. On one hand, public health measures to restrict contacts among people led to sudden suspensions of or changes in various regular trips such as commuting and shopping. On the other hand, the public transport, which often plays an important role particularly in urban areas, has been stigmatised as a high-risk environment for the respiratory disease

(Tirachini and Cats 2020). With these combined, and also together with adaptation in public transport services in response to reduced travel demand by offering less or no services, it is easy to assume that a vast majority of people changed their regular travel behaviour. To what extent did people switch to home office? How is the shift to home office related to the type of workplaces? How many people who continued to commute changed their travel mode during the COVID-19 lockdown? Why did they do so? If commuters continued to use the same travel modes, why did they do so?

To understand the magnitude and motivations of these kinds of changes in mobility caused by the COVID-19 outbreak, we conducted an online survey in 21 different languages, collecting more than 11,000 responses from more than 100 countries. In this questionnaire, we particularly aimed to understand how the lockdown changed people's commuting travels. In this paper, following a quick analysis of the Austrian sub sample (Brezina, Shibayama et al. 2020b), we present the first comprehensive analysis of this survey.

The remainder of this paper is structured as follows. In section 2, we present our methodology and data. Following this, in section 3, the analysis results are presented, followed by discussions in section 4. Section 5 draws our conclusions.

2. Methodology and data

To address the series of our research questions, various different methodologies are applicable, and it is not surprising that researches around the globe applied different methodologies. Among the researches focusing on mobility and COVID-19 which were carried out in parallel to our research, Warren and Skillman (2020) analysed the anonymized location data from mobile devices, and Bergman and Fishman (2020) analysed the data published by major providers of smartphone operating systems to understand the changes in mobility in response to the COVID-19 outbreak in the United States. Similarly, Mazzoli, Mateo et al. (2020) made use of the data from telecommunication network activities of mobile phones to analyse the interregional mobility and its impacts on spread of the virus in Spain. Similar data and methods have been applied to estimate the lockdown-related impacts on quantitative and geographic aspects of changes in mobility on national, regional or urban levels in the UK (Santana, Botta et al. 2020), Italy (Campisi, Basbas et al. 2020, Pepe, Bajardi et al. 2020), Switzerland (ETH Zurich and University of Basel 2020), Colombia (Arellana, Márquez et al. 2020), Spain (Aloi, Alonso et al. 2020), Poland (Štraub 2020, Borkowski, Jażdżewska-Gutta et al. 2021), Istanbul (Shakibaei, de Jong et al. 2020) and the USA (Klein, LaRock et al. 2020). Focusing more on the restriction of mobility and its effect on the spreading speed of the virus in Berlin, Gössling, Scott et al. (2020) applied a modelling approach. On the other hand, Mu, Yeh et al. (2020) examined the interplay between disease spread of COVID-19 and inter-city and intra-city mobility among 319 Chinese cities by utilizing synchronized epidemic data and human mobility data from Baidu. Jittrapirom and Thanaksaranond (2020) applied a questionnaire-based approach to explore risk perceptions about traveling and COVID-19. The research by Beck and Hensher (2020), which was carried out in Australia, adopts a questionnaire-based approach focusing on mobility. In a later report on their combined surveys, Beck, Hensher et al. (2020) outline the implications of relaxing restrictions on the working from home situation and commuting. And finally, Schmidt (2020) combines several different sources in his compendium of responses to COVID-19 in Austria.

We selected an online questionnaire in order to collect the "live" information from the respondents during the lockdown, including the travel mode before the outbreak so that we can understand individual changes, and motivations for changes. The above-mentioned methodologies have certain difficulties in obtaining such before-after data, and more importantly to obtain the data about people's motivations for changes. In addition, a questionnaire-based method is advantageous in that we are able to carry out international comparisons rather easily.

The online questionnaire was hosted on a major cloud-based online survey platform, and advertised on the websites of TU Wien, the research team, and institutions of volunteer translators. The survey was also widely shared among various mailing lists and on social media. This approach can be described as a virtual snowball sampling method. Although such an outreach strategy is expected to lead to low representativeness among the respondents in various terms such as age and education level, it enabled a quick outreach to potential respondents during the lockdown period, when the people's contact to the outside of their homes was largely restricted to conventional and online media.

The questionnaire was prepared first in English and German, and then translated into other languages in sequence by the research team, staffs and students of the research center, and external translation volunteers. This resulted in 21 different language versions of the questionnaire, covering many European and East Asian languages as well as some languages commonly used in the Middle East. Because of the timing of the translation, the different language versions were launched at different timings on the online platform, as summarized in Table 1 as the date of the first response. In all of the different language versions, questions and their options were unified so that comparability was ensured, except for the question asking about place of living. In this question, the postal code was generally asked; however, in the Persian (Farsi) version, the region, city and district were asked alternatively as the use of postal code is not common in Iran, where the language is mainly used.

The questionnaire consists of 36 questions in total, including country and place of living, basic demographic characteristics, questions about commuting travel and changes in it as the main part of the questionnaire, a few additional questions about mobility related to shopping, and several further questions. Some questions are skipped depending on answers of previous questions: the maximum number of questions for one respondent was 25. No incentive was given to the respondents. The language versions are not bound to the place of living: for example, a person living in Austria could respond to the Spanish version of the questionnaire, indicating Austria as the country of living. A detailed list of questions and answer options can be found in the metadata of the raw dataset (Brezina, Shibayama et al. 2020a).

Table 1. Language versions and date of first responses

Language	Date of first response
Bulgarian	30-Mar-20
Chinese	04-May-20
Czech	22-Apr-20
English	24-Mar-20
French	30-Mar-20
German	23-Mar-20
Hungarian	02-Apr-20
Indonesian	21-Apr-20
Italian	30-Mar-20
Japanese	24-Mar-20
Korean	24-Apr-20
Kurdish	15-Apr-20
Malay	19-Apr-20
Persian (Farsi)	26-Mar-20
Portuguese	07-Apr-20
Romanian	02-Apr-20
Slovak	07-Apr-20
Slovenian	25-Mar-20
Spanish	01-Apr-20
Thai	26-Mar-20
Turkish	03-Apr-20

To identify respondents' places of living, respondents were asked to select a country of living. Figure 1 shows a geographic overview of the number of responses that we received by 12 May 2020. In total, we collected more than 11,000 responses from over 100 countries.

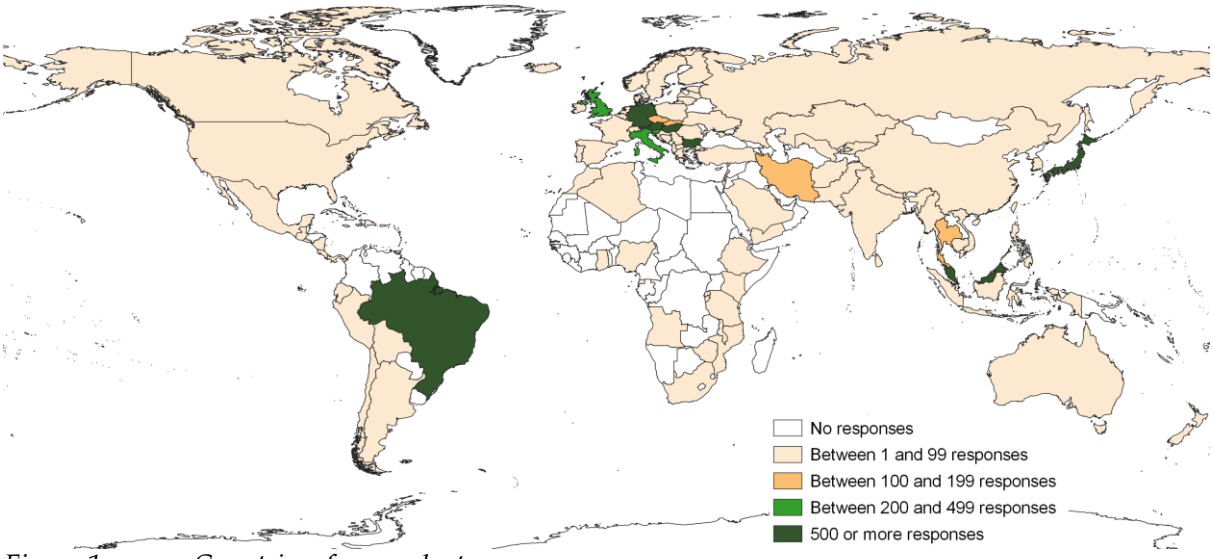


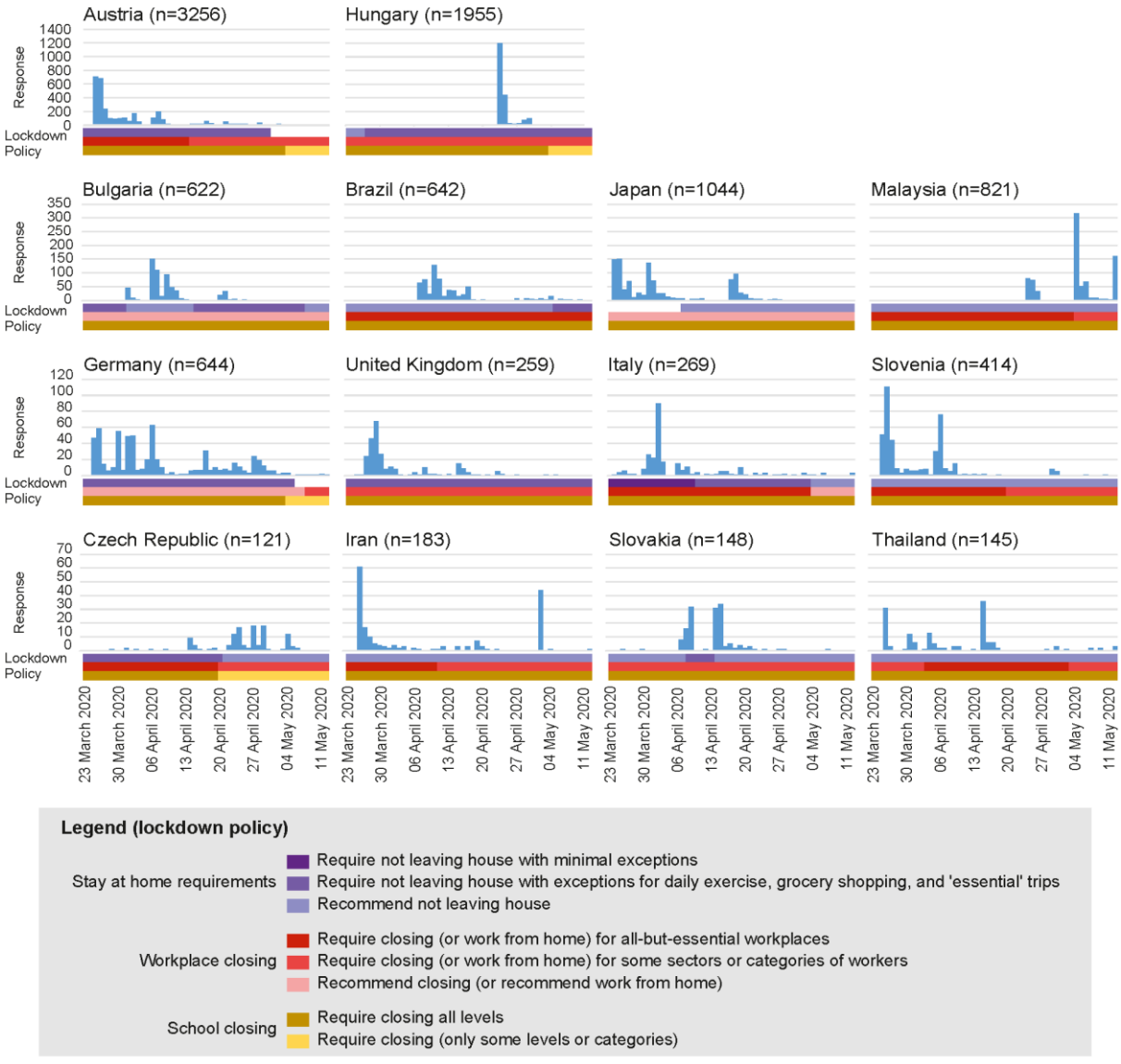
Figure 1. Countries of respondents

Table 2. Countries with 100 or more responses, their language, population and margin of error (MoE)

Country	Principal language	Responses	Population			Sample Size		MoE [%]	
			in 1000	Share 0-14 [%]	Share 15+ [%]	95% CI	85% CI	95% CI	85% CI
Austria	German	3,256	9,006	14.4	85.6	190	102	1.21	0.89
Hungary	Hungarian	1,955	9,660	14.4	85.6	190	102	1.56	1.14
Japan	Japanese	1,044	126,476	12.4	87.6	167	90	2.00	1.47
Malaysia	Malay	821	32,366	23.4	76.6	276	149	2.90	2.13
Germany	German	644	83,784	14.0	86.0	185	100	2.68	1.97
Brazil	Portuguese	642	212,559	20.7	79.3	252	136	3.13	2.30
Bulgaria	Bulgarian	622	6,948	14.7	85.3	192	104	2.78	2.04
Slovenia	Slovene	414	2,079	15.1	84.9	197	107	3.45	2.54
Italy	Italian	269	60,462	13.0	87.0	174	94	4.02	2.95
UK	English	259	67,886	17.7	82.3	224	121	4.65	3.41
Iran	Persian (Farsi)	183	83,993	24.7	75.3	286	154	6.25	4.59
Slovakia	Slovak	148	5,460	15.6	84.4	202	109	5.84	4.29
Thailand	Thai	145	69,800	16.6	83.4	212	115	6.05	4.44
Czechia	Czech	121	10,709	15.8	84.2	204	110	6.49	4.77
Other	N/A	1,032	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total		11,555	7,794,799	25.4	74.6	292	157	0.79	0.58

From this set of responses, we selected respondents from the countries with 100 or more responses for our analysis presented in this paper. Table 2 shows the countries with 100 or more responses submitted by 12 May 2020 with the number of responses. Principal languages of these fourteen countries are covered by the 21 language versions that we prepared. To set this 100-response threshold, we calculated needed sample sizes with 95% and 85% confidence intervals (CIs), assuming working-age and elderly population are our statistical population and 85% of total population fall in this group. The sample size with 95% CI is 196, and 85% CI is 106. Ideally, the threshold could be set to 200 (196 rounded up), but we decided to set to 100 (106 rounded down) to include more countries in our analysis in light of the topic's strong relation to the COVID-19

pandemic. Furthermore, we calculated the needed sample size and margin of error (MoE) for each of these fourteen countries using the population statistics from the United Nations, as summarized in Table 2. This confirms that ten countries with 200 or more responses (green background) provide a reliable dataset with less-than-5% MoE within 95% CI. The dataset from the four countries between 100 and 200 responses (yellow background) is less reliable with less-than-5% MoE within 85% of CI.



Source: Own graphics with information about lock-downs based on Hale, Webster et al. (2020).

Figure 2. Number of responses and lock-down measures of each country.

Figure 2 is a histogram-matrix of the number of the respondents from the fourteen countries by the timing of responses in UTC. Below each histogram, each country's lockdown situations are summarized as timelines in terms of stay-at-home requirements (purple), workplace closing (red) and school closing (brown), based on the data collection by Hale, Webster et al. (2020). Majorities of the survey participants from Austria, Hungary, Germany, the UK, Italy, Slovenia, Iran and Thailand responded to the questionnaire during the period of the "hardest" lockdown in these countries. Many of the respondents from Bulgaria, Malaysia, Czech Republic and Slovakia answered in the "shoulder" time soon before or after the "hardest" lockdown in these countries. Many of the respondents from Brazil answered before the country's stay-at-home recommendation was tightened to the hardest level in the country, while workplaces and schools were already ordered to close. It is also worth noting that more than half of Japanese respondents gave responses

before the stay-at-home recommendation by the government was made while workplace closure and home offices had been recommended and schools were closed. At large, the responses from the fourteen countries but for Japan are during the hardest lockdown period or in the shoulder period. With an exception of Japan, the responses can be interpreted as the information during the lockdown time.

In addition to the country of living, we also asked the postcode to identify if the respondents are from urban or rural regions. In Europe, we used a NUTS3-postcode database to convert the inputs from the respondents to NUTS 3. In a rare case that one postcode stretches over an area in two or more NUTS 3 areas, the first one appearing in the database is chosen. Then, the region typology defined by Eurostat (2016) is used to determine the characteristics of the area. Among the 3 classes set by Eurostat, "predominantly urban" regions are interpreted as "urban", and "predominantly rural" ones are as "rural". "Intermediate" regions vary from one country to another depending on the size of the NUTS 3 area: to simplify, we included this into the "urban" category because this group is defined as the NUTS 3 region in which between 50% and 80% of the population live in urban clusters. As for the results from Japan, the postcode is used to identify municipalities, and municipalities having one or more Densely Inhabited Districts (DID), which are subareas with 4,000 inhabitants/km^2 as defined by the National Statistical Office (Statistics Bureau of Japan 1996), are treated as urban areas, and the rest are treated as rural areas. In a rare case that one postcode covers two or more municipalities, the one having the smallest official municipality code is selected. In Brazil, the postcode is used to identify municipalities, and municipalities defined as urban ones by the Brazilian Institute of Geography and Statistics (IBGE) are treated as urban area, and the rest as rural. Brazilian postcode is very detailed and all postcodes were linked to one municipality. As for Iran, Malaysia, and Thailand, no classification is made as no comparable database has been found. This result is used to understand the characteristics of the respondents.

3. Results

3.1 Respondents

Figure 3 is a summary of the characteristics of the respondents, subdivided by the countries and by five different aspects – gender, age class, education, occupation and types of living area.

As for the gender, 50.7% are female, 48.3% are male, 0.4% are diverse, and 0.6% did not provide an answer. Male respondents are overrepresented in some countries. This is particularly the case in Iran, Japan and Slovakia, as well as, to a lesser extent, in the UK. Female respondents are overrepresented in Bulgaria and Thailand, as well as in Italy and in Slovenia to a lesser extent. Furthermore, respondents tend to be rather young: in many of the countries we analyse, roughly half of the respondents are between 19 and 39 years old. 57.6% of the respondents from the 14 countries are in this group.

Common to all of these fourteen countries, relatively high percentages of respondents have completed a university-level education or higher. Among all respondents from 14 countries, 66.9% have a university degree or higher. This is probably because of the questionnaire's online distribution, combined with the quick distributions made on different channels that people with higher education levels are more likely to come across, such as mailing lists and networks of universities.

As for the respondents' employment status, 55 to 77% are employees (61.4% among all 14 countries), with the exception of Brazil and Iran, where this share is lower. Between 5 to 15% are self-employed (8.3% among all 14 countries). Common to all fourteen countries is the relatively low share of students despite relatively high share of young people among our respondents, often less than 25% of the total respondents (17.8% among all 14 countries), with exceptions of Iran and Slovakia.

In many countries, respondents tend to live in urban areas (71.2% among all 14 countries). Only 6.5% of respondents live in rural areas, with an exception of Slovenia with rural respondents being 45%. We could not identify area types of 22.4% of respondents partially because the postcode was an optional question – many of Bulgarian and Brazilian respondents did not answer in particular – and unavailability of reliable postcode-area database (Malaysia, Thailand and Iran).

At large, the respondents tend to represent a highly-educated, young and urban working population more than other demographic groups.

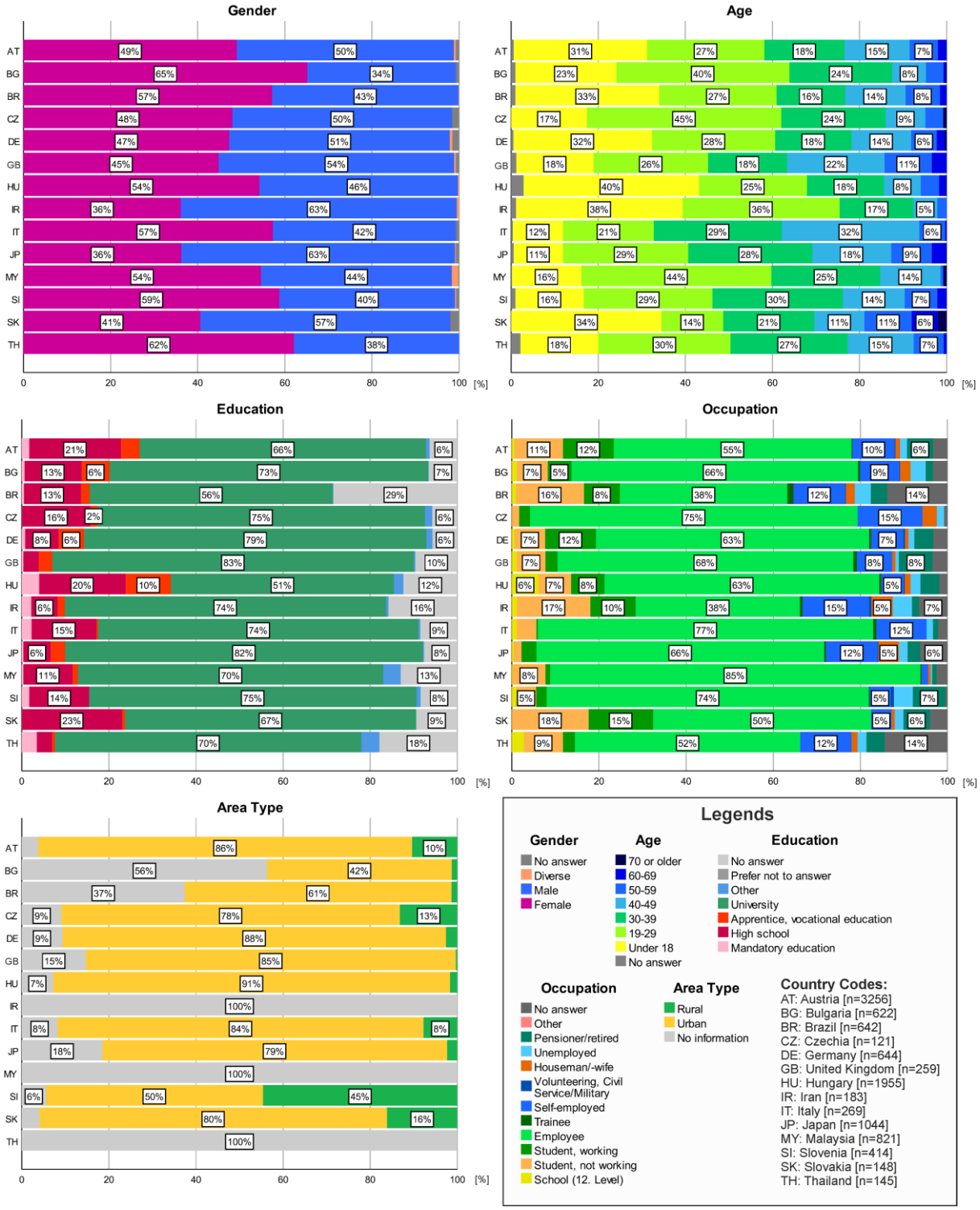


Figure 3. Characteristics of respondents, subdivided by countries

3.2 Changes in commuting in response to the COVID-19 outbreak

Practicing home office under COVID-19 outbreak

In the questionnaire, we asked both working and studying respondents about their commuting behaviour. Those in education show a relatively small percentage among the respondents. In the fourteen countries that we focus on, schools on all levels have been closed during most of the survey period (Figure 2), and a majority of the respondents in schools and at universities were staying at home. On the contrary, working respondents experienced diverse situations. As our primary aim is to understand the changes in commuting travel behaviour, we focus on the results from the working respondents in this section.

Working respondents were asked about their type of workplace and whether they commute to the workplaces or if they make use of the home office option at the time of response. Figure 4 is a summary of working style among the respondents. In many of the countries, between about 40% and 60% of the respondents are at home office. The UK and Italy have the highest share of people working at home office, while Thailand, Japan and Iran have a much lower share of respondents at home office. In all fourteen countries, 48% are at home office, 35.4% are at workplace, and 9.8% do not work, while 2.8% are in other situations and 4.0% do not provide information.

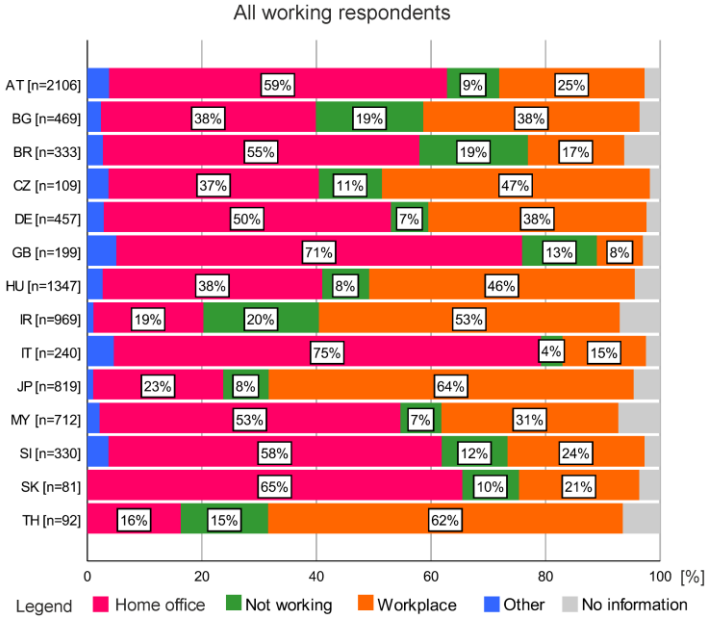


Figure 4. Percentages of working respondents and their working style under COVID-19 outbreak

For further analysis, respondents selecting "Other" and giving no information are filtered out first, and subdivided into three groups. Generally, offices, classrooms and lecture halls, etc. have better possibility for and higher affinity with home office or live streaming. This group is called *Home Office Possible* group hereafter (67.8% among all respondents from 14 countries). On the contrary, other workplace types such as direct customer services, healthcare facilities and vehicles on the move generally call for presence of the personnel at the workplace by their nature and have less affinity with home office. This group is called *Presence Essential* group hereafter (24.5%). Respondents who worked mainly in home office even before the COVID-19 pandemic are grouped as *Regularly Home Office* (7.7%). The shares of each group are summarized in Figure 5.

The result in Figure 4 is subdivided into the two commutable groups, Home Office Possible and Presence Essential. Figure 6 is a summary of the result subdivided into these two groups.

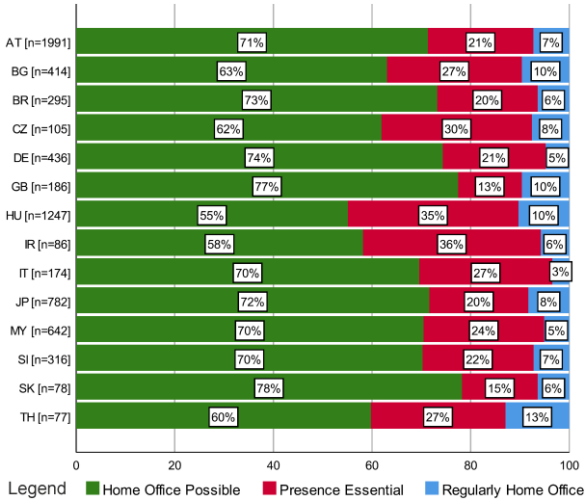


Figure 5. Summary of respondents' workplace types before COVID-19 outbreak

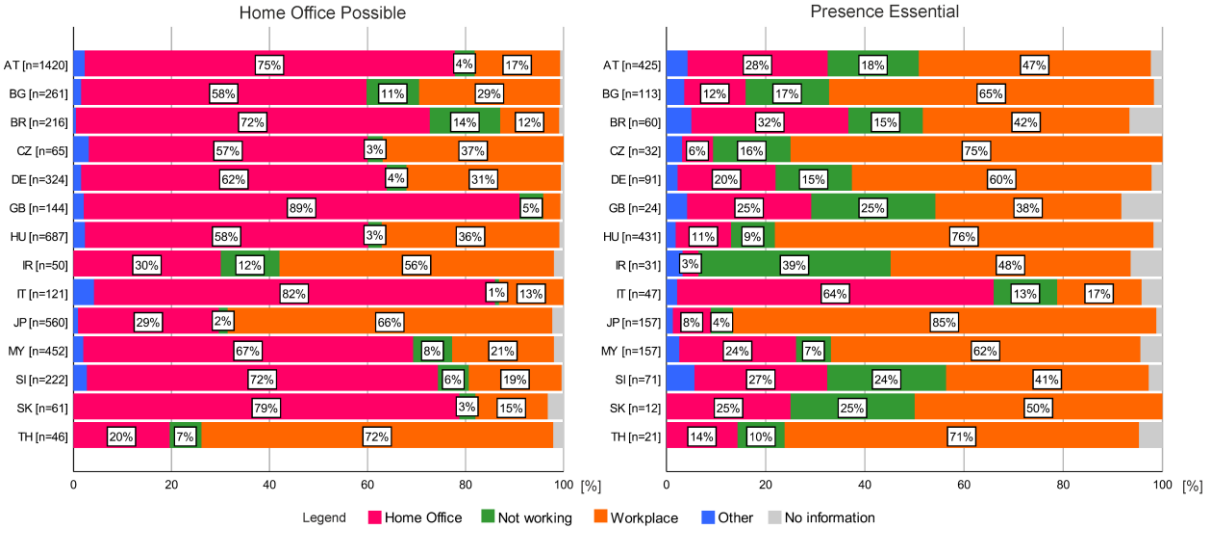


Figure 6. Working style under COVID-19 outbreak subdivided by possibility of home office

Among the respondents in the *Home Office Possible* group, the UK and Italian respondents are particularly remarkable with very high percentages utilizing home office. These are the countries that were heavily affected by the COVID-19 outbreak, and the result implies that people in these countries made use of home office possibility to a larger extent than in the other countries. Results from many of the European countries other than the UK and Italy, as well as from Brazil and Malaysia, show a similar tendency: in these countries, between 60 and 80% of the respondents in the group *Home Office Possible* were indeed at home office. Thailand, Japan and Iran show a similar tendency with lower percentages of home office.

Of note, as for Japan, the first declaration of emergency (stay-at-home recommendation in Figure 2) was issued in the evening of 7th April for large cities, including Tokyo and Osaka, and on 16th April for the whole country. Among the responses after 8th April, 53% (81 out of 152 respondents in *Home Office Possible* group) of the respondents are practicing home office, showing a similar value to many of the other countries, while the same analysis of the responses before 8th April shows only 20% (80 out of 408). The low percentage of home office in Japan is probably due to the time lag between the launch of the Japanese version of the questionnaire (24th March) and the governmental emergency declaration (7th April).

Among the respondents in the *Presence Essential* group, the percentages among those who had their workplace closed and those commuting to their workplaces under the COVID-19 outbreak are

higher than the respondents in the other group in all of the fourteen countries. In an international comparison, particularly outstanding is the closure of workplaces in Iran. Italy shows an exceptional tendency here: compared to the other countries, a much higher percentage of the respondents is making use of home office even in this group. It has to be noted, however, that only 47 respondents in this group are from Italy. Several workplaces in this category, such as customer care personnel or medical workers mainly conducting consulting or counselling do have the possibility of home office. It is possible that respondents with these types of workplaces from Italy are overrepresented; however, it is not possible to verify this, as we did not ask the concrete job of the respondents.

Mode choice

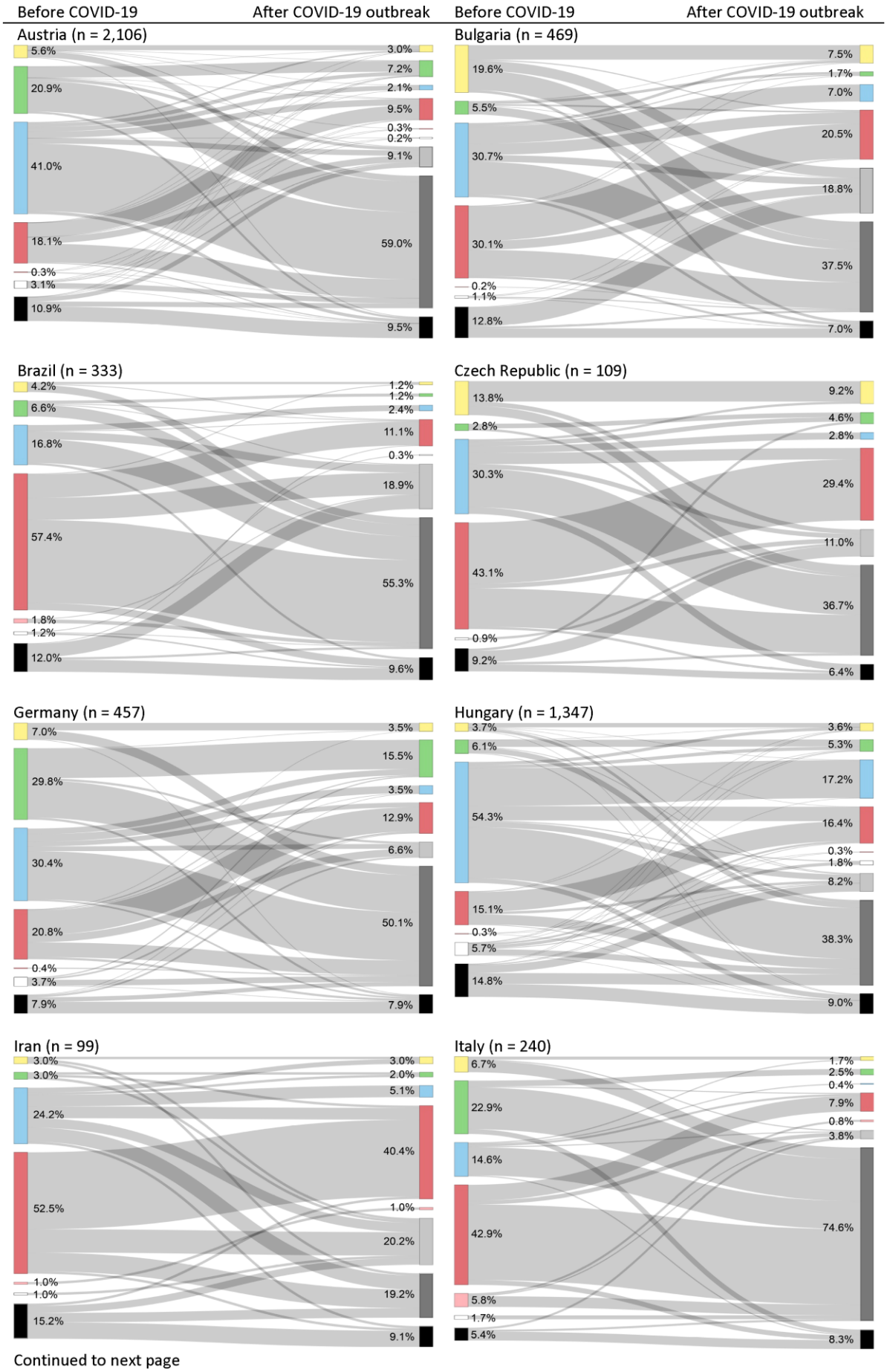
In the questionnaire, we asked the transport mode that had been used most frequently and covering the longest distance before the outbreak of COVID-19 for commuting to and from workplaces. Similarly, for the respondents who were commuting under the COVID-19 outbreak, we asked the transport mode used. Together with the results obtained from the questions about home office, the change of the commuting travel modes is summarized with Sankey Diagrams as shown in Figure 7.

As for the commuting travel mode before the COVID-19 outbreak, the high shares of public transport users in Austria, Hungary and Japan are remarkable: this is probably due to the high share of respondents form urban regions, in particular from the capital cities of these countries. In each of these three countries, more than 60% of the respondents are from the capital regions, namely Vienna, Budapest and Tokyo, where extensive public transport networks exist. It is also remarkable that the shares of bicycle users are high in the UK, Germany, Austria, Slovenia, and Italy. This is probably because some interest groups in cycling in these countries shared the online questionnaire via their social media and mailing lists.

Common to many of the analysed countries, a shift from public transport to car is observed. This is particularly striking in Hungary and Iran, as well as in Czechia and Bulgaria to a lesser extent. Shifts from car to other modes are commonly rare in all of the fourteen countries. At large, public transport loses the users both due to home office and to changes to the other modes. It has to be noted that Slovenia suspended all public transport services during the lockdown, and our result with no public transport user during the COVID-19 outbreak in Slovenia is in line with this. Interestingly, in the UK, there are also no public transport users observed, even though the service was not fully suspended.

Comparing the two Southeast Asian countries, Thailand and Malaysia, it is noteworthy that the Thai motorcycle users tend to continue to commute by motorcycle and do not practice home office, while some Malaysian motorcycle users also practice home office. Since the number of respondents using motorcycles from Thailand is small (only eight respondents), this result has to be interpreted carefully.

Focusing on home office, it is notable that the Japanese respondents practicing home office are mostly pre-COVID-19 public transport users. Those who used to commute with car, bicycle or by walking tend to remain in their workplaces under COVID-19 outbreak circumstances. Considering the high share of respondents from the Greater Tokyo Area (ca. 65 % of the respondents from Japan), this result is in line with the urban structure there, where offices are concentrated in the central districts. These districts are characterised by a majority of commuters using public transport to commute, while other types of workplaces tend to be more dispersedly located. As we did not ask the location of the workplace, this has to be studied further.



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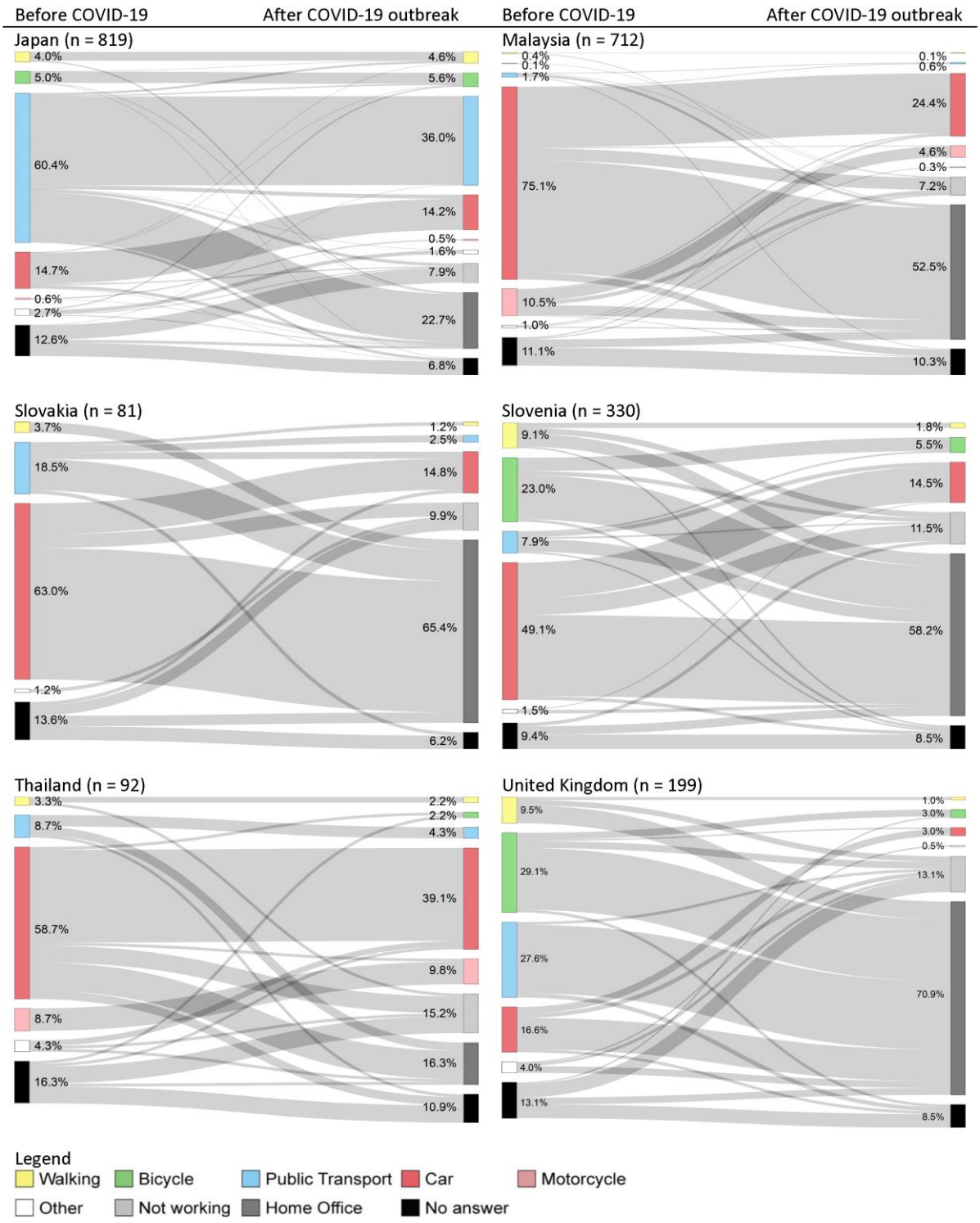

Figure 7. Sankey diagrams of changes in commuting mode choice between before COVID-19 (left) and during the COVID-19 outbreak (right)

Reasons for changes in mode choice

We asked the reasons to change commuting travel modes for those who changed them. We also asked the reasons not to change the commuting travel modes for those who continued to commute with the same transport mode as they did before the COVID-19 outbreak. These questions were asked as text-based open questions and the respondents were allowed to answer freely by typing text. These texts were coded manually by the translation volunteers into the classification as

summarized in Table 3. In this coding process, we were only able to cover the primary languages of the fourteen countries that we analyse, namely Bulgarian, Czech, English, German, Hungarian, Italian, Japanese, Malaysian, Persian (Farsi), Slovenian, Slovak and Thai. Due to this limitation, some answers had to be omitted, for example the one from an Austrian resident who responded in Spanish, but this kind of cases are very limited and supposed to not have an influence on the analysis below.

Table 3. Classifications of reasons (not) to change commuting travel modes

Reason to change commuting travel modes	Reason not to change commuting travel modes
• Avoiding the risk of infection • Safety and Exercise • General unsafe feeling • Longer Interval or no public transport • Order by employer • Faster • Other • Not interpretable text	• No infection risks • No alternatives • No fear of COVID-19 • Alternatives are time-consuming • High travel cost • Low infection risk due to reduced passengers / by avoiding peak hours / short travel time etc. • (Lack of) Order by employer • No reason to change • Other • Not interpretable text

Among those who changed the commuting travel mode, particularly interesting are those who changed from public transport to other modes (reason to change), and those who continued to use public transport (reason not to change). Although, to the best of our knowledge, no epidemiological evidence was reported by the time of our survey that a considerable number of COVID-19 infections had taken place in public transport, it may have been conceived as a high-risk environment for COVID-19 infections by its users, as many people share a closed space. As discussed in the introduction, industry organizations published guidelines to reduce the risk at stations and on board, implying such risk is well perceived by the service providers on one hand, and presumably communicated to the users through implementation of risk reduction measures on the other hand. Therefore, some people may have opted for using other modes of transport instead of using public transport to avoid such infection risks. On the other hand, some people may have decided to continue to use public transport, or might have no other choice.

Table 4 summarizes the coding results of those who changed from public transport to other means of transport in response to COVID-19. 72% of the respondents pointed risk avoidance as the primary reason to do so. The countries having higher numbers of respondents using public transport tend to show a similar tendency: 70 to 80% of respondents from Austria, Bulgaria, Germany, Hungary and Japan who changed their commuting travel modes from public transport to other modes referred to risk avoidance as their main reason for the change. In Austria and Hungary, a small number of respondents mentioned a general unsafe feeling in public transport, although they did not specifically mention the infection risk. Slovenia is outstanding in that the service provision of public transport was suspended in response to COVID-19, leading to all such respondents indicating the same reason – no public transport available. Other countries do not have enough respondents to enable any country-specific conclusion. Among our respondents from the UK and Malaysia, there was no responded who changed from public transport to other modes and gave valid answer to this question.

Table 5 is a summary of the coding results of those who continued to use public transport as their primary commuting travel mode during the COVID-19 outbreak. 59% of such respondents (304 out of 515) indicated that they had no alternative. In addition, 7.4% (38 respondents) stated that alternatives are time-consuming or too expensive. Particularly in Japan but also in some other countries, some respondents conceive low infection risk due to the reduced number of passengers,

or actively change the commuting travel behaviour to avoid peak hours. In our sample, none of the UK and Malaysian respondents reported the continuation of commuting with public transport. The same applies to Slovenia, too – this is in line with the country's general cessation of public transport during the lockdown.

Table 4. Reasons to change commuting travel modes from public transport to other modes

	Avoiding the risk of infection	Safety and exercise	General unsafe feeling	Longer intervals or no public transport	Alternative is faster	Decision by employer	Other	Not interpretable text	Total
Austria	73	4	2	1	4	5	4	1	94
Bulgaria	21	1	0	2	0	1	0	0	25
Brazil	1	0	0	1	0	0	0	0	2
Czechia	1	0	0	1	1	0	2	0	5
Germany	16	1	0	2	0	0	2	0	21
Hungary	81	2	4	0	1	8	16	1	113
Iran	1	0	0	0	0	0	0	0	1
Italy	1	0	0	0	0	0	0	0	1
Japan	18	0	0	0	0	1	5	0	24
Slovenia	0	0	0	6	0	0	0	0	6
Slovakia	1	1	0	1	0	0	0	0	3
Thailand	0	0	0	1	0	0	0	1	2
Total	214	9	6	15	6	15	29	3	297

Table 5. Reasons not to change commuting transport mode among public transport users

	No infection risk	No fear of COVID-19	No alternative	Alternatives are time-consuming	Alternatives are too expensive	Low infection risk*	(Lack of) Order by employer	No reason to change	Other	Not interpretable text	Total
Austria	4	0	20	3	0	5	0	5	3	0	40
Bulgaria	7	0	14	1	0	0	0	0	0	0	22
Brazil	0	0	6	0	0	0	0	0	1	0	7
Czechia	0	0	0	0	0	0	0	1	0	0	1
Germany	0	0	8	0	0	2	0	2	1	0	13
Hungary	0	2	90	13	0	4	1	29	28	2	169
Iran	0	0	4	0	0	0	0	0	0	0	4
Italy	0	0	1	0	0	0	0	0	0	0	1
Japan	5	6	159	12	9	35	13	9	6	1	255
Slovakia	0	0	1	0	0	0	0	0	0	0	1
Thailand	1	0	1	0	0	0	0	0	0	0	2
Total	17	8	304	29	9	46	14	46	39	3	515

*Low infection risk due to reduced passengers / avoiding peak hours / short travel time etc.

At large, the result implies that those who continued to commute and had an opportunity to change the travel mode changed their mode from public transport to other modes considering the infection risk, while those who continued to use public transport had to do so as there were no alternatives available or not deployable.

Changes in travel duration

In the questionnaire, we asked the one-way duration of commuting travels before the outbreak of COVID-19. For the respondents who changed their commuting travel mode during lockdowns, we also asked the one-way duration of their new travel modes. Among possible combinations of the modes, particularly interesting are those who changed their travel mode from public transport to the other means. Is the travel time shorter or longer? How is it related to the motivation of changing travel modes? Table 6, Table 7 and Table 8 are the cross-tables of the commuting time with public transport before the outbreak of COVID-19, and the commuting time with the other means of transport. In these tables, the green areas indicate shorter commuting time with the changed means of transport, and the pink areas indicate longer commuting time with the changed means of transport. The analysis in this section is based on the entire survey data, including responses from countries with less than 100 responses.

Among the 79 bicycle users (Table 6), 40 respondents have the same ranges of the commuting travel time, while 29 respondents report shorter commuting time, and 10 respondents report longer commuting time.

Table 6. Cross-table of one-way commuting duration before and during COVID-19: public transport to bicycle

		During COVID-19 outbreak (Bicycle) [min]								
		1-5	5-10	10-20	20-30	30-45	45-60	60-90	> 90	Total
Before COVID-19 (PT) [min]	1-5	0	0	0	0	0	0	0	0	0
	5-10	1	0	0	0	0	0	0	0	1
	10-20	0	1	6	1	0	0	0	0	8
	20-30	0	1	9	16	5	0	0	0	31
	30-45	0	0	1	9	11	3	1	0	25
	45-60	0	0	0	1	4	6	0	0	11
	60-90	0	0	0	0	1	1	1	0	3
	> 90	0	0	0	0	0	0	0	0	0
Total		1	2	16	27	21	10	2	0	79

Among the 217 car users (Table 7), 28 respondents have the same ranges of the commuting travel time, while 185 respondents report shorter commuting time, and only four report longer commuting time.

Table 7. Cross-table of one-way commuting duration before and during COVID-19: public transport to car

		During COVID-19 outbreak (Car) [min]								
		1-5	5-10	10-20	20-30	30-45	45-60	60-90	> 90	Total
Before COVID-19 (PT) [min]	1-5	0	0	0	0	1	0	0	0	1
	5-10	0	0	0	0	0	0	0	0	0
	10-20	0	11	3	1	0	0	0	0	15
	20-30	0	9	33	8	0	0	0	1	51
	30-45	0	4	28	29	8	1	0	0	70
	45-60	0	1	5	29	14	7	0	0	56
	60-90	0	0	0	6	6	8	1	0	21
	> 90	0	0	0	0	0	0	2	1	3
Total		0	25	69	73	29	16	3	2	217

Among the 51 commuters who changed from public transport to walking (Table 8), 13 respondents had the same range of the commuting time, while only one respondent reported shorter commuting time, and 37 reported longer commuting time.

Table 8. Cross-table of one-way commuting duration before and during COVID-19: public transport to walking

		During COVID-19 outbreak (Walking) [min]								
		1-5	5-10	10-20	20-30	30-45	45-60	60-90	>90	Total
Before COVID-19 (PT) [min]	1-5	0	0	0	0	0	0	0	0	0
	5-10	0	0	2	2	1	0	0	0	5
	10-20	0	0	5	9	2	1	0	0	17
	20-30	0	0	1	5	12	1	0	0	19
	30-45	0	0	0	0	2	6	1	0	9
	45-60	0	0	0	0	0	1	0	0	1
	60-90	0	0	0	0	0	0	0	0	0
	> 90	0	0	0	0	0	0	0	0	0
Total		0	0	8	16	17	9	1	0	51

At large, those who changed the commuting transport mode from public transport to bicycle or car tend to report shorter travel time, while those who changed to walking tend to report longer travel time.

Relationship between respondents' attributes, lockdown policy and home office

Lastly, as our first attempt, we analysed the relationship between the practice of home office and various attributes of respondents and lockdown policy of each country with a binary logistic regression model. We filtered the results from the fourteen countries to respondents having jobs and valid attribute information about possibility of home office (Figure 5), age class, having school-age children or not, area type (urban or rural) (for these three attributes see Figure 3), and one-way travel duration to workplaces (previous subsection) to obtain 5,349 datasets. For age and one-way travel duration to workplaces, the median of each class is used: for this, the group under 18 is interpreted as between 15 and 18, and the group over 70 as between 70 and 75 because we filtered respondents with jobs. Similarly, as for the one-way commuting travel time between home and workplace, the class over 90 minutes is interpreted as between 90 and 120 minutes. Regarding lockdown policy, as the most relevant indicator collected by Hale, Webster et al. (2020), we used *workplace closing* in each country of the respondents and on the day of responses (Figure 2). This ordinal-scale indicator is interpreted as lockdown intensity.

Backward elimination of explanatory variables leads to a significant model (Chi-square: 1231.214; df: 4; p-value: <0.001) as summarized in Table 9. The variables for area type (urban or rural) and having school-age children are not part of the final model. Not surprisingly, the possibility of home office has the largest coefficient among all, followed by the policy to close workplaces. The negative coefficient of the age may be explained by older respondents using less home office due to slightly lower capability with information and communication technologies, and the positive coefficient of the one-way travel time may be explained as the longer commuting distance motivates home office more.

Table 9. Results of binary logistic regression

	coefficient	**Wald**	**p-value**	**OR**
Lockdown policy (workplace closing)	0.852	336.764	<0.001	2.344
One-way commuting travel time	0.005	12.558	<0.001	1.005
Home office possibility	2.021	687.197	<0.001	7.543
Age	-0.018	41.051	<0.001	0.982
Constant	-2.761	232.505	<0.001	0.063

4. Discussion

4.1 Learning

Our survey results confirm that home office was used more often by those with better affinity workplaces, such as office workers and teachers. On the contrary, those with workplaces where presence is essential were likely to experience workplace closing and less home office. In the fourteen countries which we analysed, the percentage of those using home office shows a similar tendency: approximately 40 to 60% of working respondents were in home office during each country's most severe lockdown or the shoulder period soon before or after. A general learning from our survey result is that home office proves to be possible typically for 40 to 60% of workers, if a strong measure is imposed, and in a higher percentage among office workers. This may serve as an impetus for a new working style enabling less energy intensive mobility: even before COVID-19 lockdowns, teleworking and its potential impact on traffic reduction had been discussed widely (e.g. Andrey, Burns et al. 2004, Moos, Andrey et al. 2006), but with little possibility of large-scale field tests and impact control. The COVID-19 pandemic may have served as an unexpected large-scale real-life test of home office.

Among our respondents, we observed some changing their commuting modes from public transport to other modes. About three-fourth of their motivations was associated to the perceived infection risk in public transport (Table 5). More generally, lockdowns reduced the number of public transport passengers. At the time of our analysis it is unclear how the practice of home office will continue in the future: reduced public transport occupation may potentially call for authorities and operators to adjust service volumes and financial structures. Passengers and fare-box revenue may permanently be reduced, if home office is continuously triggered by COVID-19.

Although, by the time of the research, no COVID-19 cluster tracing back epidemiologically to the public transport had been reported (O'Sullivan 2020, Sadik-Khan and Solomonow 2020), such potential infection risks are discussed widely. Besides the literature mentioned in the introduction that focuses on infection risks on board, Harris (2020) concludes that public transport was a major disseminator of the coronavirus focusing on New York City using an economic geography approach. Our results show that about 72% of respondents name infection risk as the motivation to change from public transport to other modes. This partially reflects such public discussions. A deeper investigation of the infection risks in public transport as well as recommendations for keeping satisfactory hygienic level will be needed (Tirachini and Cats 2020). It will help to communicate the risks more accurately with passengers and to recommend appropriate policy measures so that the passengers can be confident about the safety on board. Eventually this would also be helpful not only for COVID-19 but also generally for all infectious diseases transmitted through close human contacts.

An interesting analysis result of our survey is that the respondents who changed from public transport to bicycle and car also report shorter travel times with the new modes. Merely 2% (6 out of 297 respondents – see Table 4) pointed out that faster travel is their primary motivation for changing their travel mode. Together with the high percentage of those who pointed infection risks on public transport, our survey result implies that commuters who changed their travel mode are motivated mainly by the perceived infection risks, but actually also harvest travel time benefits. Those who changed from public transport to walking tend to report longer travel times, which implies that this group accepted longer travel time in return for lower perceived infection risk. This might not be a serious problem during the lockdowns as the total traffic volume is largely reduced, but this might also imply some potential modal shift from public transport towards private cars triggered by perception of infection risks. Mitigation of this is one of the primary challenges that many cities have tried to address by implementing various measures, as, for example, summarized by European Cyclist's Federation (2020) for cycling-related measures. To avoid an unfavourable shift towards private cars, policy measures to discourage such changes and to encourage the use of bicycle will have to be implemented.

4.2 Implications for transport system

A general insight derived from our survey as well as other similar research in parallel is that the transport system has the capability to respond to an imminent external threat. The COVID-19 pandemic demonstrated that, within a few days or weeks, human mobility behaviour was able to be adapted to health care requirements. This led to a significant reduction of negative externalities caused by road vehicles and greenhouse gas emissions (e.g. Le Quéré, Jackson et al. 2020). Policy options have been discussed in this area for decades, but discussions and cautiously applied measures have shown little effect so far, as regularly attested by emission inventory reports (e.g. Anderl, Geiger et al. 2019). The COVID-19 measures to reduce viral spread corroborated a reduction of mobility expenditure through implementation of policy measures. Needless to say, such a dramatic and ad-hoc reduction will not serve as a direct role model for continued post-lockdown implementation. Rather, transport science and policy will urgently need to study ways of restraining the transport system's negative environmental impact once the pandemic will be overcome and climate change challenges will be as inescapable as ever.

The spatial distribution of the two commutable workplace types – *Home Office Possible* and *Presence Essential* (section 3.2) – is not a subject of this research. Nevertheless, consideration with this regard may pose a promising line of future research. While *Home Office Possible* types of workplaces such as offices and educational facilities are more likely to be located in high-density areas like CBDs, many *Presence Essential* types of workplaces, such as production sites, logistics centres, and to some extent retail businesses are more likely to be located in low-density areas such as outskirts of cities. If the practice of home office persists with the COVID-19 pandemic as a trigger, workplaces in high-density areas with higher potential of active modes and access to public transport lines will be more likely to shift to home office. On the contrary, those in low-density and thus more automobile-dependent areas will be more likely to remain in place. This will mean that commuting traffic to destinations with higher potential of active modes and public transport will be likely to diminish, while commuting traffic to destinations with higher automobile-dependency will be likely to remain. To what extent such a shift to home office will take place is not estimable with our results because we did not ask for locations of workplaces in our questionnaire. Nevertheless, this effect will probably not be ignorable as implied by the considerable result that between 55 and 77% of our respondents work at *Home Office Possible* types of workplaces (Figure 5).

Further research in this regard will be needed, but at the same time transport planning and policy-making will have to respond to this new kind of challenge. Towards sustainable commuting mobility, encouraging home office to mitigate commuting traffic through policy measures alone is deemed to be not strong enough as the possibility of home office is more influential (section 3.2). Access to and within areas with environment-friendly means of transport where *Presence Essential* types of workplaces are more likely to be located will gain more importance to shift commuting modal share towards environment-friendly transport modes. For example, safe and attractive infrastructures for active modes in such areas will have to be prioritized. In a long term, land-use policy will have to adapt itself so that residential areas and such *Presence Essential* business districts are within a near proximity to be travelled with active modes. Policy towards sustainable transport will also have to be appraised from the perspective of resiliency during epidemic of respiratory diseases, not only from an ecological perspective.

Regarding public transport, there seems to have been an ambivalent situation during the pandemic. Ceteris paribus, the reduction of the number of passengers led to an increase in the level of service for passengers – less crowded vehicles offer more seating opportunities and are expected to run more punctually. However, on a systemic level, this passenger reduction has led to a decrease in cost-recovery rates from ticket revenues, and this may also remain so in the future. This is particularly challenging where no systematic scheme exists to retain public transport services being provided even with few passengers, as this may lead to service suspension of public transport due to financial reasons. In this respect, regulatory provisions to mitigate the risk of sudden service disruptions such in EU Regulation 1370/2007 is turned out to be advantageous and

resilient for ensuring continuity of transport policies to encourage the use of public transport. On the contrary, during and after a pandemic, a decrease or discontinuation of service is more likely, if public transport is operated by the private sector for own account, but further research will be needed in this regard.

4.3 Caveats and limitations

As elaborated in section 3.1, our analysis results have to be understood in the context of the highly-educated, relatively young and working people living in urban areas, who are more represented than other groups. The selection of respondents was made through a snowball sampling method to enable a wide outreach during the lockdown and to collect quick responses. Therefore, the results may not fully represent the whole population. People without completed secondary education are less represented: if these groups were included, the results about the practice of home office would be different. We did not analyse the result subdivided into urban and rural areas, as people living in rural areas are also less represented and, due to our non-mandatory postcode-based method, area information from some countries are not available. If such analysis would be made possible, this might affect the results too.

This bias is also confirmed in modal shares. A systematic comparison of our results with representative samples from national travel surveys of all fourteen countries is not feasible due to data availability and different survey methods. Nevertheless, a small comparison of the commuting modal share with national travel surveys in Austria, Germany, Japan and Slovenia (Table 10), where reliable data is available, gives us some insights. It is clear that our sample underrates car commuters and shows higher shares of public transport commuters to varying degrees (+2 percentage-points to +37 percentage-points). Except for Japan, cycling commuting trips are overrated and the share of walking commuting trips is only slightly smaller or larger in our sample (-2 to +2 percentage-points). High shares of public transport and cycling trips can be explained by our young, urban and highly educated respondents. The differences in modal split compared to national transport surveys illustrate the sampling bias in favour of such populations.

Table 10. Comparison of modal split in national transport surveys to our sample

Country	Walking	Bicycle	Public Transport	Car	Other	
	Modal split in literature [%]					**Sample type; Source**
AT	8	7	20	65	0	Work commuting trips, nationwide; (Wolf-Eberl and Posch 2018)
DE	9	13	15	63	0	Work commuting trips, nationwide; (infas 2017)
JP	7	13	32	44	4	Work commuting trips, average of 70 major cities; (MLIT 2017)
SI	8	8	7	72	5	Work commuting trips, nationwide; (Halilović, Cerar et al. 2020)
	Differences to our sample [percentage-points]					
AT	-2	+16	+26	-45	+4	
DE	-1	+19	+18	-40	+4	
JP	-2	-7	+37	-27	0	
SI	+2	+17	+2	-18	-3	

Although our survey reached out to more than 100 countries, respondents concentrate largely in Europe, Japan, Malaysia and Brazil. Other countries which have been affected severely from COVID-19, such as China, South Korea and the United States are not well covered by our respondents.

It has to be also noted that our questionnaire focused on the mobility situation during the lockdown period: the result should be understood as a snapshot during lockdowns, and the situation is supposed to have already changed as many countries may have already lifted the hardest lockdown measures.

5. Conclusion

Despite some limitations caused by the nature of the quickly prepared and implemented survey, our online survey in 21 different languages enabled us to capture the changes in commuting mobility in 14 countries. Our analysis result shows that the home office is, at least among rather highly educated and young urban working population, used typically by between ca. 40 and 60% of people. This might imply an ultimate magnitude of a strong measure to encourage home office, despite the limitations embedded in the nature of this questionnaire-based research. The research result also implies that an effective policy measure for commuting mitigation does have impacts on actual travel behaviour of people.

Although the COVID-19 countermeasures cannot be directly applicable as policy measures aiming at travel mitigation, the reduction of travel during the COVID-19 outbreak confirms a conceivable possibility of encouraging reduction of everyday travel through implementation of strong policy measures. However, the effect of such policies may be mainly prevalent where *Home Office Possible* type of workplaces tend to be located, e.g. CBDs. This kind of areas is often densely built and have good affinity with active modes and public transport. To gain positive impacts on reduction in greenhouse gases and other negative externalities of commuting transport, measures to encourage the use of active modes in the area where *Presence Essential* types of workplaces is likely to be located is deemed to gain relative importance and thus particularly recommendable.

Among those who had to continue to commute and who changed the commuting travel mode from public transport to others, the infection risks in public transport is the most often mentioned reason: nevertheless, many of those who changed to private cars and to bicycles enjoy reduced travel time, too. It is still unclear to what extent and how long this trend continues. Measures to encourage the use of active travel modes where possible is strongly recommended, as this would potentially mitigate an undesirable modal shift towards private motorized modes triggered by COVID-19, and will work positively if the pandemic comes to an end. To this end, transport policy has to be flexible enough to respond to sudden changes of circumstances, not just caused by epidemic events but by any other reason.

Acknowledgements

We are grateful to the following volunteers who (a) translated the questionnaire into various languages and (b) helped with coding the open response variables: Mohammad Sadegh Aminian (Farsi), Miha Lokar (Slovene), Amphai Wejwithan (Thai), Leo and Benno Schmieder (Italian), Ralitsa Dimova (Bulgarian), Ebru Vesile Öcalir (Turkish), Simone Becker Lopes (Portuguese), Igor Ripka & Genia Ortis (Slovakian), Dana-Maria Tutui (Romanian), Francisco Porras Bernárdez (Spanish), Reynaldo Siahaan (Indonesian), Rie Matsui and Han Woong Yoo (Korean), Aso Validi (Kurdish), Miklos Radics & Flora Bolonyai (Hungarian), Masria Mustafa and Zanariah Abd Rahman, (Malaysian), Jitka Ondráčková (Czech), Ulrich Leth (German) and Yu and Chie Nakajima (Chinese). Of note, French and Japanese versions were translated by Barbara Laa and Takeru Shibayama respectively.
We also thank Guenter Emberger for his comments and feedbacks to the questionnaire and the analysis results, Melissa Kapfenberger for her management of the online survey, and Helmut Lemmerer for feedback to the questionnaire.

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