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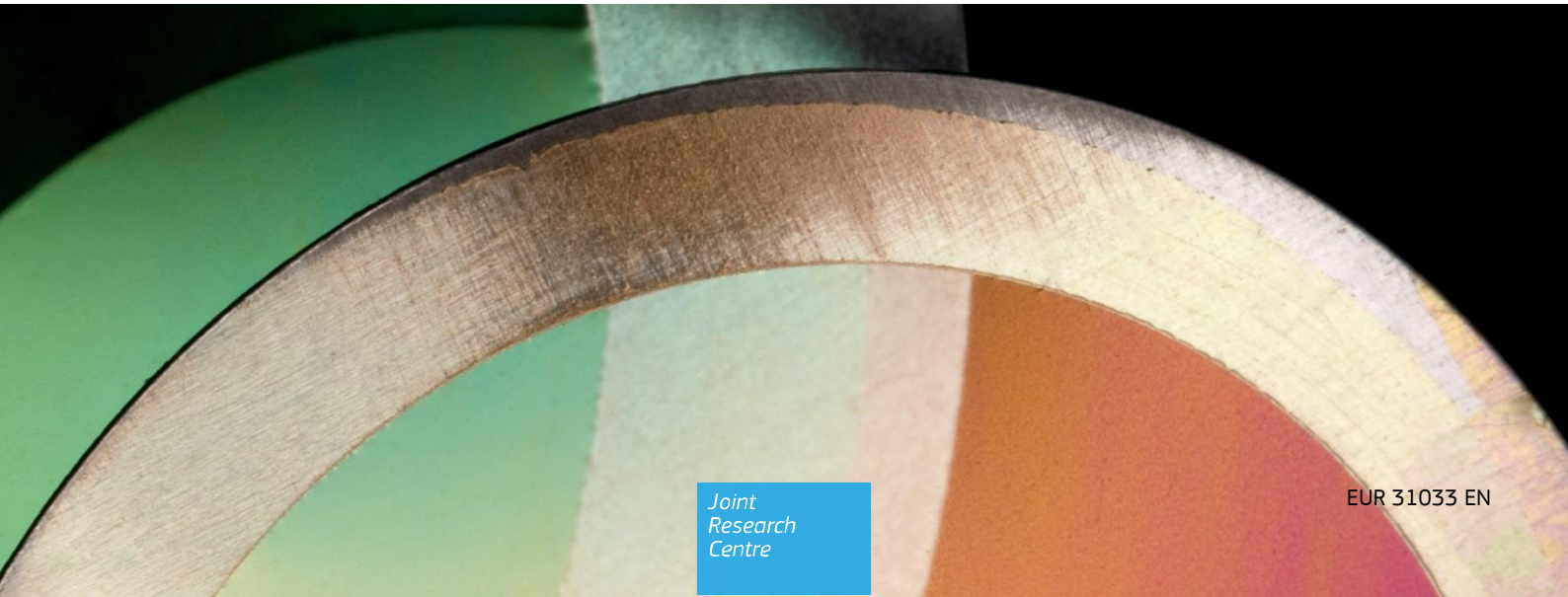
Impact of the COVID-19 Pandemic on Mobility in Spain

An Exploratory Data Analysis Based on Open Sources

Radics, M., Christidis, P.

2022



Joint Research Centre

EUR 31033 EN

Contact information
Name: Miklós Radics
Address: European Commission, Joint Research Centre, c/ Inca Garcilaso 3, Sevilla, Spain
Email: miklos.radics@ec.europa.eu

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Contents

Abstract

This report presents the results of an analysis on mobility related consequences of the COVID-19 pandemic and the applied restricting measures in Spain covering the period of March 1, 2020 – October 1, 2021. The analysis focuses on how the number of trips changed on national, autonomous community and provincial levels as well as on the potential causes behind the changes. Multiple open mobility data sources were used that describe the evolution of the number of trips published by the Spanish Ministry of Transport and tech companies.

Results show that due to the unpredictable consequences of the coronavirus disease and strict governmental responses, the number of trips dropped drastically in all Spanish autonomous communities to 40-50 % compared pre-pandemic levels after the first state of alarm was introduced in March 2020. After hard lockdown was lifted, mobility levels gradually returned to 70-80% compared to the baseline level regardless of the number of coronavirus infections and deaths of the subsequent waves of infection that exceeded the first wave. The pandemic brought significant changes in the individual behaviour that also has an impact on trip demand and distribution. Although the second state of alarm ended in May 2021, and since then only minor restrictions influence mobility, after 1.5 years of pandemic public transport is still underperforming and teleworking levels are higher compared to the pre-pandemic situation in major Spanish cities.

Executive summary

Aim and methodology

The present report discusses the results of an analysis on mobility related consequences of the COVID-19 pandemic in Spain. The aim of the research is to explore how travel habits have changed since the beginning of the pandemic on national, autonomous community and provincial levels and the role of mobility restrictions in the changes. The timeframe of the analysis is March 1, 2020 – October 1, 2021.

The analysis is based on multiple open data sources covering the dynamics of the pandemic (number of cases and deaths) and mobility. Mobility data are derived from the Spanish Ministry of Transport, Mobility and Urban Agenda, Google (COVID-19 Community Mobility Reports) and Apple (Mobility trends reports) mobility data. These data sources allow us to compare the number of movements to the baseline that describes the pre-pandemic situation. A further data source describes government responses to the pandemic (Oxford Covid-19 Government Response Tracker).

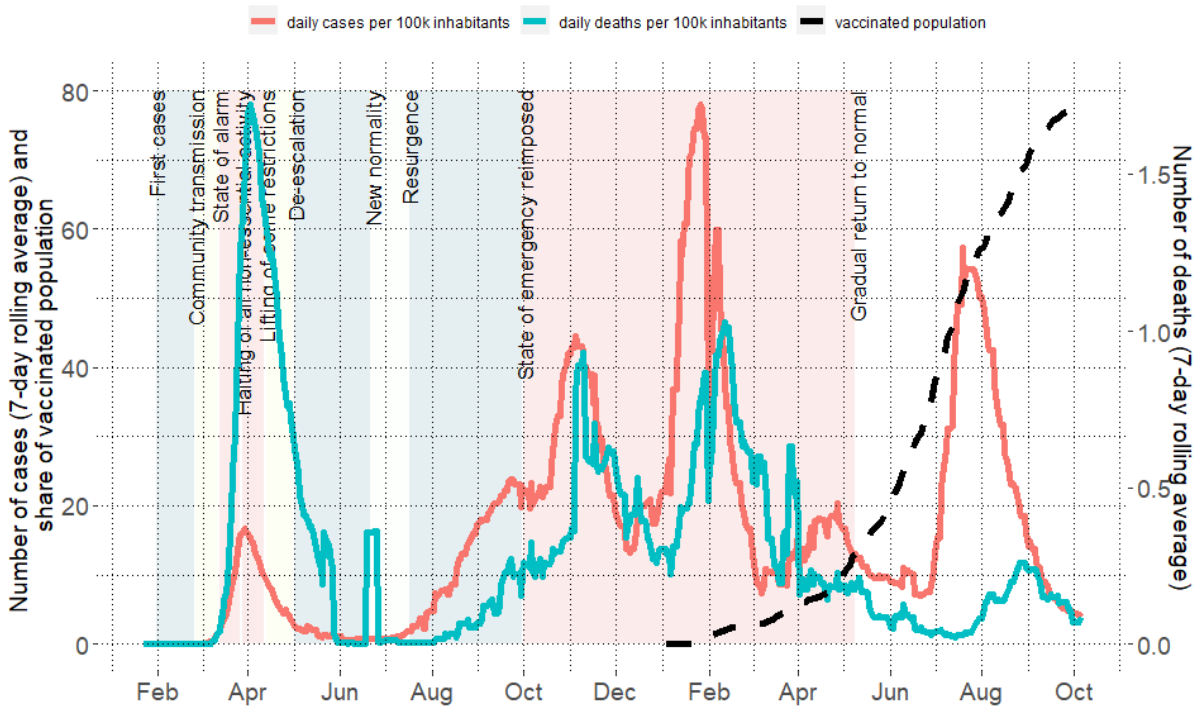
The data visualizations presented in this paper are made available online through an interactive dashboard. The users of the dashboard can define the timeframe and the variables to be included on the plots and maps.

Context

After the first cases were identified in February 2020 in Spain, the first state of alarm was imposed on March 13, 2020 with hard lockdown prohibiting all non-essential movements. Although from April restrictions were gradually lifted, the state of alarm lasted until June 21, 2020. As a reaction to the increase in the number of cases, the second state of alarm was introduced on October 24, 2020 and was lifted on 9 May, 2021.

The figure below shows how the pandemic evolved over time in Spain. The background colours of the chart represent the above discussed periods of the pandemic and are in line with the stringency of governmental responses. Five waves of infection can be observed in almost every region of Spain.

Figure 1. Number of confirmed cases and number of deaths in Spain (7-day rolling average)

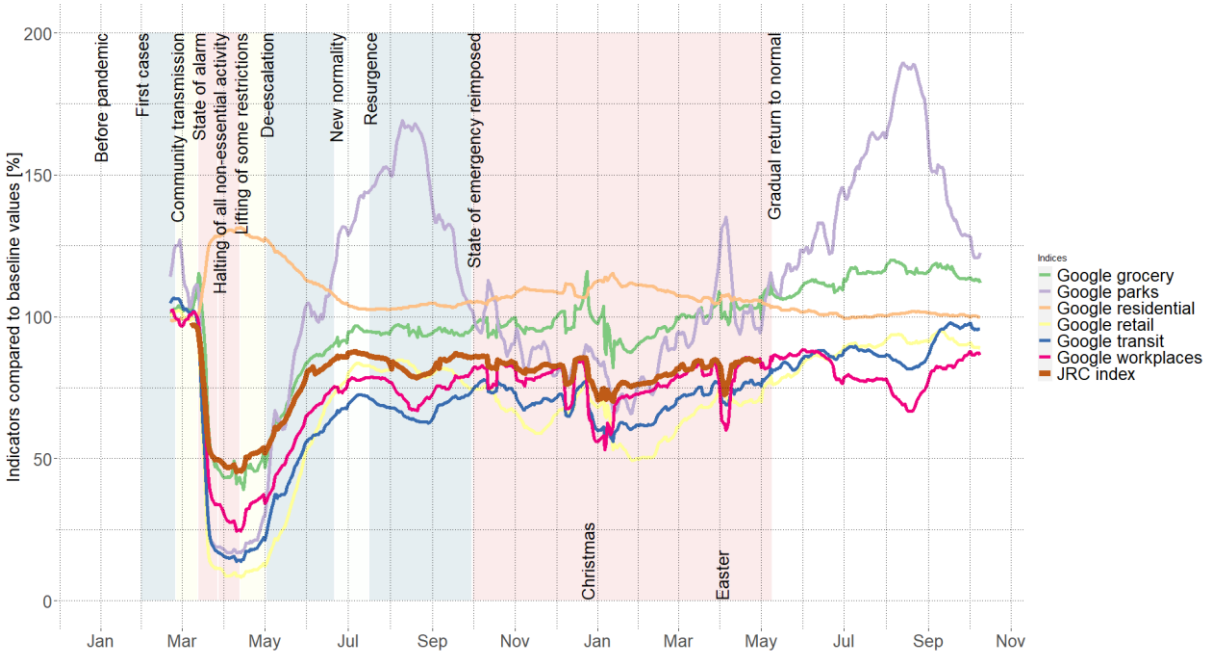


Source: JRC analysis (Datadista 2021; INE 2021a; Narrativa 2021)

Results

Due to the restrictions of the first state of alarm and the unpredictable consequences of the coronavirus disease, the number of trips dropped drastically in all Spanish autonomous communities to 40-50 % compared to baseline regardless the number of reported coronavirus cases. Google mobility reports show that trips related to retail, workplaces or public transport journeys dropped to under 25% compared to baseline. After most of the restrictions were lifted, mobility levels returned to 70-80% compared to baseline by the summer of 2020. Although the number of coronavirus infections and deaths of the subsequent waves exceeded the first wave, mobility levels remained relatively high compared to baseline (above 75%). The main reason is that after hard lockdown was lifted, it was not re-imposed. During the second state of alarm, movements were affected dominantly by night curfew and travel restrictions on interregional trips which in some regions were extended to interprovincial trips.

Figure 2. Comparison of JRC index (based on mobile cell information) with Google indices on national level



Source: JRC analysis (Google 2021a; MITMA 2021a)

The relaxation of movement restrictions and the relatively low levels of infections during the summer of 2020 let people travel more. Differences across Spain in terms of mobility levels were more dominant during the summer of 2020 and 2021 when attractive tourist destinations reached higher levels and cities which residents tend to leave their residence dropped to lower levels. Out of the holiday seasons, during the two states of alarm the trends were less scattered across Spain and mobility levels dominantly remained below pre-pandemic levels.

September 2021

An important question for the future is the long-term effects of the pandemic on mobility and the take-up of teleworking, online shopping, home delivery and other means that have become the norm since the beginning of the pandemic to reduce movements and contacts. Google workplace index shows that in greater cities people in overall tend to work more from home. Visits of workplaces in September 2021 on national level reaches 83% compared to pre-pandemic values, while even lower levels in great cities' provinces. Google transit index shows that public transport has not recovered either. Although the national average is 97% when whole Spain is considered, provinces of major cities remain below baseline. A possible future research line would be a prediction on how sustainable mobility could be affected in long term by the changes due to the pandemic.

Potential policy impact

Although data availability on restrictions limited the possibilities of analysing in-depth the effects of restrictive measures on mobility, national level data shows that government decisions in the beginning were somewhat delayed, then followed the evolution of infections. Despite a few exceptions, restrictions had an immediate result on the number of trips, especially during the first state of alarm when restrictions were highly enforced.

Limited data availability on government responses to the pandemic turned out to be a barrier that hindered impact assessment. A well-structured, detailed database on government measures would be necessary to evaluate the impacts of the movement restrictions and conclude evidence-based policy proposals.

1 Introduction

Mobility is a proxy of social interactions and, as such, is an important indicator to monitor in order to explain the dynamics of the pandemic. Authorities at various national or local levels established mobility restrictions early on during the COVID-19 pandemic as a measure to limit the spread of infections. Apart from the mobility restrictions, the pandemic brought significant changes in the individual behaviour that also had an impact on trip demand and distribution.

This report analyses the effects of the pandemic and the applied restricting measures on mobility across Spain at national, autonomous community and provincial levels. The following three main types of data sources were used for the analysis:

— data on how people moved around in Spain since the pandemic started (open data based on mobile phone locations, Apple and Google data ([1]) about travel habits of their users);

— data about how the pandemic evolved over time (number of coronavirus infections and deaths);

— data about restrictions.

The main research questions are as follows:

— How different policy measures that aimed to decrease movements have affected travel behaviour across Spain (such as mobility restrictions, school closures etc.)?

— How and why travel habits changed over time on the analysed three levels?

— How can distinct sources of data (mobile cell information data, open Google and Apple data) be used to analyse mobility patterns?

The timeframe of the analysis is March 1, 2020 – October 1, 2021.

([1]) Apple Mobility Trends Reports and COVID-19 Community Mobility Reports (see section 4 for more details).

2 Context

This section summarizes the timeline of the pandemic in Spain to contextualize the presented analysis.

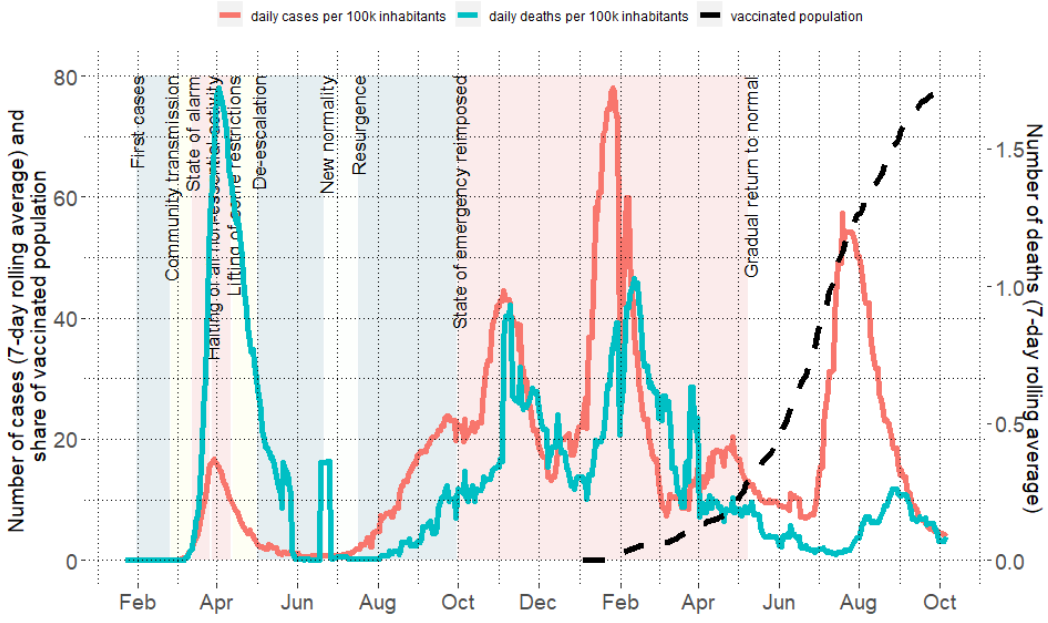
After the first known case caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2, also known as COVID-19) was identified in Wuhan, China, in December 2019 (Anon 2021a), the pandemic reached Spain on January 31, 2020, when a tourist was tested positive for SARS-CoV-2 in La Gomera, Canary Islands (Line 2020). The virus started to spread across Spain and by March 13, all 50 provinces (excluding the two autonomous cities) had been reported the first confirmed case (Anon 2021b; Ansede 2020).

The timeline of the pandemic (based on the increase of the number of cases and governance responses on national level) can be divided to periods as follows (Anon 2021b):

- first cases (January 31, 2020 –February 25, 2020);
- community transmission (February 26, 2020 – March 12, 2020);
- state of alarm (March 13–27, 2020);
- halting of all non-essential activity (March 28, 2020 – April 12, 2020);
- lifting of some restrictions (April 13, 2020 – May 1, 2020);
- de-escalation (May 2, 2020 – July 2020);
- resurgence (July 17, 2020 – October 2020);
- state of emergency reimposed (October 1, 2020 – May 9, 2021).

Figure 3 shows how the number of confirmed coronavirus cases and deaths evolved over time in Spain. The background colours of the chart represent the above-mentioned periods of the pandemic and are in line with the stringency of governmental responses (see section 4.2 for further information). We can identify 5 waves during the visualized period that impacted autonomous communities at the same time but with different intensity (for the grid plot covering all autonomous communities see *Figure 16*).

Figure 3. Number of confirmed cases and number of deaths in Spain (7-day rolling average)



Source: JRC analysis (Datadista 2021; INE 2021a; Narrativa 2021)

During the first wave of the pandemic the number of tests to identify infected persons was limited and consequently, the number of reported coronavirus cases was lower as well (Ponce-de-Leon et al. 2021). However, the number of reported infections describe well the dynamics of the pandemics. This limitation should be taken into consideration when the different waves are compared later in this study.

3 Related work

The aim of the literature review was to focus on papers that aimed to understand how the pandemic affected mobility in Spain (and in some exceptions other European countries) analysing similar data sources that are used in the current study, to explore what other researchers had done with similar data sources and applying similar methodologies focusing on overland passenger transport (excluding aviation and freight transport).

Table 1 summarizes the reviewed articles and their most important characteristics. There are various studies that focus on shorter periods of the pandemic with different geographical scopes to understand the relations between human mobility and the pandemic. However, there is a significant gap in the literature. The number of studies that cover the whole country and the whole timeline of the pandemic is limited, and the authors are not aware of other research that analyses multiple data sources for such a wide timeframe and geographical scope as the current analysis. The present work intends to fill this gap.

Table 1. Reviewed articles and their main characteristics that focus on Spain

Relevance [2]	Title	Date of publi-cation	Data source	Aim	Methodology	Highlights, comments
+	Post-COVID-19 Travel Behavior Patterns: Impact on the Willingness to Pay of Users of Public Transport and Shared Mobility Services in Spain (Awad-Núñez, Julio, Gomez, et al. 2021)	MAR 2021	nationwide survey (Spring 2020 to overview the recent changes)	*"to study and understand the willingness to adopt a set of measures to improve the safety conditions of public transport and shared mobility services against possible contagion from COVID-19 and the willingness to pay for them"*	choice modelling framework based on Heckman specification	
+++	Comparative Analysis of Geolocation Information through Mobile-Devices under Different COVID-19 Mobility Restriction Patterns in Spain (Pérez-Arnal et al. 2021)	FEB 2021	-Facebook Data for Good -COVID-19 Community Mobility Reports (Google) -Apple Mobility Trends Reports	*"to explore the behavior and inter-relations of private sources of mobility data in the context of Spain"*	-exploratory analysis -Pearson correlation between Facebook and Google data	-examined period: March – May 2020-identified mild differences between regions during the three months -significant differences depending on the day of the week -unforeseen anti-correlation between two variables that, according to their definition, should have a similar behaviour: Google's residential vs. Facebook's remain-in-tile
++	Lockdown and Adaptation: Residential Mobility in Spain During the COVID-19 Crisis (Duque-Calvache, Torrado, and Mesa-Pedrazas 2021)	NOV 2020	Spanish nationwide online survey on the effects and social changes caused by COVID-19 (Duque-Calvache et al. 2020)	*"the paper analyses the residential changes that occurred in Spain during the 2020 lockdown and the later de-escalation period, focusing on movement triggers, motivations and destinations"*		-role of social inequality in the control of a contagious disease -mobility may spread the virus, but the underlying problem is inequality

[2] Overall relevance in terms of methodology, data, geographical scope, aim and findings. Legend: +++: highly relevant, ++: relevant, +: less relevant, but worth mentioning (the highly relevant ones are highlighted with grey shading).

Relevance [2]	Title	Date of publi-cation	Data source	Aim	Methodology	Highlights, comments
+	A Spatial-Temporal Model for the Evolution of the COVID-19 Pandemic in Spain Including Mobility (Aràndiga et al. 2020)	OCT 2020	mobility data between provinces and autonomous communities of Spain, provided by the INE	*"to analyze the influence of mobility on the evolution of a disease after a lockdown period and to study the appearance of small epidemic outbreaks"*	*"mathematical model for the simulation of infectious disease outbreaks including mobility data"*	-period: March 16, 2020 – June 22, 2020 -reference day: a typical working day before lockdown
+	Acceptability of Sustainable Mobility Policies Under a Post-COVID-19 Scenario. Evidence from Spain (Awad-Núñez, Julio, Moya-Gómez, et al. 2021)	JUN 2021	online survey during the lockdown in Spring (2020, published on digital social networks, such as Twitter, Facebook, or LinkedIn)	*"to study and understand individuals' acceptability towards a set of generic measures related to urban mobility in Spain, one of the countries most affected by the COVID-19 pandemic"*	analysis on an online explorative survey	the majority is in favour of a new urban hierarchy (new car restrictions, more pedestrian space, and switch to more sustainable mobility)
++	Effects of the COVID-19 Lockdown on Urban Mobility: Empirical Evidence from the City of Santander (Spain) (Aloi et al. 2020)	MAY 2020	traffic counters, public transport ITS, recordings from traffic control cameras and environmental sensors	*"to analyze the impact of the confinement measures or quarantine and to make comparisons between journey flows and times before and during the confinement"*		risk of a decline in the sustainability of mobility in urban areas
+	Those Who Cannot Stay at Home: Urban Mobility and Social Vulnerability in Barcelona During the COVID-19 Pandemic (Checa et al. 2020)	NOV 2020	-validations of public transport tickets (metro, suburban railway and tram) -mean income of the area where each of the accesses is made	*"to analyze, in the metropolitan area of Barcelona, the differentiated behavior of the population with respect to daily mobility"*		*-"people living in vulnerable areas have been able to reduce their mobility less and more slowly than the rest of the population"* *-"the inability to reduce daily commuting becomes both cause and expression of social exclusion"*

Relevance [2]	Title	Date of publi-cation	Data source	Aim	Methodology	Highlights, comments
+++	Mobility in Andalusia During the Covid-19 Pandemic (January 2021) (Christidis, Ciuffo, et al. 2021)	JAN 2021	-movement data based on mobile cell network information -Google -Apple	to analyse the evolution of mobility in Andalucía during the covid-19 pandemic	-JRC mobility indicator -exploratory analysis	-mobility significantly reduced during the two waves of the pandemic -rebound in mobility levels when movements were less restricted
+++	COVID-19 Flow-Maps an Open Geographic Information System on COVID-19 and Human Mobility for Spain (Ponce-de-Leon et al. 2021)	NOV 2021	movement data based on mobile cell network information	*"to present a cross-referenced geographic information system (GIS) named COVID-19 Flow-Maps to manage, retrieve, visualise and analyse regularly updated time-series data on population mobility networks and daily reports of COVID-19 cases in Spain"*	developed index: mobility associated risk	an online dashboard was developed for interactive visualization of the different metrics and results [3]
+++	Distancia-COVID project, mobility reports	SEPT 2020	aggregated and anonymized data from mobile phone records	*"to chart movement trends after the major mobility and social restrictions imposed by the Spanish government at different geographical scale"*		regular mobility reports on national level and on smaller scale (Asturias, Balearic Islands, Cantabria, Madrid), the last report was published in September 2020

Source: JRC analysis

[3] The dashboard is available here: http://fowmaps.life.bsc.es/.

Table 2. Reviewed articles and their main characteristics with a geographical scope outside of Spain

Relevance [4]	Title	Date of public-cation	Data source	Aim	Methodology	Highlights
+++	Population Mobility Reductions During COVID-19 Epidemic in France Under Lockdown [France] (Pullano et al. 2020)	JUNE 2020	mobile phone trajectories	*"to measure mobility changes before and during lockdown at both local and country scales"*	statistical analysis, network analysis and maps	-*"trips were reduced by 65%, similarly to reductions found in Belgium, Spain, and Italy during lockdown"* -*"fear of an imminent change in policy imposing stricter restrictions pushed individuals relocate themselves even to farther away regions where to spend the period of lockdown"* -*"once lockdown entered into effect, population mobility reductions were heterogeneous across regions"*
+++	Mobility and Economic Impact of COVID-19 Restrictions in Italy Using Mobile Network Operator Data [Italy] (Vespe et al. 2021)	MAY 2021	aggregate and anonymized mobile positioning data	*"analyze the impact of restrictions on mobility in Italy, with a focus on the period from 6 November 2020 to 31 January 2021, when a three-tier system based on different levels of risk was adopted and applied at regional level to contrast the second wave of COVID-19"*		

(4) Overall relevance in terms of methodology, data, geographical scope, aim and findings. Legend: +++: highly relevant, ++: relevant, +: less relevant, but worth mentioning (the highly relevant ones are highlighted with grey shading).

Relevance [4]	Title	Date of public-cation	Data source	Aim	Methodology	Highlights
++	The Post-Pandemic Recovery of Transport Activity: Emerging Mobility Patterns and Repercussions on Future Evolution [European level] (Christidis, Christodoulou, et al. 2021)	JUNE 2021	-*"several conventional and innovative data sources"* -EU Travel Survey	*"analyze the main factors that can influence future supply and demand and explore how they may affect trip generation, distribution and modal split in passenger transport"*	TRIMODE model - detailed strategic EU-level transport model	-*"expected short-term reduction in the number of trips, average trip distance, and use of public transport"* -*"the projected trends in transport activity per mode raise worries as regards all three sustainability dimensions (economic, environmental, social)"*
+++	Measuring the Impact of COVID-19 Confinement Measures on Human Mobility using Mobile Positioning Data [across Europe] (Santamaria et al. 2020)	JUL 2020	anonymized and aggregated mobile positioning data	*"how the mobile positioning data can be used to analyse the impact of the confinement measures on mobility in fourteen EU countries (including Spain)"*	-elaboration of a mobility indicator -qualitative and quantitative assessment	-*"the confinement measures explain a large part of the mobility patterns observed (in most cases more than 50%, up to 90%)"*

Source: JRC analysis

4 Data

This section gives an introduction of the data that was used for the analysis. The research is based on open data sources that are publicly available on the data owners' websites or through APIs. The following distinct types of data were used for the analysis:

— movement data based on mobile cell information, a transport model of Spain and estimations of tech companies on their users' mobility habits (Google and Apple);

— data on restrictions that describe the measures that were put in place to slow the spread of coronavirus infections;

— data on the evolution of infections and deaths caused by the coronavirus;

— and additional socio-demographic data.

4.1 Data on mobility

Data sources that describe how people moved within Spain since the beginning of the pandemic are discussed in this section.

4.1.1 MITMA cell information data

Cell information based mobility data was made open by the Spanish Ministry of Transport, Mobility and Urban Agenda (MITMA, Ministerio de Transportes, Movilidad y Agenda Urbana) to foster research about the pandemic (MITMA 2021a) ([5])([6]). The dataset consists of two data tables:

— a trip matrix (contains the daily number of trips between zones estimated for the whole population, see Figure 4):

- activity related to the trips: home, work, other;
- distance (0.5-2, 2-5, 5-10, 10-50, 50-100, 100- [km]);
- number of trips between estimated for the whole population;

Figure 4. Head of the raw dataset (MITMA mobile phone data)

	fecha	origen	destino	actividad_origen	actividad_destino	residencia	edad	periodo	distancia	viajes	viajes_km
1:	20200221	01001_AM	01001_AM	casa	otros	1	NA	0	0005-002	4.350	8.659
2:	20200221	01001_AM	01001_AM	casa	otros	1	NA	0	002-005	9.775	33.090
3:	20200221	01001_AM	01001_AM	casa	otros	1	NA	1	005-010	6.235	56.873
4:	20200221	01001_AM	01001_AM	casa	otros	1	NA	3	002-005	4.350	17.387
5:	20200221	01001_AM	01001_AM	casa	otros	1	NA	3	005-010	4.350	27.336
6:	20200221	01001_AM	01001_AM	casa	otros	1	NA	3	010-050	15.398	228.776

Source: (MITMA 2021a)

— data on the number of trips with the estimated number of people who fall in each category (see Figure 5):

- number of trips: 0, 1, 2, 2+;
- number of persons falling in the categories above.

Figure 5. Head of the raw dataset (MITMA mobile phone data)

	fecha	distrito	numero_viajes	personas
1:	20200221	01001_AM	0	2296.359
2:	20200221	01001_AM	1	209.913
3:	20200221	01001_AM	2	1898.217
4:	20200221	01001_AM	2+	3944.864
5:	20200221	01002	0	3357.881
6:	20200221	01002	1	663.189

Source: (MITMA 2021a)

([5]) Referred as MIMTA mobile data throughout the paper.
([6]) Ponce-de-Leon et al. (2021) explain the reconstruction of the data in detail.

Further important characteristics of the data are as follows:

— The covered time period is February 29, 2020 – May 9, 2021 (until the end of the second state of alarm, after May 10, 2021 data is not available).

— Reference period: February 14-20, 2020.

— Geographical granularity of the data: census districts.

4.1.2 **Apple (Mobility trends reports)**

Apple Mobility Trends Reports ([7]) show the relative volume of directions requests in Apple Maps per country/region, sub-region or city (defined as the greater metropolitan area) compared to a baseline volume on January 13, 2020 (values of each day are compared to the baseline volume). The most important characteristics of the data are as follows (see Figure 6) (Apple 2021):

— Activity categories: driving, transit and walking.

— Geographical granularity of the data:

- country level;
- regional (autonomous community) level covering 17 regions, excluding the two autonomous cities;
- no data on provincial level;
- data on city level: Seville, Barcelona, Madrid and Valencia.

— Covered period: data available since January 13, 2020 (daily aggregation).

Figure 6. Head of the raw dataset (Mobility trends reports, Apple)

	country	sub.region	subregion_and_city	geo_type	date	driving	transit	walking
1	Spain	Andalusia	Andalusia	sub-region	2020-01-13	0.00	0.00	0.00
2	Spain	Andalusia	Andalusia	sub-region	2020-01-14	-0.02	-9.50	-2.81
3	Spain	Andalusia	Andalusia	sub-region	2020-01-15	1.18	-4.85	-0.42
4	Spain	Andalusia	Andalusia	sub-region	2020-01-16	7.54	-3.98	7.09
5	Spain	Andalusia	Andalusia	sub-region	2020-01-17	25.65	4.07	34.36
6	Spain	Andalusia	Andalusia	sub-region	2020-01-18	26.31	10.75	39.73

Source: (Apple 2021)

4.1.3 **Google (COVID-19 Community Mobility Reports)**

According to Google, *"the dataset is intended to help remediate the impact of COVID-19. The data shows how visits to places, such as grocery stores and parks, are changing in each geographic region."* (Google 2021b) The most important characteristics of the data are as follows (see Figure 7) (Aktay et al. 2020; Google 2021a, 2021b) ([8]):

— Place categories:

- Grocery & pharmacy (grocery markets, food warehouses, farmers markets, specialty food shops, drug stores, and pharmacies);
- Parks (local parks, national parks, public beaches, marinas, dog parks, plazas, and public gardens);
- Transit stations (public transport hubs such as subway, bus, and train stations);
- Retail & recreation (restaurants, cafes, shopping centres, theme parks, museums, libraries, and movie theatres);
- Residential (places of residence);
- Workplaces (places of work).

— Geographical scope: covers all 17+2 regions (autonomous communities) and 50+2 provinces of Spain.

— Covered period: data is available since February 15, 2020 (daily values).

([7]) Referred as Apple data throughout the paper.
([8]) Referred as Google data throughout the paper.

— Baseline: "*changes for each day are compared to a baseline value for that day of the week…the baseline is the median value, for the corresponding day of the week, during the 5-week period Jan 3–Feb 6, 2020*" (Google 2021b).

— Data source: "*data from users who have opted-in to Location History for their Google Account, so the data represents a sample of users of Google (this may or may not represent the exact behavior of a wider population)*" (Google 2021b).

Figure 7. Head of the raw dataset (COVID-19 Community Mobility Reports, Google)

	country_region_code	country_region	sub_region_1	sub_region_2	date	retail_and_recreation_percent_change_from_baseline	grocery_and_pharmacy_percent_change_from_baseline
1	ES	Spain			2020-02-15	2	-1
2	ES	Spain			2020-02-16	2	3
3	ES	Spain			2020-02-17	0	1
4	ES	Spain			2020-02-18	-2	0
5	ES	Spain			2020-02-19	0	1
6	ES	Spain			2020-02-20	1	1

	parks_percent_change_from_baseline	transit_stations_percent_change_from_baseline	workplaces_percent_change_from_baseline	residential_percent_change_from_baseline
1	26	8	0	-2
2	13	5	-1	-2
3	9	3	3	-1
4	5	4	3	0
5	11	2	3	-1
6	15	5	3	-1

Source: (Google 2021a)

4.1.4 MITMA macro transport model of Spain

The National Transport Model of MITMA is a tool that supports long distance mobility related strategic planning. The model allows to obtain the origin-destination matrices of passenger and freight transport. Data from 2017 and estimations for 2030 and 2050 can be downloaded from the website of the ministry ([9]). The total number of annual trips between provinces for the modes of private car, bus, train, aviation are made available on the website (see Figure 8) (MITMA 2021c, 2021b).

Figure 8. Head of the raw dataset (MITMA macro model)

	ORIGEN	DESTINO	O_D	Vehículo_privado	Autobús	Ferrocarril	Avión	Ferry	Total
1:	ES01	ES02	ES01_ES02	13,881	-	-	-	-	13,881
2:	ES01	ES03	ES01_ES03	67,631	4,435	-	-	-	72,066
3:	ES01	ES04	ES01_ES04	10,003	-	-	-	-	10,003
4:	ES01	ES05	ES01_ES05	38,360	-	3,177	-	-	41,537
5:	ES01	ES06	ES01_ES06	16,648	31	-	-	-	16,679
6:	ES01	ES08	ES01_ES08	215,221	6,438	14,624	-	-	236,283

Source: (MITMA 2021c)

4.2 Data on restrictions

Due to the multilevel governance structure of Spain, decisions on restricting measures that aimed to slower the spread of coronavirus were made on different levels by different entities from national to municipal level. The authors of the study are not aware of a repository that compiles measures from these different levels for the whole timeline of the pandemic in an easy-to-handle format. RTVE, a state-owned public radio and television corporation, publishes daily updates covering all Spain, but data is available only since January 2021, historic data cannot be obtained and structuring the text of the website to a dataset for further analysis is demanding ([10]). Another possible solution would have been analysing official gazettes, but the work demand of this task was above the capacity of this project. Therefore, the results of the Oxford Covid-19 Government Response Tracker (OxCGRT) are used, which is a research project that aims to collect systematic information on policy measures of governments of more than 180 countries (Hale et al. 2021). Another option could have been the CoronaNET research project that compiled information on government responses and actions to the pandemic covering 198 countries since January 1, 2020 (Cheng et al. 2020). The project applies NLP ([11]) and web scraping for collecting news articles and governmental documents, and the collected data is fine-tuned and categorized by trained research assistants. The OxCGRT dataset contains 23 indicators organized into five groups (OxCGRT [2020] 2021): containment and closure policies, economic policies, health system policies, vaccination policies and miscellaneous policies.

([9]) Referred as MITMA model data throughout the paper.

([10]) https://www.rtve.es/noticias/20211123/mapa-confinamientos-espana-coronavirus-restricciones/2041269.shtml (accessed: 24 November, 2021)

([11]) Natural language processing (NLP). For further information see: https://www.wikiwand.com/en/Natural_language_processing (accessed: 24 November, 2021).

In Spain national and subnational data is available, the covered provinces are as follows ([12]): Basque Country, Catalonia, Madrid, Castille and Leon, Valencia, Asturias, Navarre, Andalusia, Balearic Islands, Aragon, La Rioja, Castille-La Mancha, Canary Islands, Galicia, Extremadura. Four indices were developed by Hale et al. (2021) on a 0-100 scale to help understand the raw data: overall government response index ([13]), containment and health index ([14]), stringency index ([15]) and economic support index ([16]). An important limitation of the discussed indices is that they were developed for comparative purposes and not for impact analysis on national level. As the indices describe the changes of policies and as other data sources are not available in a suitable format, we decided to use these data sources.

4.3 Data on cases and vaccination

Data on the number of coronavirus infections and deaths in Spain are accessed through the API of Covid-19 Tracking Project (Narrativa 2021). The obtained dataset contains information on the followings:

- number of confirmed daily cases;
- number of daily recoveries;
- number of daily deaths on provincial and regional levels.

Data on vaccination is downloaded from the data repository of Datadista (Datadista 2021).

As it was mentioned earlier, in the initial months of the pandemic, during the first wave, tests to identify infected persons were less available than in the later stages of the pandemic. Therefore, the number of reported infections during the first wave was lower as well (Ponce-de-Leon et al. 2021). In addition to that, the number of confirmed infections greatly depends on the number of tested persons. It should be noted that there were probably temporal and spatial differences in the number of tested persons.

4.4 Other data sources

Socio-demographic data was retrieved from the website of the National Statistics Institute of Spain (INE 2021a, 2021c).

([12]) However, the indices are calculated only on national level. Data on subnational level only covers restricting measures and events that are related to the pandemic.

([13]) *"The index records how the response of governments has varied over all indicators in the database, becoming stronger or weaker over the course of the outbreak."*

([14]) *"The index combines 'lockdown' restrictions and closures with measures such as testing policy and contact tracing, short term investment in healthcare, as well investments in vaccines."*

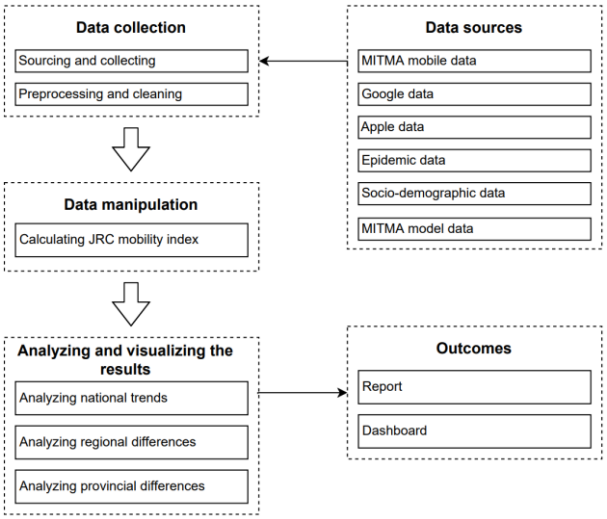
([15]) *"The index records the strictness of 'lockdown style' policies that primarily restrict people's behaviour. It is calculated using all ordinal containment and closure policy indicators, plus an indicator recording public information campaigns."*

([16]) *"The index records measures such as income support and debt relief. It is calculated using all ordinal economic policies indicators."*

5 Methodology

The main steps of the data analysis are presented by Figure 9. After exploring and finding all the data sources that were presented in the previous section, data was downloaded, cleaned and pre-processed to a suitable format for further data manipulation.

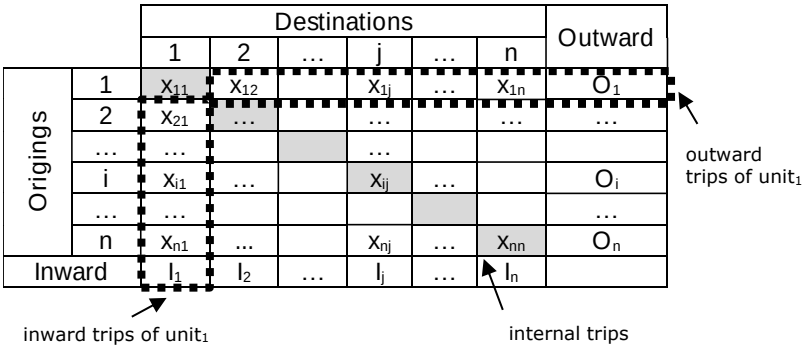
Figure 9. Explanation if the works flow, data sources and results



Source: JRC

Google and Apple mobility data required minor pre-processing only as the daily values (number of trips or search requests) are already compared to the baseline value. However, MITMA mobile data includes the daily number of trips. Therefore, the methodology developed by Christidis et al. (2021) was applied to calculate the JRC mobility index which is presented below. First, the daily number of trips was aggregated on autonomous community and provincial levels. Internal (trips with origin and destination within the same province/region), outward (trips that end in a different province/region but start at the same) and inward (trips that end in the same province/region but started in a different one) were calculated. The following origin-destination matrix explains how inward, outward and internal trips are calculated. x_{ij} is the number of trips per day with the origin at i and destination at j. The total number of trips of an administrative unit is the sum of internal, outward trips that start from the selected unit and inward trips that end in the selected unit.

Figure 10. Explanation if internal, inward and outward trips



Source: JRC

The number of trips per day per for each administrative unit is calculated as follows:

$$\text{inward trips for unit i: } I_i = \sum_i x_{ij} \quad (1)$$

$$\text{outward trips for unit i: } O_i = \sum_j x_{ij} \quad (2)$$

$$\text{internal trips for unit i: } Int_i = x_{ij}, (i = j) \quad (3)$$

$$\text{total trips for unit i: } T_i = I_i + O_i + Int_i \quad (4)$$

JRC mobility index is calculated by comparing the mean of the daily number of trips of the baseline week to the daily values for each administrative unit (the index is calculated for inward, outward, internal and total trips) ([17]). After JRC mobility index was calculated, all three indices (Apple, Google and JRC) were in a suitable format for the analysis and data visualization.

5.1 Dashboard

The data visualizations presented in this paper are made available online through an interactive dashboard ([18]) that can be used to make regional and provincial comparisons according to the preferences of the users. All the presented data sources are available in the dashboard, the users can define the timeframe and the variables to be included on the plots and maps. Currently four tabs are available. Two interactive plots provide access to regional and provincial analysis where the presented mobility and government response indices as well data on infections can be set and filtered. Further two interactive maps describe movements between provinces before the pandemic (MITMA model data) and during the pandemic (MITMA mobile data).

5.2 Software

The following software were used:

— Microsoft Excel (for quick data manipulation);

— R programming language, RStudio IDE ([19]) (all phases of the project)

- main libraries for data manipulation: data.table, dplyr, lubridate, zoo, readr, rjson, tidyr;
- main libraries for visualization: ggplot2, leaflet, rnaturalearth, rgeos, RColorBrewer, geosphere, plotly;
- main libraries for dashboard: shiny, shinyWidgets;

— QGIS (for GIS data preparation and manipulation).

The project is saved in a public Github repository ([20]).

([17]) In the following sections of the document JRC mobility index refers to all trips unless it is mentioned that other trips are analysed.
([18]) The dashboard is available here: https://mikiradics.shinyapps.io/dashboard/
([19]) Integrated Development Environment
([20]) The scripts are available here: https://github.com/mikiradics/covid_spain.git

6 Results

In this section the main highlights of the data analysis are discussed.

6.1 Trends on national level

First, trends on national level are presented (data is aggregated on national level, including all Spanish autonomous communities).

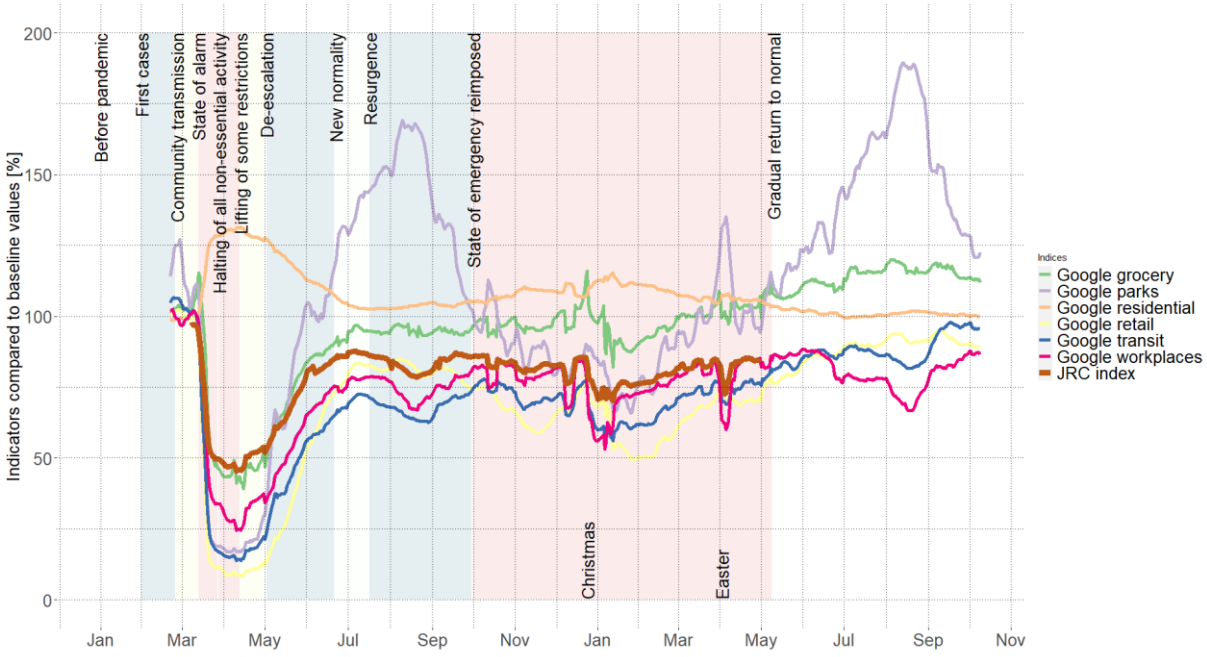
The comparison of JRC mobility index and Google indices on national level shows (Figure 11) that mobility levels dropped dramatically during the first lockdown, after the first state of alarm was introduced on March 13, 2020. JRC mobility index decreased by 50% compared to baseline as strict movement restrictions were in place for all non-essential activities. Among Google indices grocery & pharmacy index decreased the least as movements described by the index are necessities that could be done during the lockdown. Google workplaces index dropped by 75%, other movement indices even more.

After the first state of alarm, during the summer of 2020 when some restricting measures were lifted, JRC mobility index recovered and reached ~80% compared to baseline. Google workplaces, transit and retail indices follow similar trends to JRC mobility index until the end of the second state of alarm.

From September 2020 until the end of the second state of alarm, until May 2021, JRC mobility index and Google indices follow similar trends, holidays can be observed (such as Christmas and the preceding shopping period described by Google grocery and retail indices, or Easter).

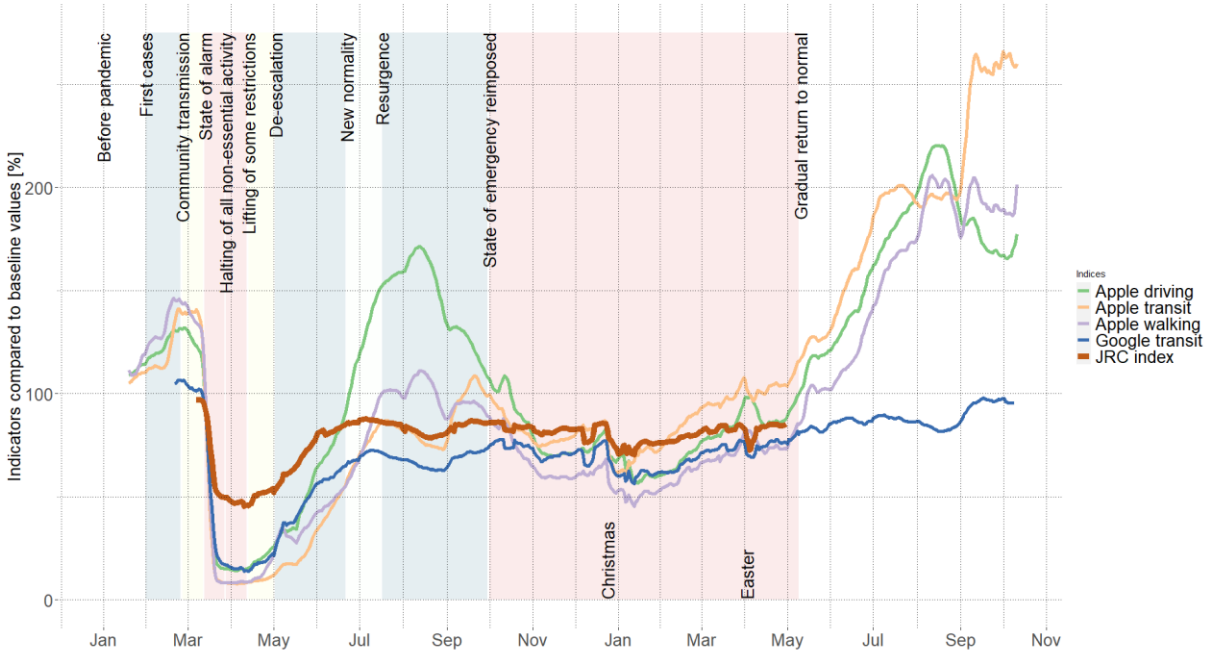
After the first lockdown, throughout the rest of the timeframe of the analysis, the level of Google residential index follows holiday periods (during the summer, when the number of cases decreased, people moved more; while during the winter, out of the summer holiday season, when the number of cases was higher, higher share of the population tended to stay at home). It is also notable that the high extremes of Google parks can be misleading as the baseline is from the winter of 2020; however, the index clearly shows that many people spend summer holidays in parks (green, natural areas).

Figure 11. Comparison of JRC index with Google indices on national level



Source: JRC analysis (Google 2021a; MITMA 2021a)

Figure 12. Comparison of JRC index with Apple indices (and Google transit as reference) on national level



Source: JRC analysis (Apple 2021; MITMA 2021a)

Having a look at JRC mobility index and Apple indices (Figure 12) we can observe that until the end of the second state of alarm the trends of Apple, JRC and some Google indices are similar, but after the second state of alarm Apple indices follow a different trend with higher extremes. This may be due to the methodology of how Apple indices are calculated. As it is described in the manual (Apple 2021), Apple compares the daily values to a single day before the pandemic (January 13th, 2020) and provides data on the frequency of search requests not on actual movements. It can be concluded that Apple data cannot be used directly for comparison with other data sources presented in this document.

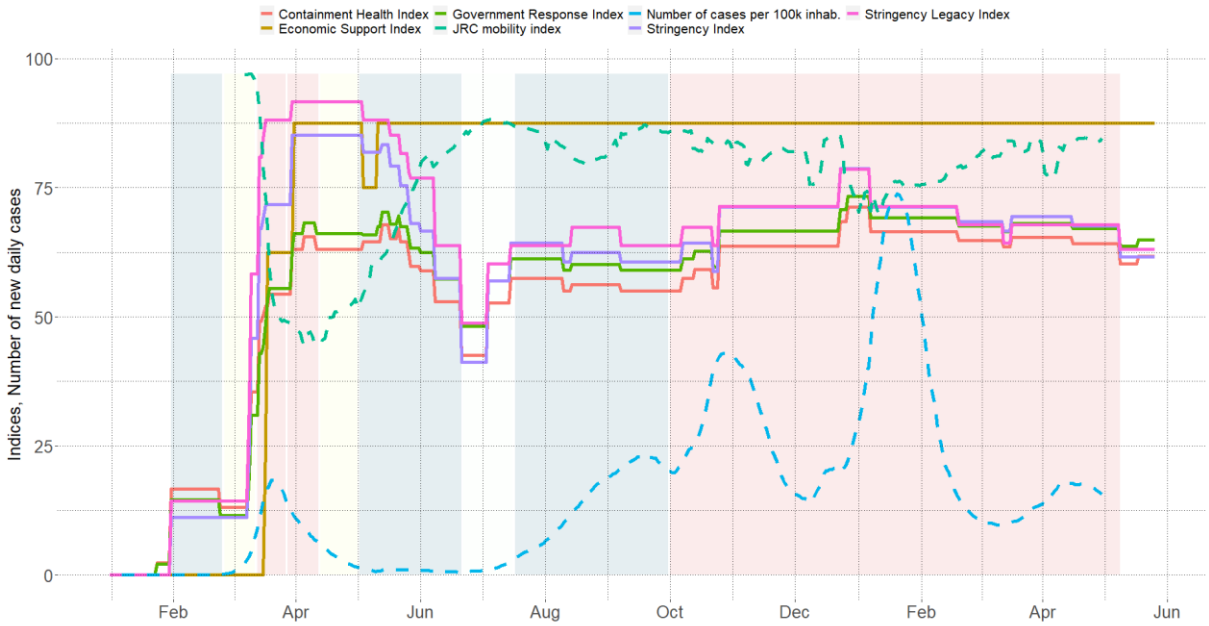
Based on the above described two comparisons it can be concluded that Google data seem to be a more reliable data source than Apple to analyse the mobility situation in Spain. Pérez-Arnal et al. (2021) concluded a similar result: as Apple follows a different approach for calculating the indices (the number of directions requests in Apple Maps), the authors decided not to include this dataset in their analysis.

Figure 13 shows that government decisions are initially delayed, then follow the evolution of the caseload (steady tightening in early 2020, followed by a gradual opening and withdrawal of the state of alert), and then, in line with the expected increase in the number of cases, the measures follow the trend in the number of cases.

Stringency index is the most relevant for the purpose of the current study as this index describes the strictness of lockdown policies that aimed to restrict movements during the pandemic. According to the discussed index, lockdown policy was the strictest in April and May 2020; however, the first lockdown was introduced earlier, on March 13, 2020. The index is the lowest in the summer of 2020 when most of the travel restrictions were lifted, and after the summer of 2020 it's rather constant.

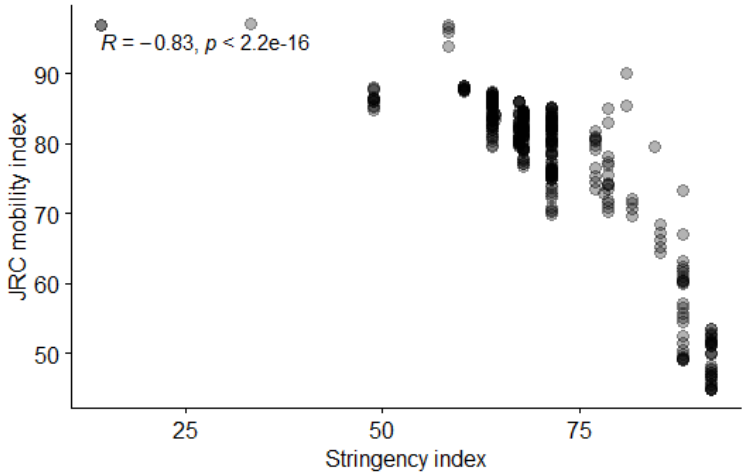
The colours used for each phase of the pandemic correspond to the stringency of restrictions that come from the above-described indices and to the timeline of the pandemic discussed in section 2 (see the background colours of Figure 13).

Figure 13. Oxford Covid-19 Government Response Tracker indices, JRC mobility index, and the number of new daily cases (data on national level)



Source: JRC analysis (MITMA 2021a; OxCGRT 2021)

Figure 14. Scatter plot of JRC mobility index and Stringency index

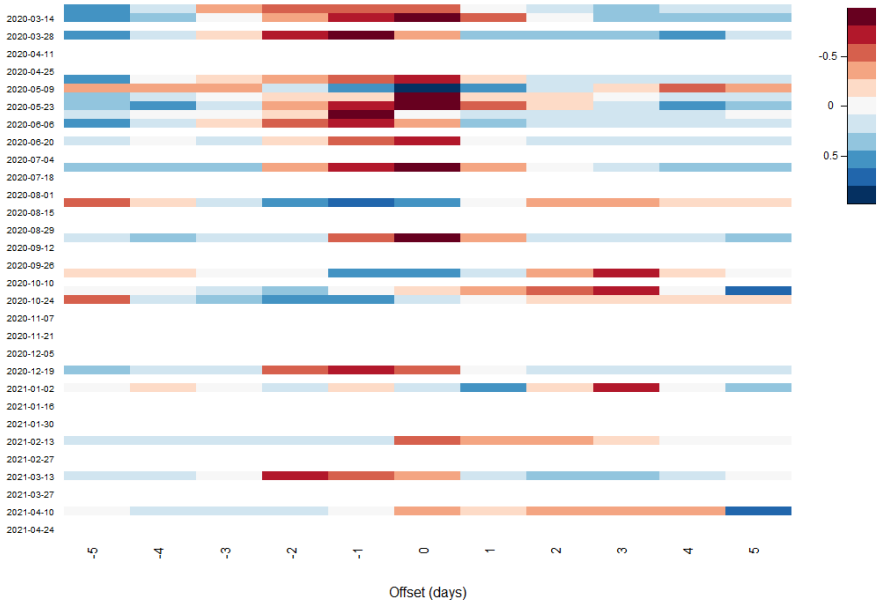


Source: JRC analysis (MITMA 2021a; OxCGRT 2021)

It can be concluded that there is a high correlation between mobility levels and lockdown measures (see Figure 14); however, the Pearson correlation describes the global synchrony only and does not provide information about the directionality of the two. To see whether policy measures led changes in mobility, a windowed time lagged cross correlation analysis was carried out which results help us to identify relationships between the two timeseries (see Figure 15). We can see that correlations are the highest when the offset is 0 until the summer of 2020 which means that restrictions had an immediate result on mobility. It is an expected result presuming that movement restrictions were highly enforced during the first state of emergency. During the summer of 2020 there are two exceptions when correlation between the two is positive which means that despite the introduced restrictions the number of movements kept increasing. After September 2020 the number of trips increased during the second state of alarm while the level of stringency index was constant. In October, in the beginning of the state of alarm and in January there are two weeks where the restrictions were introduced three days ahead movements started to decrease.

Only a national level index was made available in the case of Spain, therefore regional or provincial analysis cannot be carried out.

Figure 15. Heatmap based on the results of the windowed time lagged cross correlation analysis (rows are empty when stringency index is constant)



Source: JRC analysis (OxCGRT 2021)

The initial dramatic drops in mobility during the first state of emergency are due to the strict stay at home obligations and the uncertainty regarding the possible escalation of the pandemic. The relaxation of movement restrictions and the relatively low levels of infections during the summer of 2020 let people travel and move more. The introduction of the second state of alarm, the increase in the number of cases and the arrival of multiple waves decreased the number of trips compared to pre-pandemic times, but mobility levels remained higher than during the first state of alarm as curfew measures let people move more who adapted their lifestyle to the lasting pandemic situation.

6.2 Trends on regional level

In this section regional differences are highlighted that differ from the findings discussed on national level.

The **number of cases per 100k inhabitants on regional level** shows a relatively diverse picture when regional data is compared to national average (Figure 16). The five waves of the pandemic can be observed in almost every region; however, the severity of the waves differ. The first wave of the pandemic, in March-April 2020 was most intense in la Rioja, Castile La Mancha and Community of Madrid. During the summer of 2020 an intense wave hit Aragon, a wave with similar intensity in the same period cannot be observed in other regions. During the second state of alarm two waves occurred but the picture is more diverse. The number of active cases in Cantabria, on the Canary Islands remained below the national average. The fifth wave in July-August reached the highest numbers in Catalonia.

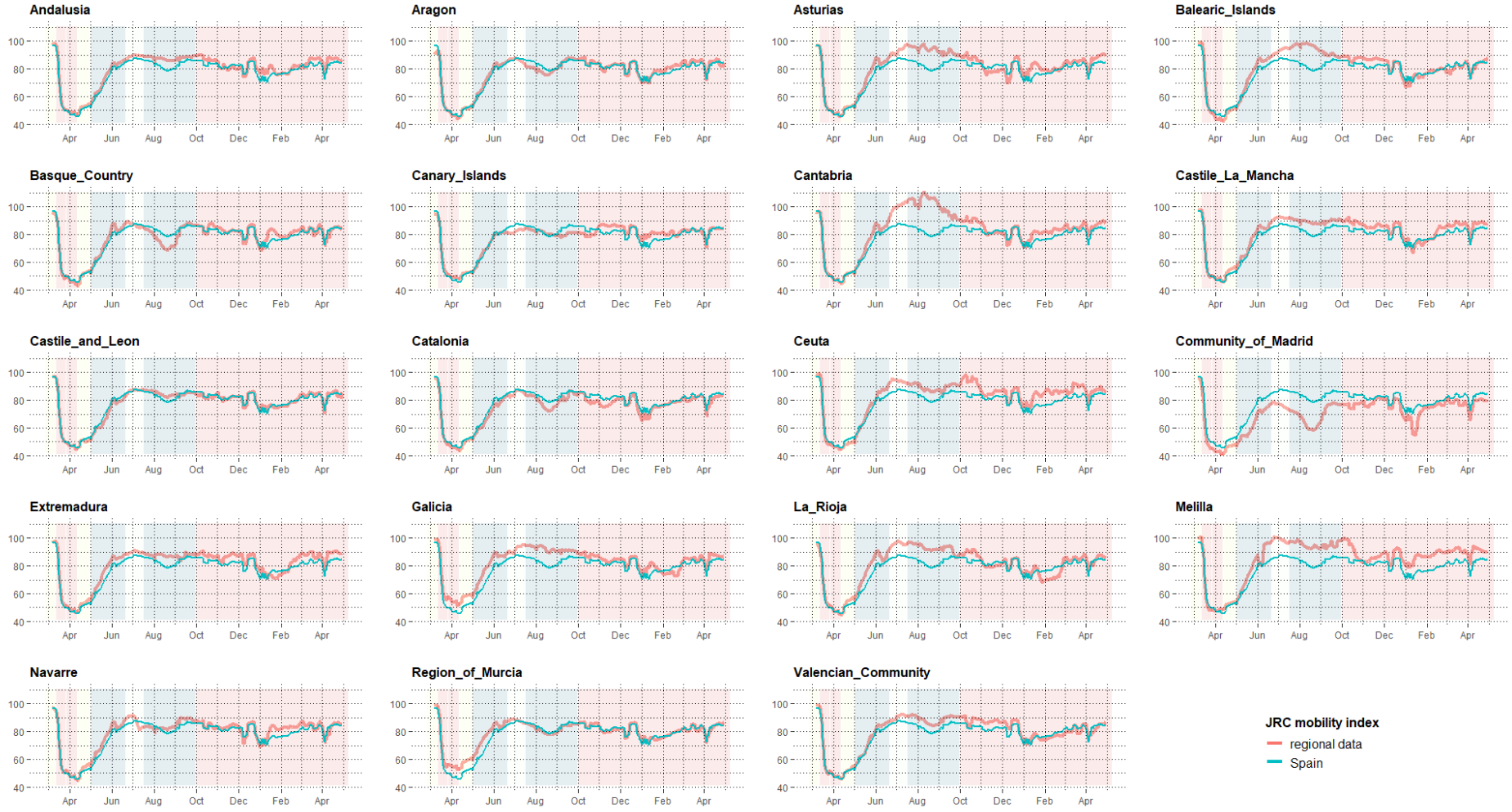
The **total number of trips per region (JRC mobility index)** follows a rather similar pattern in most regions (Figure 17 and Figure 18). During the initial period of the pandemic, the number of trips decreased drastically in all regions regardless the number of reported coronavirus cases due to uncertainty and strict lockdown (Pérez-Arnal et al. (2021) drew a similar conclusion). Mobility levels dropped to similar levels in almost all regions, the Community of Madrid is the region where mobility reached the lowest levels while Galicia and Region of Murcia remained above the national average. After the first state of alarm, mobility levels return to 70-80% compared to baseline. There are two extremes during the resurgence period in August – September 2020: tourist destination such as Cantabria, Asturias, Galicia, Balearic Islands (above the majority) and Community of Madrid (below the majority).

In the de-escalation phase all regions recover with similar pace, the Community of Madrid remains below the national average. The differences are becoming more visible during the summer of 2020 when regions with attractive tourist destinations reach higher levels of mobility while regions with lower levels of tourism, or regions which inhabitants typically leave their residence during the summer remain below or around the national average. During the second state of alarm most regions follow the national average trend with minor differences. In January there is a dramatic decrease in the Community of Madrid which cannot be observed in other regions. In February La Rioja remains above the Spanish average for almost the whole month. After the second state of alarm, since May 6, 2021, MITMA mobile movement data is not available.

Figure 16. The charts show how the number of **new active cases** for each autonomous community (red) changed since the beginning of the pandemic compared to whole Spain (blue) [cases / 100k inhabitants]. The background colours describe to the different phases of the pandemic (see figures in section 6.1).

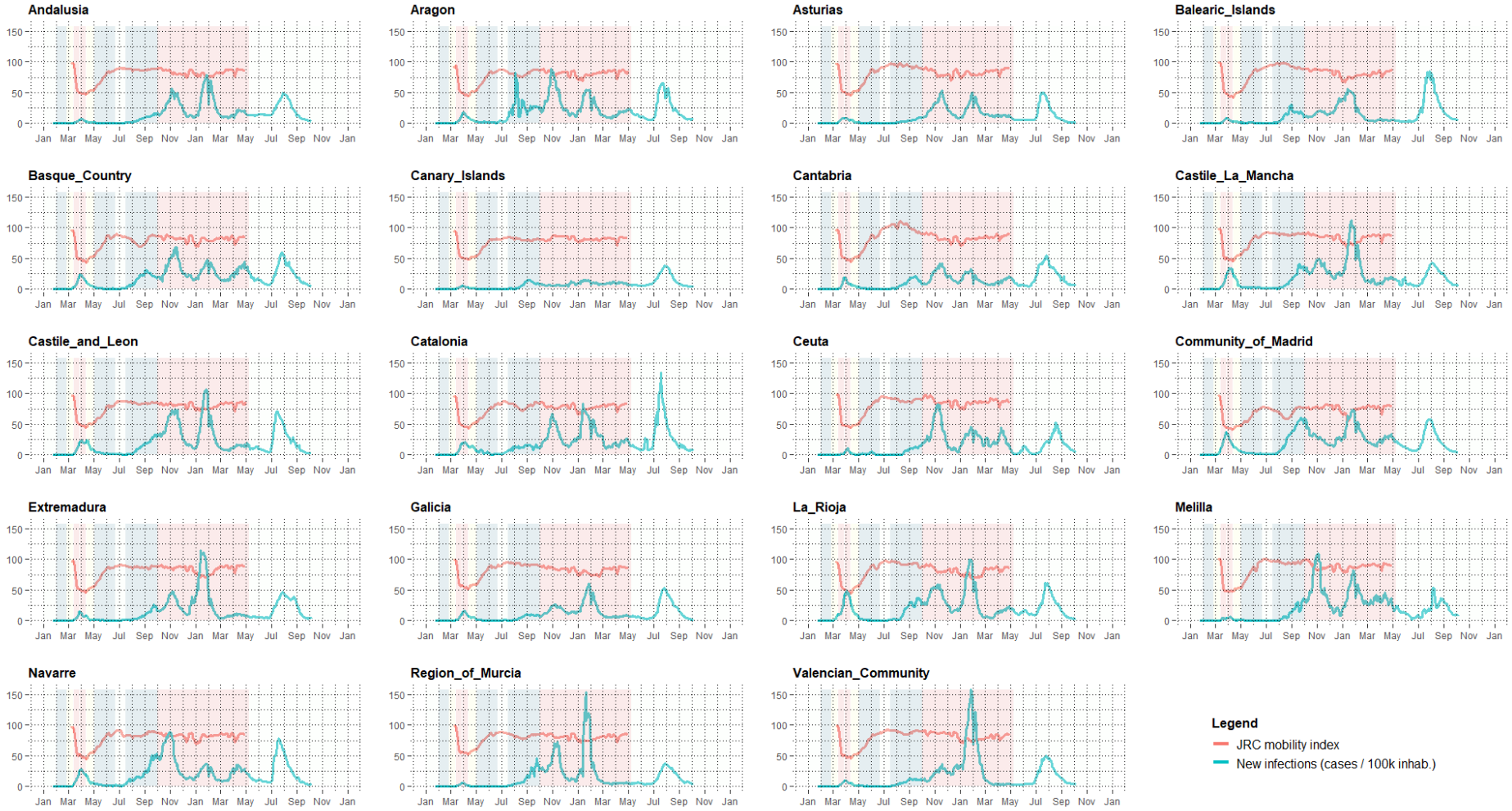
Source: JRC analysis (Narrativa 2021)

Figure 17. The charts show how the **JRC mobility index** for each autonomous community (red) changed since the beginning of the pandemic compared to JRC mobility index for all Spain (blue) [base=100]. The background colours describe to the different phases of the pandemic (see figures in section 6.1).



Source: JRC analysis (MITMA 2021a)

Figure 18. The charts show how the **JRC mobility index** for each autonomous community (red) [base=100] changed since the beginning of the pandemic compared to the **number of new active cases** (blue) [cases / 100k inhabitants]. The background colours describe to the different phases of the pandemic (see figures in section 6.1).



Source: JRC analysis (MITMA 2021a; Narrativa 2021)

Besides the general highlights on national level (discussed in section 6.1), the following regional differences can be observed when Google indices are analysed.

Google retail & recreation index (Figure 19) shows a decrease before Christmas 2020 (in Asturias, Basque Country, Castile and Leon, Catalonia). In Cantabria, during the summer of 2020 and 2021, the Google retail & recreation increases drastically compared to other regions, a similar pattern can be observed on the Balearic Islands during the summer of 2021. These extremes are probably due to the high numbers of tourists compared to the baseline (winter of 2020).

Google grocery & pharmacy index (Figure 20) follows the national average trend in most regions as the activities covered by the index are related to basic needs that must have been done during the pandemic. During the summer holiday similar regional differences can be observed as in the case of JRC mobility index (the index is higher in regions with more tourists while the levels in the Community of Madrid is lower where many people leave the city during the summer.)

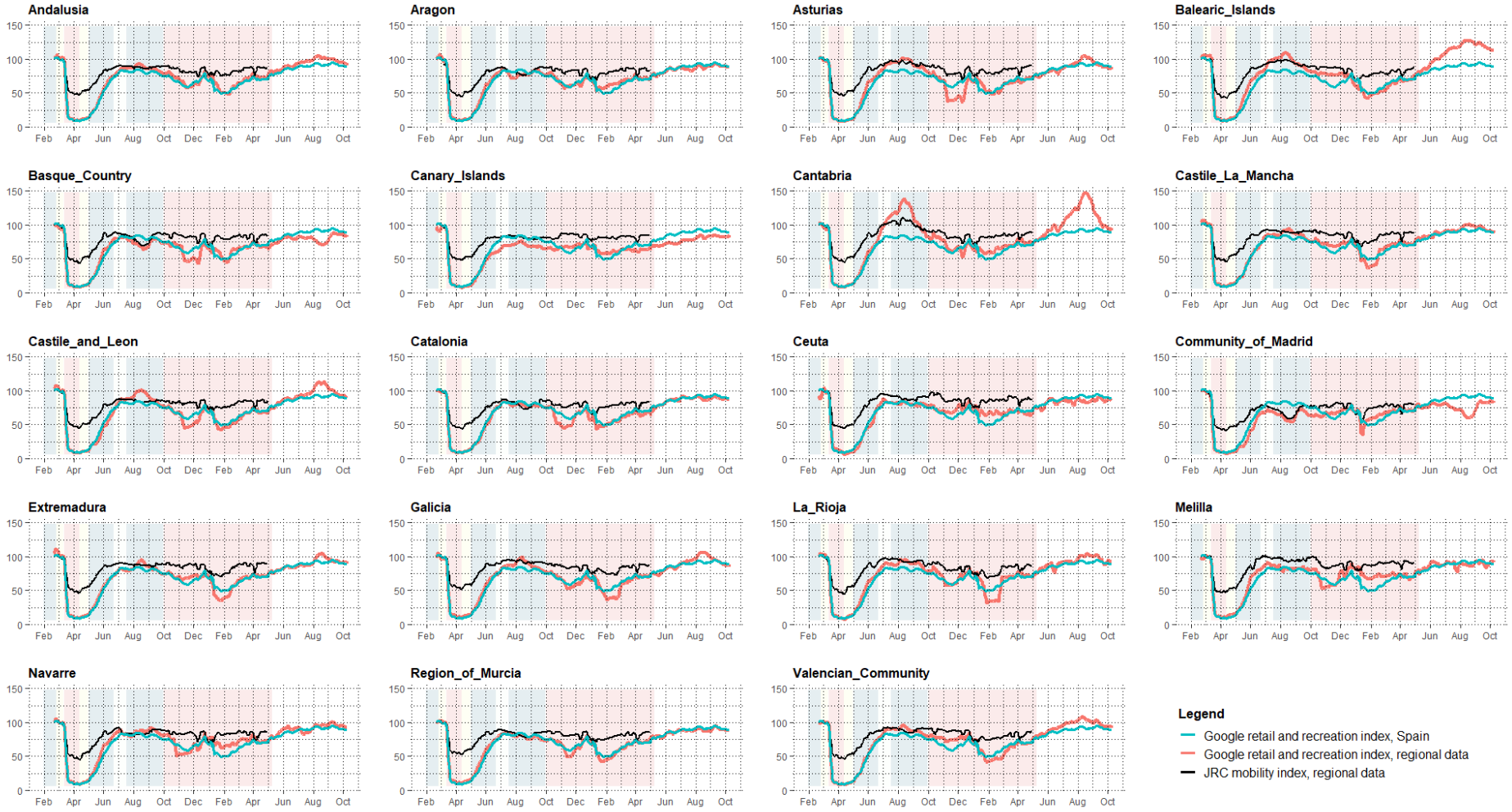
Google parks index (Figure 21) highlights those regions which are visited by most people to spend time in the nature during the summer: Asturias, Balearic Islands, Cantabria, Galicia. The charts also show that the Canary Islands remained a less visited place during the pandemic and many people leave the Community of Madrid during the summer.

Google transit stations index *(Figure 22)* follows similar patterns across regions, the summer holiday periods are exceptions: public transport usage is higher in regions with higher levels of tourism. Although national average suggests that transit remains below pre-pandemic levels, regional data show that there are regions that reached or even exceeded 100% recovery.

Google workplaces index *(Figure 23)* remains below the levels that could be observed before the pandemic in the case of almost all regions. Cantabria, Castile and Leon and La Rioja are the ones that reach a greater than 90% level compared to baseline after the summer of 2021.

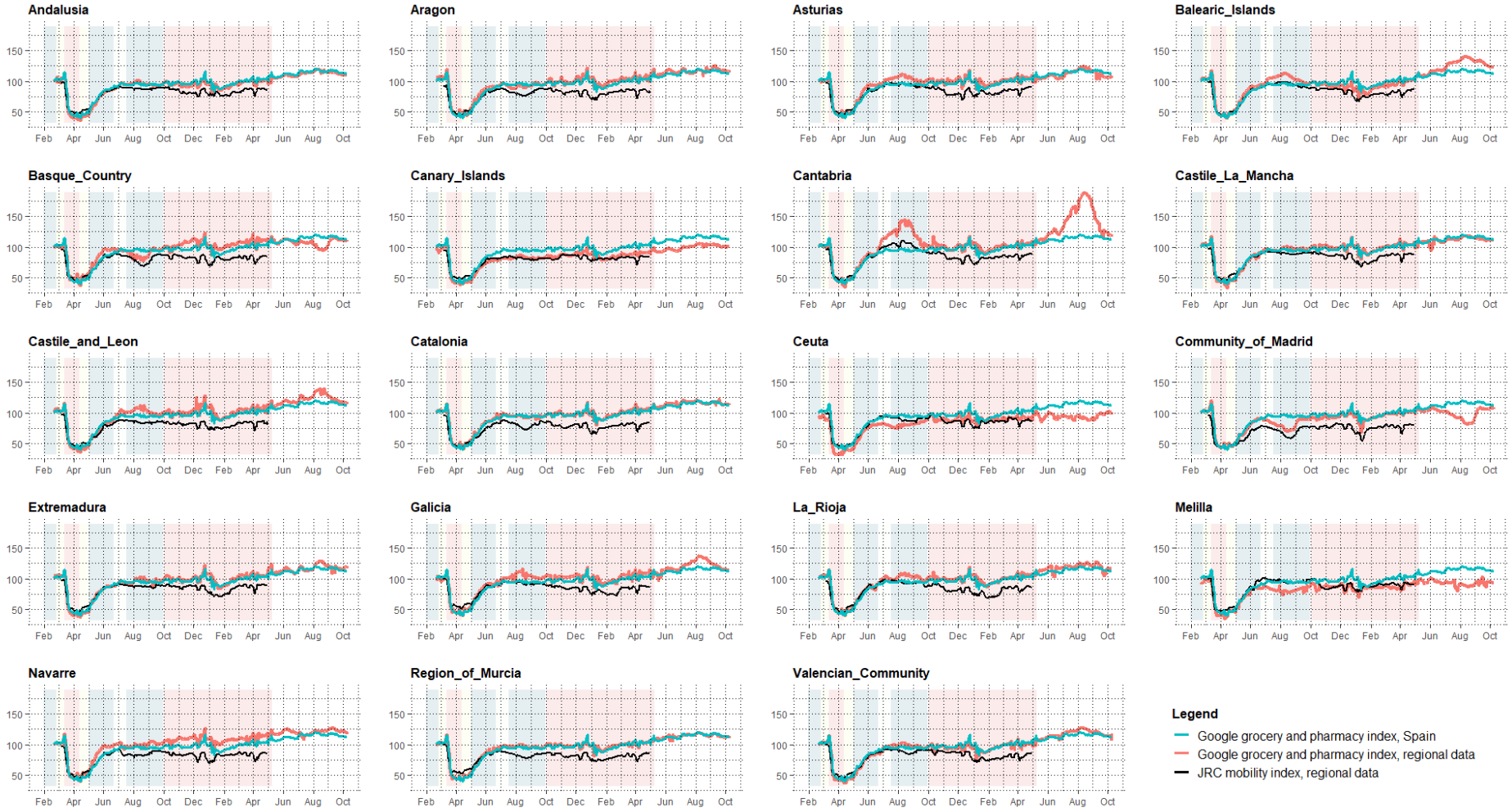
Google residential index *(Figure 24)* follows similar trends in all regions**.** Residents of the Canary Islands stayed at home during the summer of 2021 above the national average.

Figure 19. The charts show how **Google retail & recreation index** for each autonomous community (red) [base=100] changed since the beginning of the pandemic compared to Google retail index on national level (blue) [base=100] and **JRC mobility index** on autonomous community level (black) [base=100]. The background colours describe to the different phases of the pandemic (see figures in section 6.1).



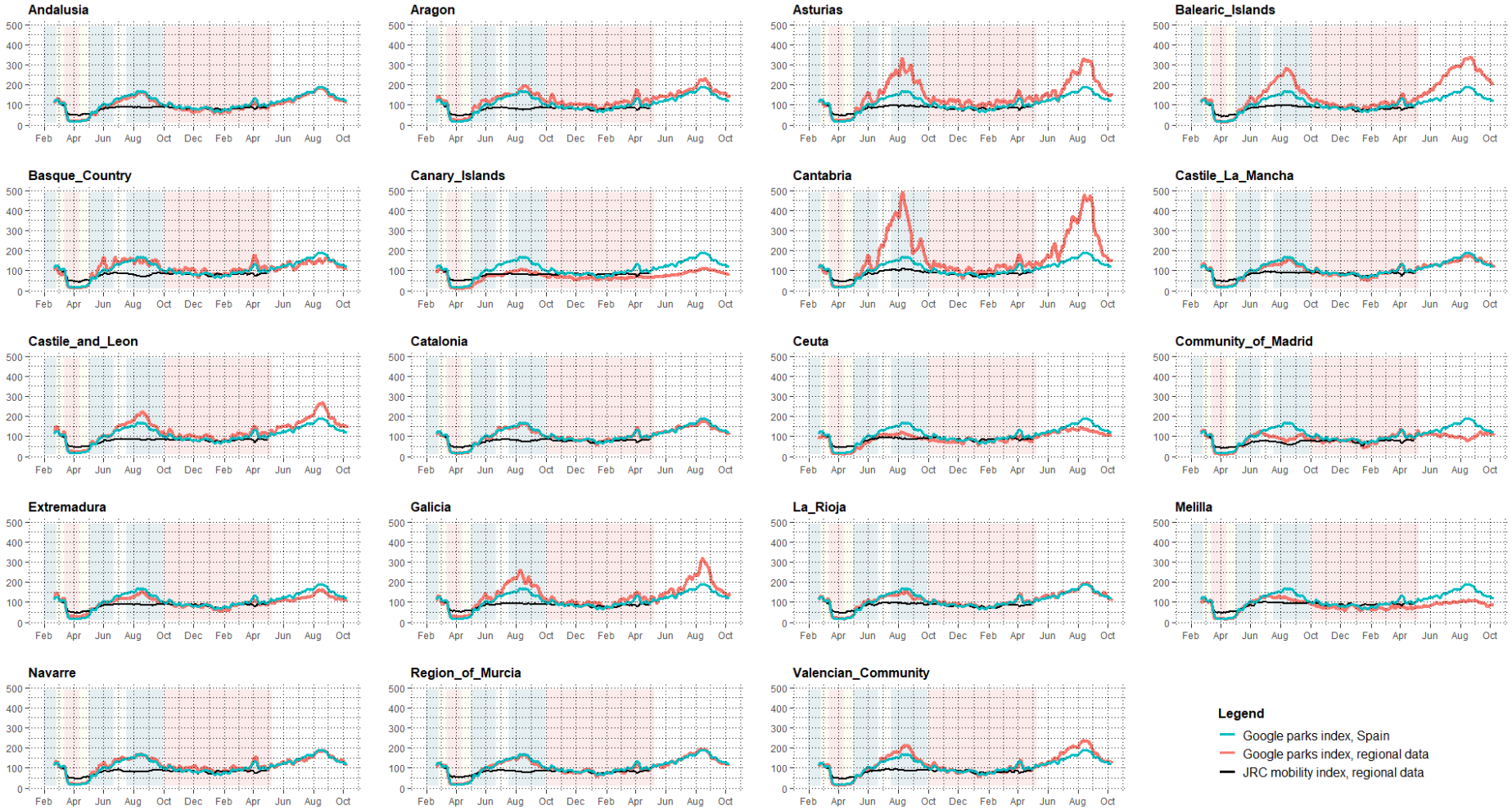
Source: JRC analysis (Google 2021a; MITMA 2021a)

Figure 20. The charts show how **Google grocery & pharmacy index** for each autonomous community (red) [base=100] changed since the beginning of the pandemic compared to Google retail index on national level (blue) [base=100] and **JRC mobility index** on autonomous community level (black) [base=100]. The background colours describe to the different phases of the pandemic (see figures in section 6.1).



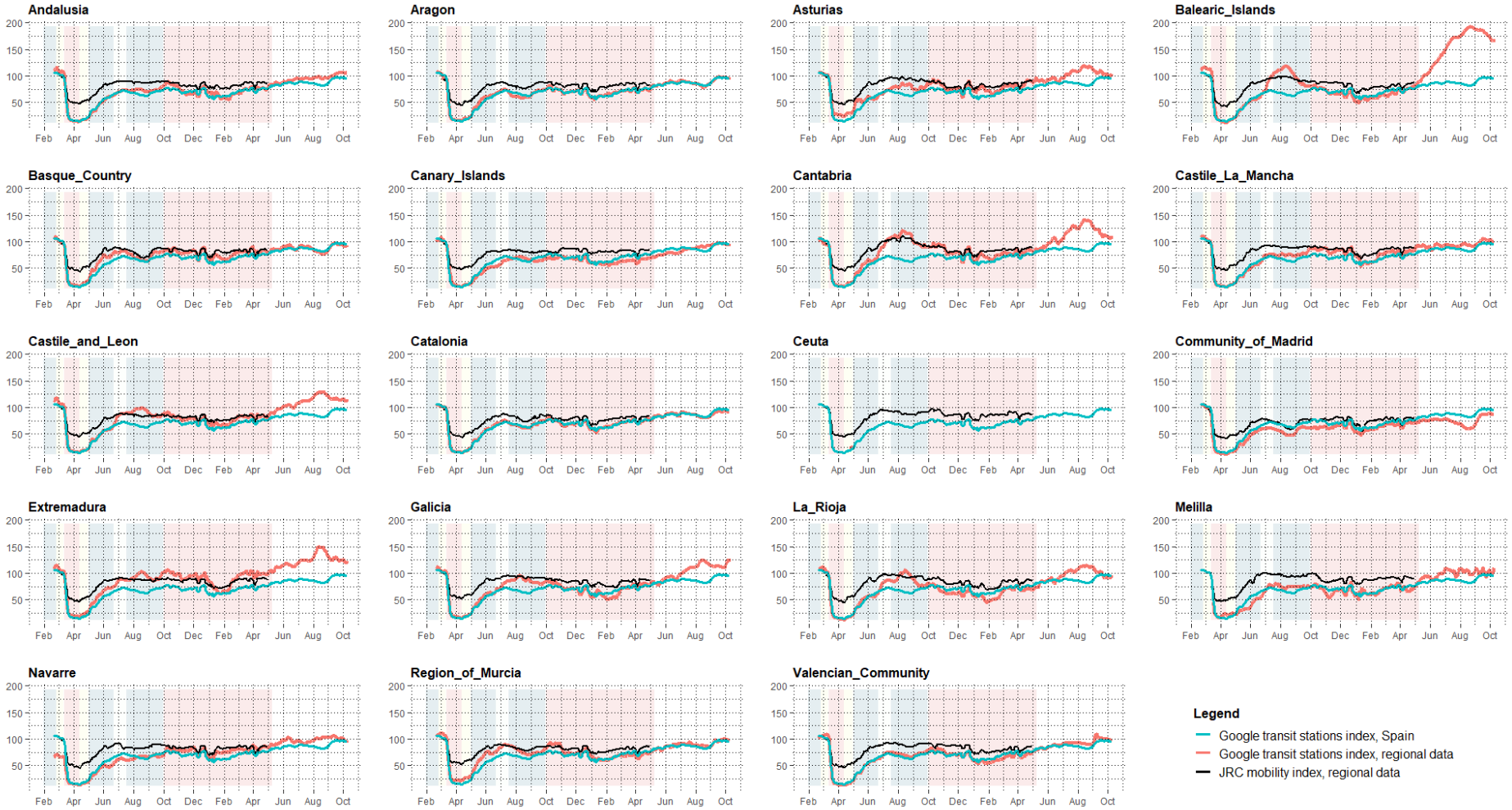
Source: JRC analysis (Google 2021a; MITMA 2021a)

Figure 21. The charts show how **Google parks index** for each autonomous community (red) [base=100] changed since the beginning of the pandemic compared to Google retail index on national level (blue) [base=100] and **JRC mobility index** on autonomous community level (black) [base=100]. The background colours describe to the different phases of the pandemic (see figures in section 6.1).



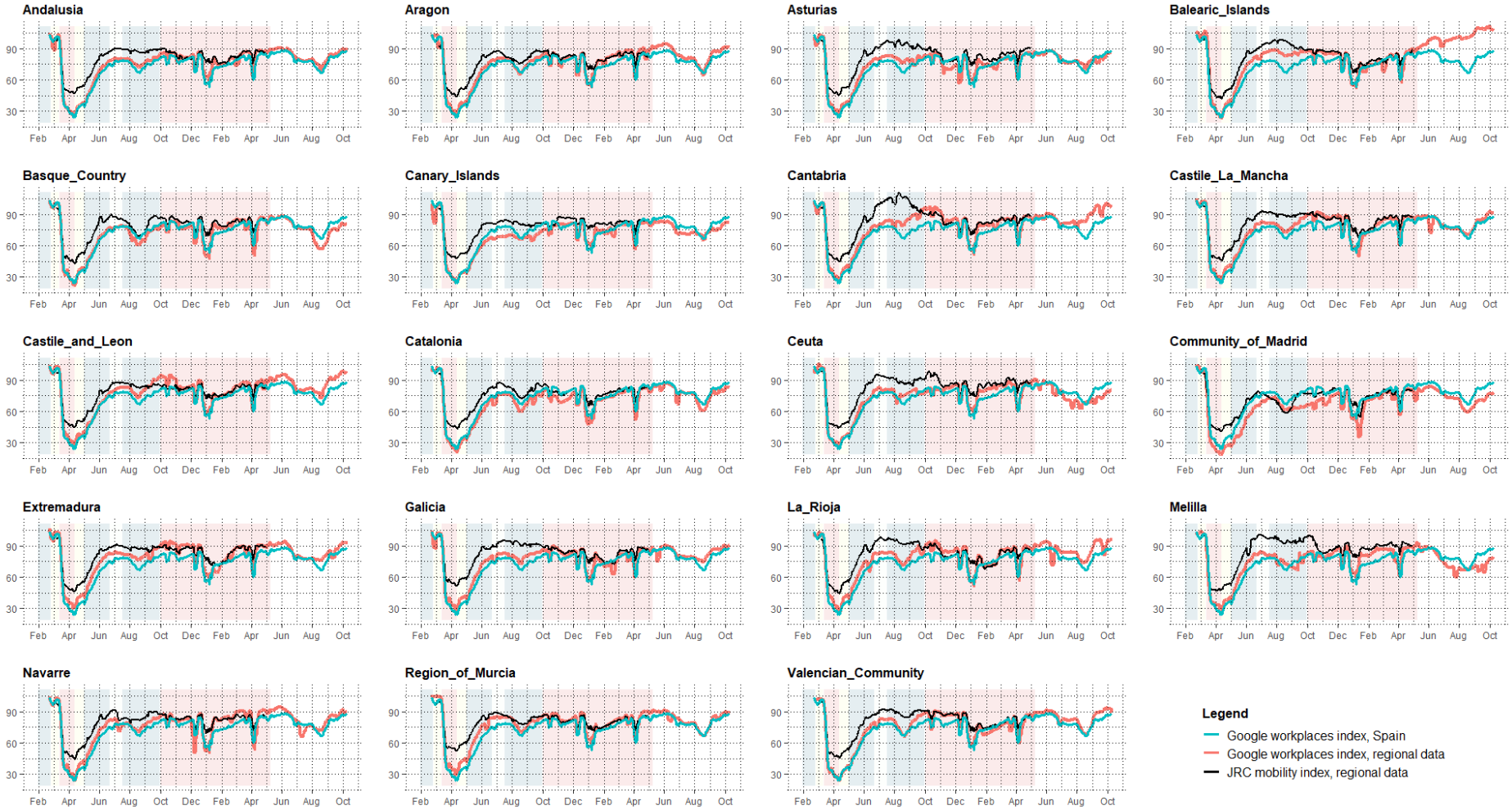
Source: JRC analysis (Google 2021a; MITMA 2021a)

Figure 22. The charts show how **Google transit stations index** for each autonomous community (red) [base=100] changed since the beginning of the pandemic compared to Google retail index on national level (blue) [base=100] and **JRC mobility index** on autonomous community level (black) [base=100]. The background colours describe to the different phases of the pandemic (see figures in section 6.1).



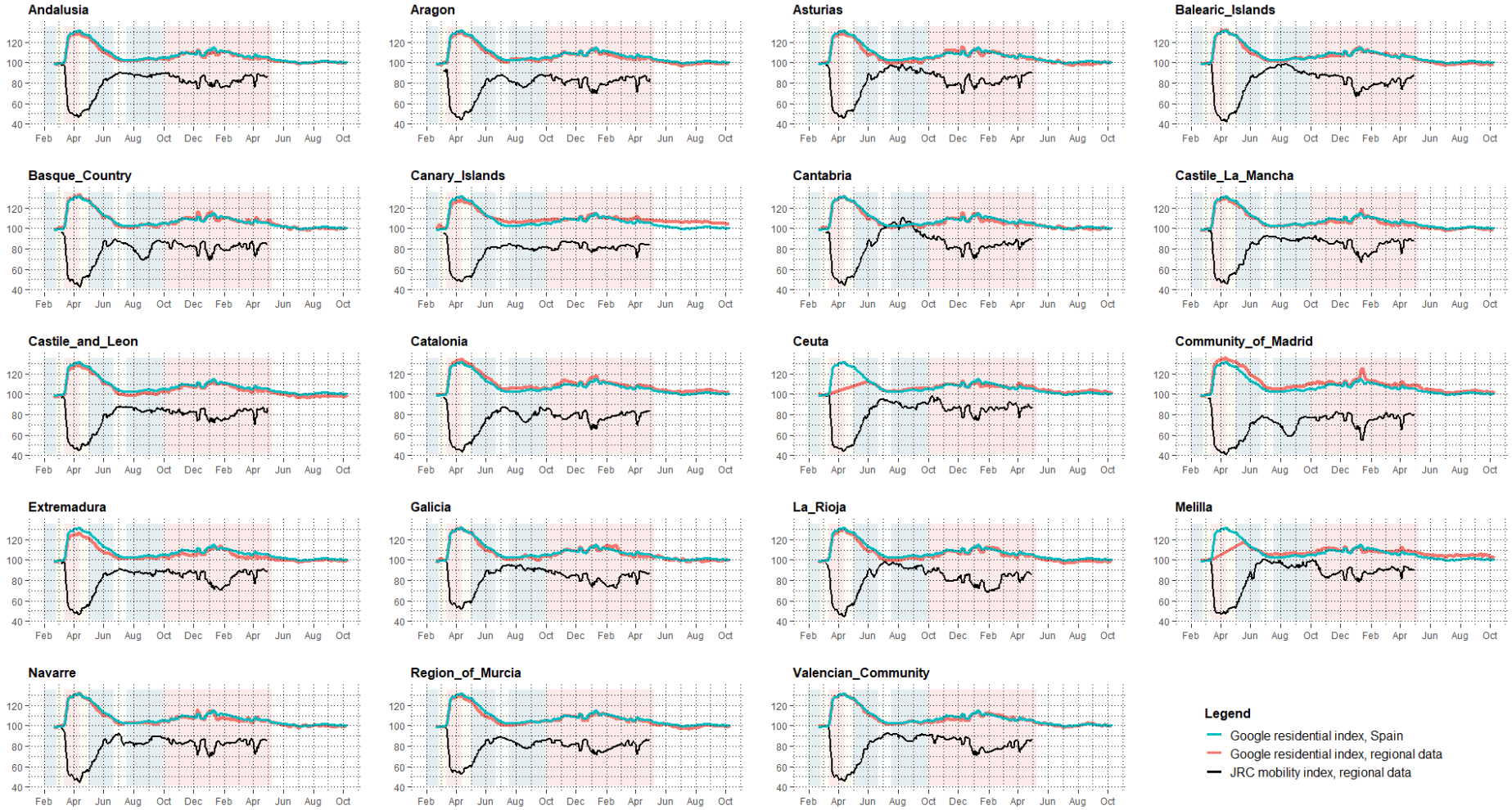
Source: JRC analysis (Google 2021a; MITMA 2021a)

Figure 23. The charts show how **Google workplaces index** for each autonomous community (red) [base=100] changed since the beginning of the pandemic compared to Google retail index on national level (blue) [base=100] and **JRC mobility index** on autonomous community level (black) [base=100]. The background colours describe to the different phases of the pandemic (see figures in section 6.1).



Source: JRC analysis (Google 2021a; MITMA 2021a)

Figure 24. The charts show how **Google residential index** for each autonomous community (red) [base=100] changed since the beginning of the pandemic compared to Google retail index on national level (blue) [base=100] and **JRC mobility index** on autonomous community level (black) [base=100]. The background colours describe to the different phases of the pandemic (see figures in section 6.1).



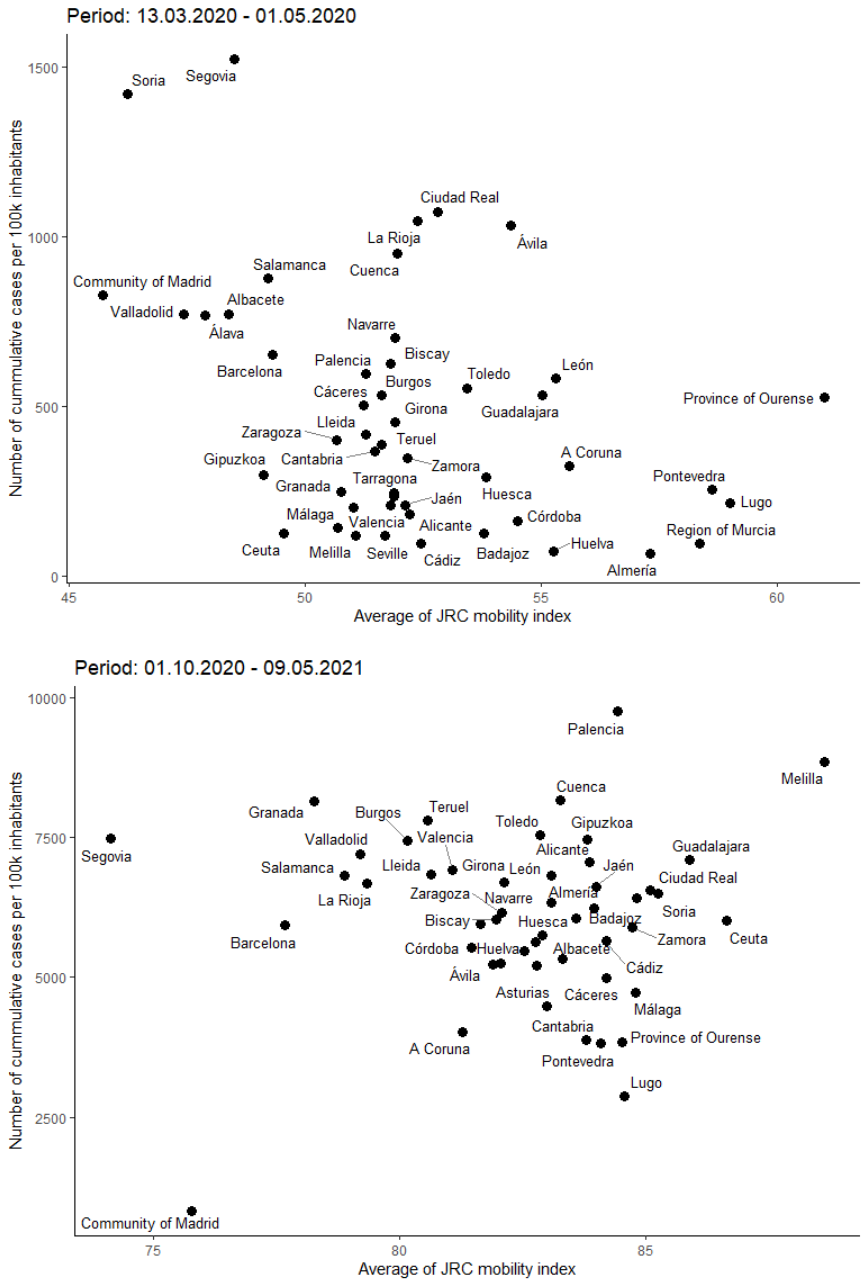
Source: JRC analysis (Google 2021a; MITMA 2021a)

Regional differences show that the two states of alarm had a great impact on mobility in all Spanish region. When movement restrictions were in place mobility levels were lower, while during the summers of 2020 and 2021 mobility levels increased in all regions. As the relaxation of movement restrictions and the summer holidays coincided, mobility levels increased more in popular tourist destinations.

6.3 Trends on provincial level

Comparing mobility trends during the first and second state of alarm (see Figure 25) we can see that in general, the number of trips dropped more dramatically during the first state of alarm in all provinces. There is a trend that suggests that provinces where mobility levels dropped less were more effected by the pandemic and had higher number of cases per 100,000 inhabitants during the first state of alarm while the picture is more scattered during the second state of alarm.

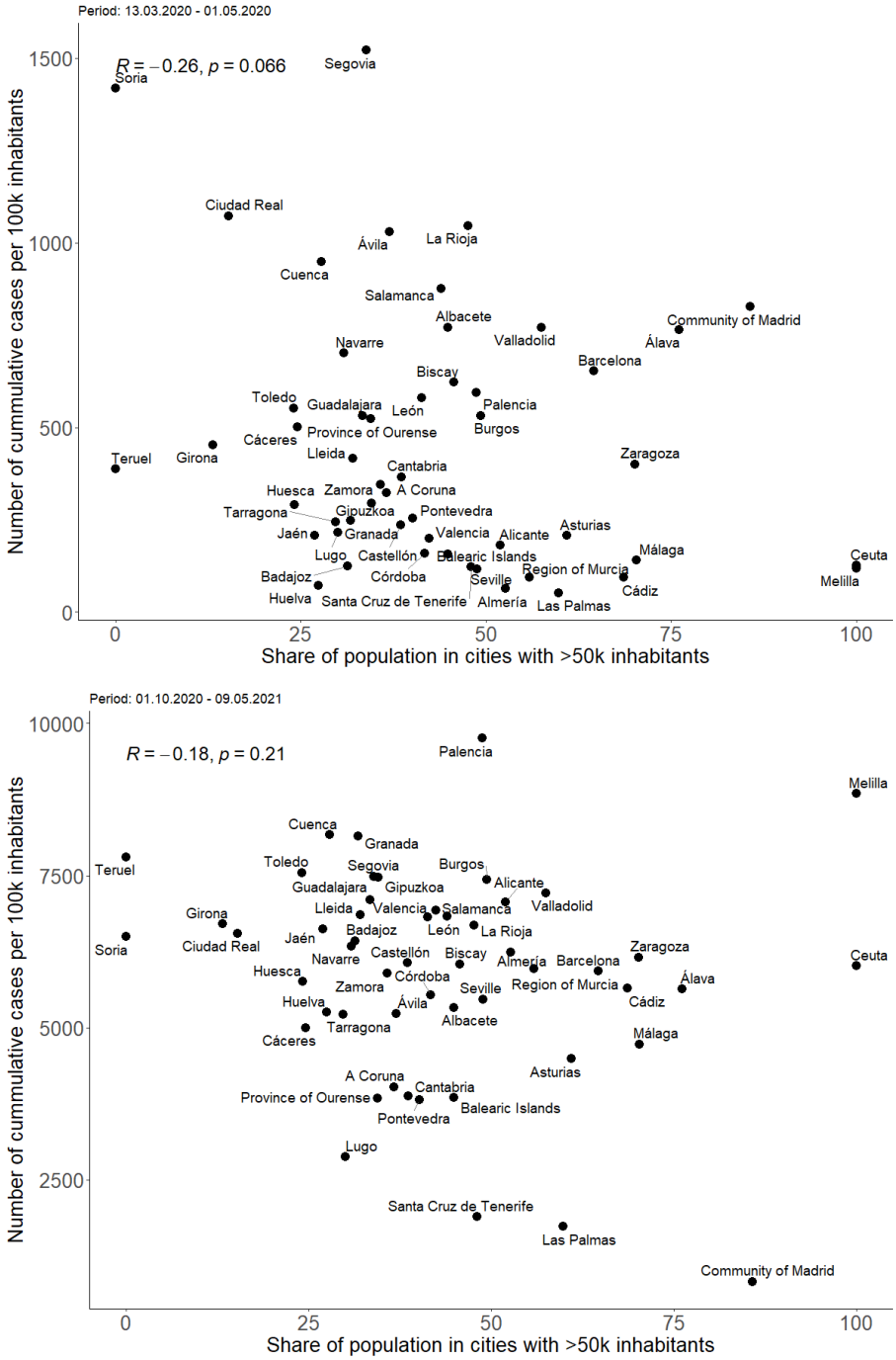
Figure 25. Scatterplots showing how the average of JRC mobility index relates to the number of cumulative cases of Spanish provinces during the first and second state of alarm



Source: JRC analysis (INE 2021a; MITMA 2021a; Narrativa 2021)

Besides displacements, the share of urban population might have effect on the spread of infections. However, Figure 26 suggests that there is a weak correlation between provinces urbanization rate (share of population in cities with more than 50,000 inhabitants) and the number of confirmed cases (considering the periods of the two states of emergency) when the two states of alarms are examined.

Figure 26. Scatterplot showing how population density relates to the number of cumulative cases of Spanish provinces (time period: 01.03.2020 - 01.10.2021, Pearson correlation) ([21]).



Source: JRC analysis (INE 2021a; Narrativa 2021)

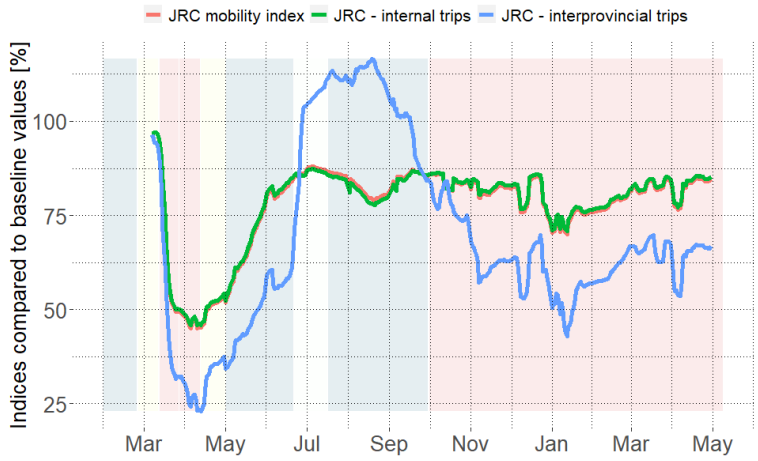
Figure 27 shows how movements across provinces and within provinces evolved over the timeframe of the analysis. The share of internal trips compared to the total number of trips remains above 90% in most provinces,

([21]) For the data table with further information about Spain see Annex.

therefore JRC mobility index follows the trend of internal trips. Provinces with higher shares of interprovincial trips (above 10% of all trips) are as follows: Guadalajara, Cuenca, Toledo, Ávila, Araba/Álava, Segovia, Teruel.

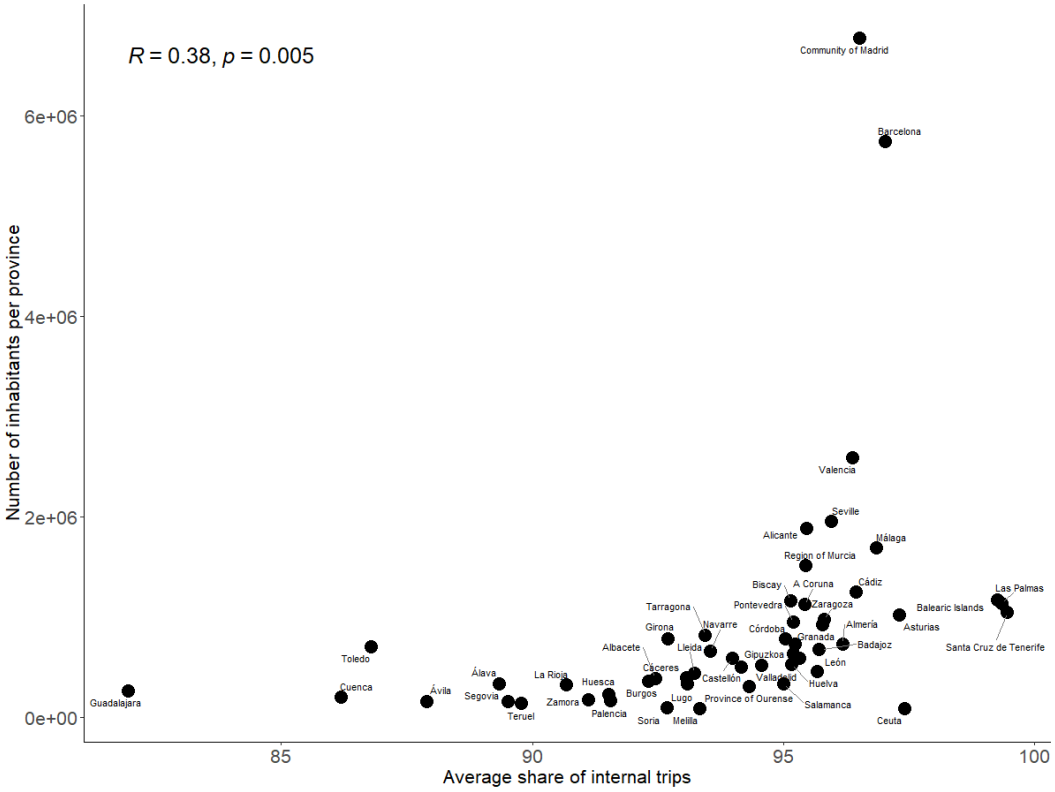
During the summer period of 2020, the share of interprovincial trips increased due to the summer holidays as well as this period was in between the two states of alarm; out of this period, many provincial boarders were closed for non-essential movements. It is also interesting that people on weekends during the summer tended to travel across provinces more while stayed within the province and travelled less out of the summer period.

Figure 27. JRC mobility indices on national level



Source: JRC analysis (MITMA 2021a)

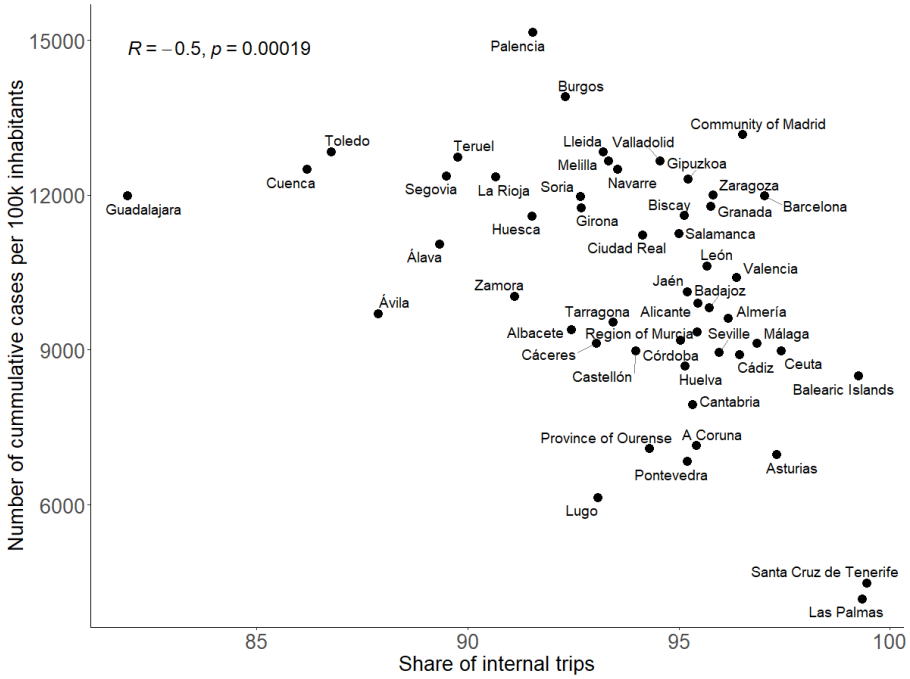
Figure 28. Scatterplot showing the share of interprovincial trips (mean values for the whole timeframe of the analysis) compared to the number of inhabitants of each province



Source: JRC analysis (INE 2021a; MITMA 2021a)

Figure 28 suggests that the share of interprovincial trips for provinces below a certain population vary independently from the size of the population (as population is not the only influencing factor), while provinces with a population above ~1.5 million inhabitants tend to have lower share of interprovincial trips compared to the total number of trips. Bigger provinces function as centres of gravity that attracts trips from other provinces. *Figure 29* shows the relation between the share of internal trips and the number of cumulative cases for the whole timeline of the analysis.

Figure 29. Scatterplot of internal trips and the number of cumulative cases of Spanish provinces during the examined timeframe



Source: JRC analysis (INE 2021a; MITMA 2021a; Narrativa 2021)

To see the provincial differences across Spanish autonomous communities, those autonomous communities were filtered out that consist of only one province (which are already covered in the previous section (see annex for the Spanish provinces and autonomous communities). Only highlights in addition to what have been discussed above are mentioned here.

Figure 30 shows how the severity of the different waves of the pandemic differs when the number of active **coronavirus cases** are compared on provincial level.

The number of trips (**JRC mobility index**, Figure 31) follows similar patterns across provinces during the initial periods of the pandemic; however, the number of confirmed cases per capita differ. During the summer, the situation is more scattered, the two extremes (in terms of mobility levels) are Cantabria (over 100% recovery) and Madrid (~55% compared to baseline), the reason is probably the open summer period when people left the capital and went for vacations. During the rest of the year, there are no major extremes in the number of trips, mobility levels across provinces follow similar trends.

During holiday periods higher mobility levels can be observed in tourist destinations, while lower in provinces with less tourists. For example, in the case of Andalusia, JRC mobility index increases in provinces on the coastline, while the index decreases in other provinces. Similar patterns can be observed in the Community of Valencia, provinces with higher levels of mass tourism tend to have higher mobility levels. Differences among provinces in Aragon and Catalonia during the summer are also greater.

Google retail & recreation index (Figure 32) suggests similar provincial differences as it is described in the previous sections: during holiday periods more visited provinces tend to have higher levels of mobility, out of holiday seasons only minor differences can be observed. Similar characteristics dominate **Google grocery & pharmacy index** (Figure 33), **Google parks index** (Figure 34) *and* **Google residential index** (Figure 37).

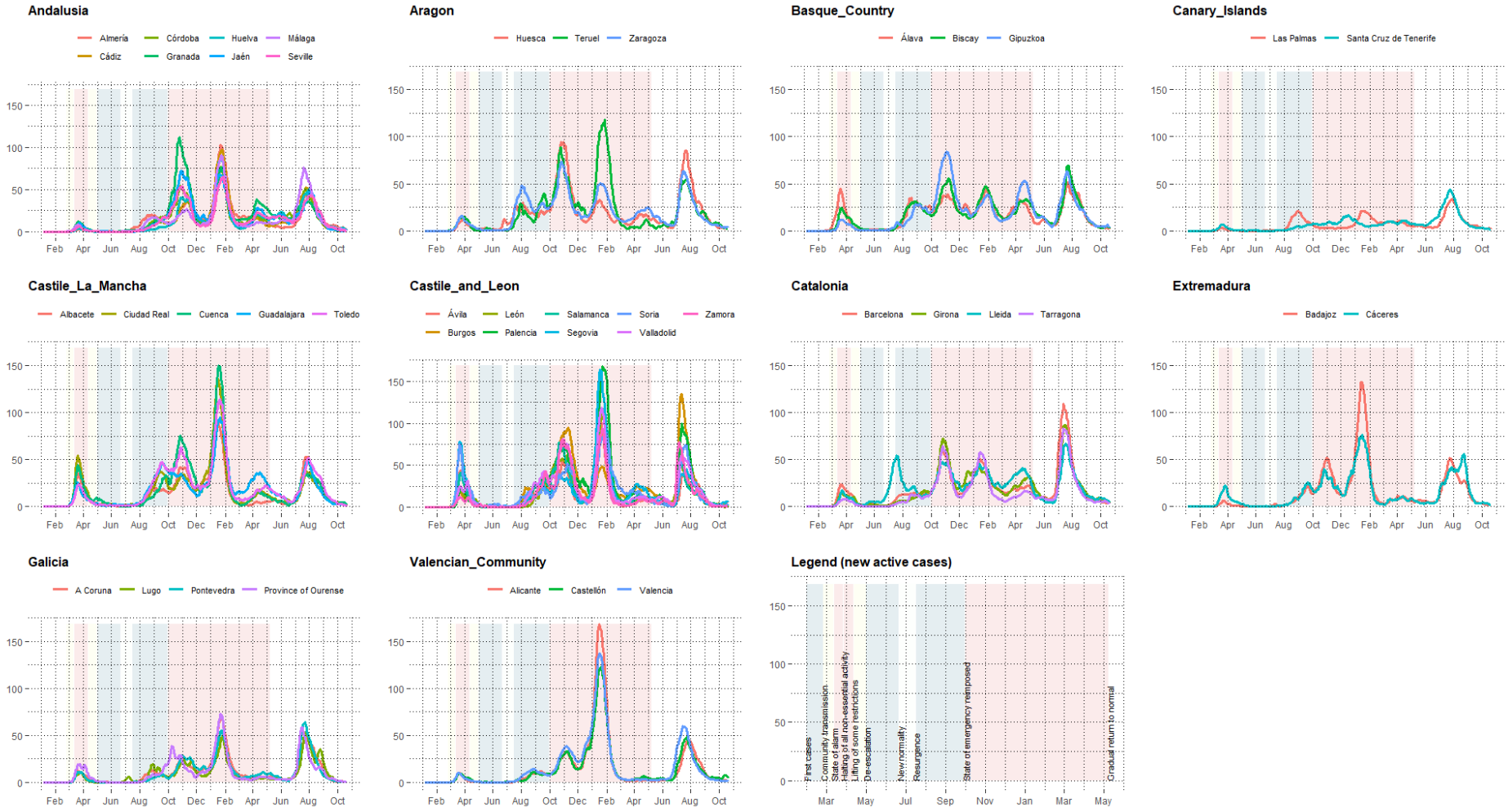
Although regional averages suggest that **Google transit stations index** remains below pre-pandemic levels after the summer of 2021, on provincial level we can see that there are some provinces that exceed pre-

pandemic levels (Figure 35). However, there are a few provinces that reach above 125% levels compared to baseline, which seems to be a questionable result and further analysis is needed for confirmation.

Google workplaces index (Figure 36*)* remains low in provinces with bigger cities (such as Seville in Andalusia, Valencia in the Community of Valencia or Barcelona in Catalonia). The greater differences among provinces can be observed in Catalonia. The level of teleworking highly depends on the type of work and bigger cities probably offer more jobs that allow people to work remotely.

Google residential index (Figure 37) shows greater differences in Catalonia, where the index in Barcelona remains above other provinces during the whole timeframe.

Figure 30. The charts show how the number of **new active cases** for provinces of the selected autonomous communities changed since the beginning of the pandemic [cases / 100k inhabitants]. The background colours describe to the different phases of the pandemic (see Legend and section 6.1)

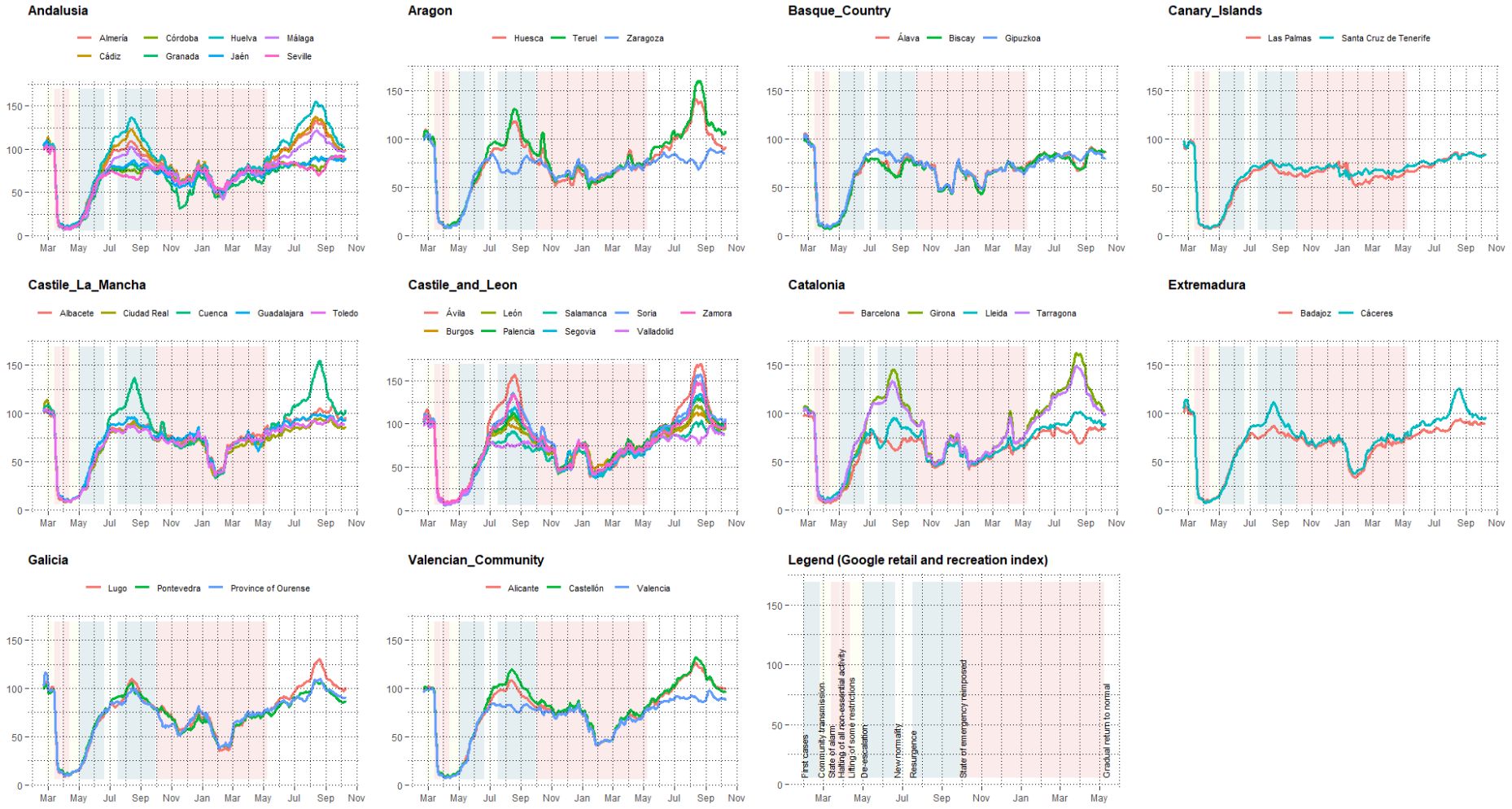


Source: JRC analysis (Narrativa 2021)

Figure 31. The charts show how the **JRC mobility index** for provinces of the selected autonomous communities changed since the beginning of the pandemic [base=100]. The background colours describe to the different phases of the pandemic (see Legend and section 6.1)

Source: JRC analysis (MITMA 2021a)

Figure 32. The charts show how **Google retail & recreation index** for provinces of the selected autonomous communities [base=100] changed since the beginning of the pandemic. The background colours describe to the different phases of the pandemic (see Legend and section 6.1)

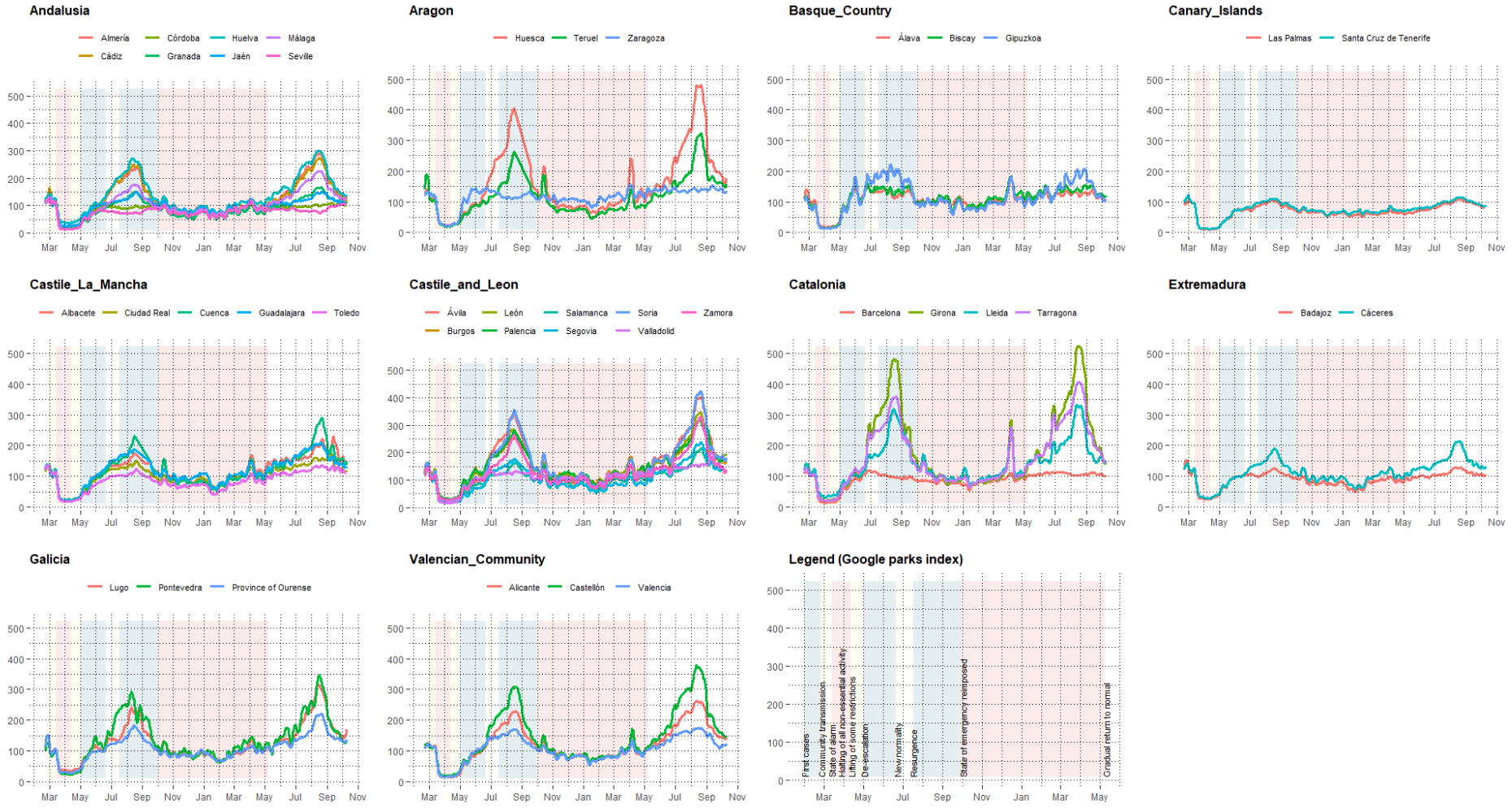


Source: JRC analysis (Google 2021a)

Figure 33. The charts show how **Google grocery & pharmacy index** for provinces of the selected autonomous communities [base=100] changed since the beginning of the pandemic. The background colours describe to the different phases of the pandemic (see Legend and section 6.1)

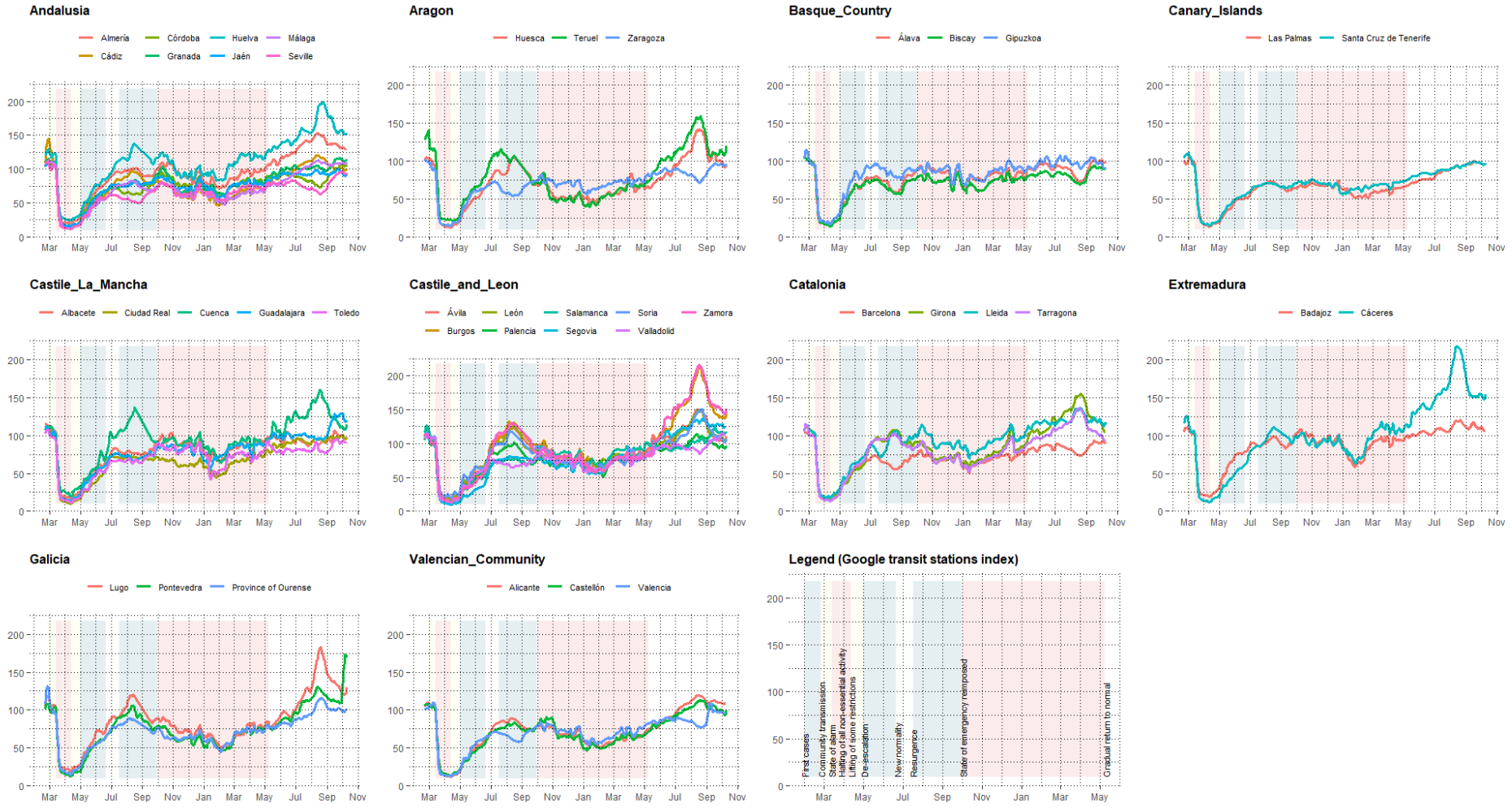
Source: JRC analysis (Google 2021a)

Figure 34. The charts show how **Google parks index** for provinces of the selected autonomous communities [base=100] changed since the beginning of the pandemic. The background colours describe to the different phases of the pandemic (see Legend and section 6.1)



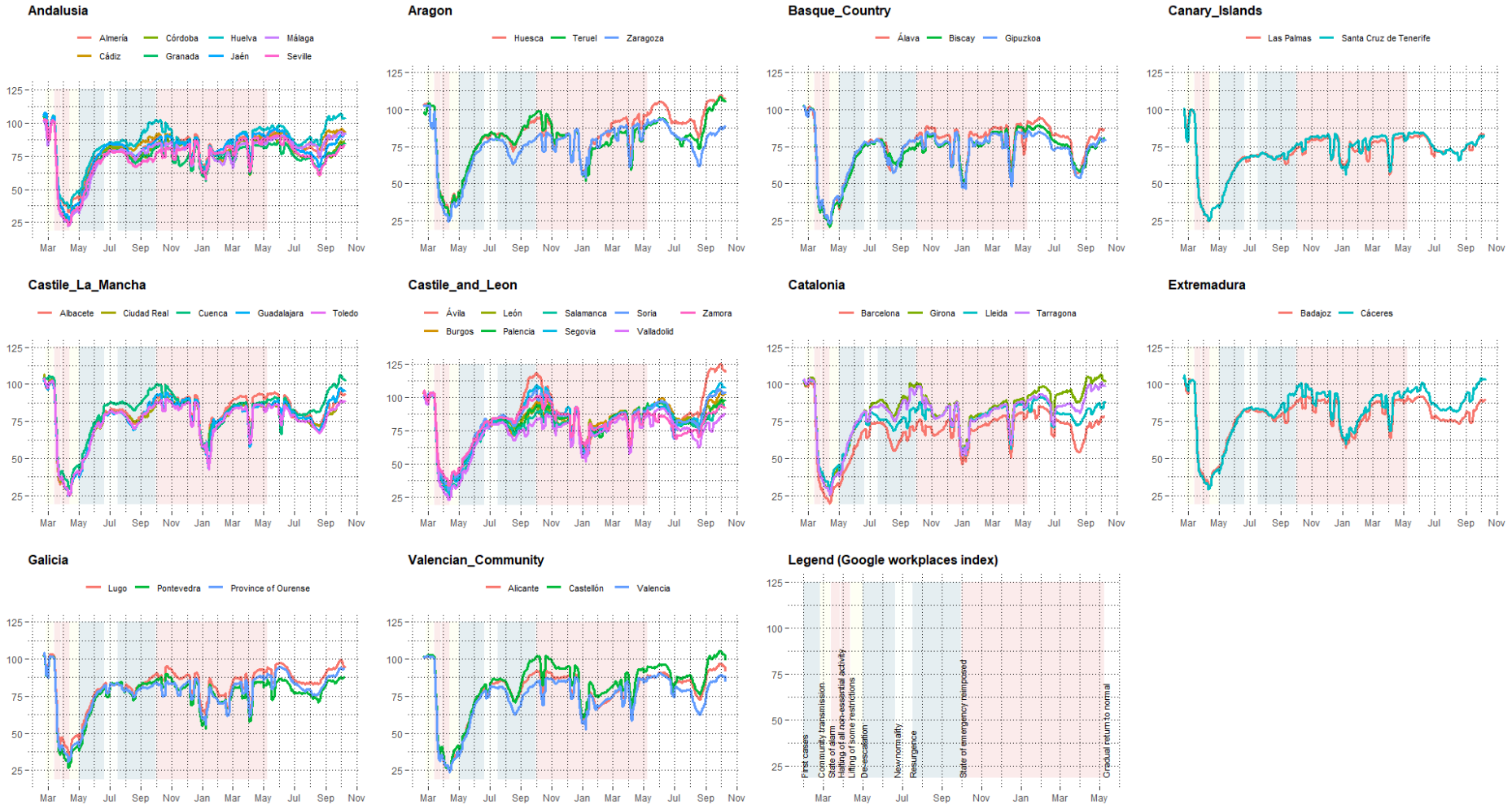
Source: JRC analysis (Google 2021a)

Figure 35. The charts show how **Google transit stations index** for provinces of the selected autonomous communities [base=100] changed since the beginning of the pandemic. The background colours describe to the different phases of the pandemic (see Legend and section 6.1)



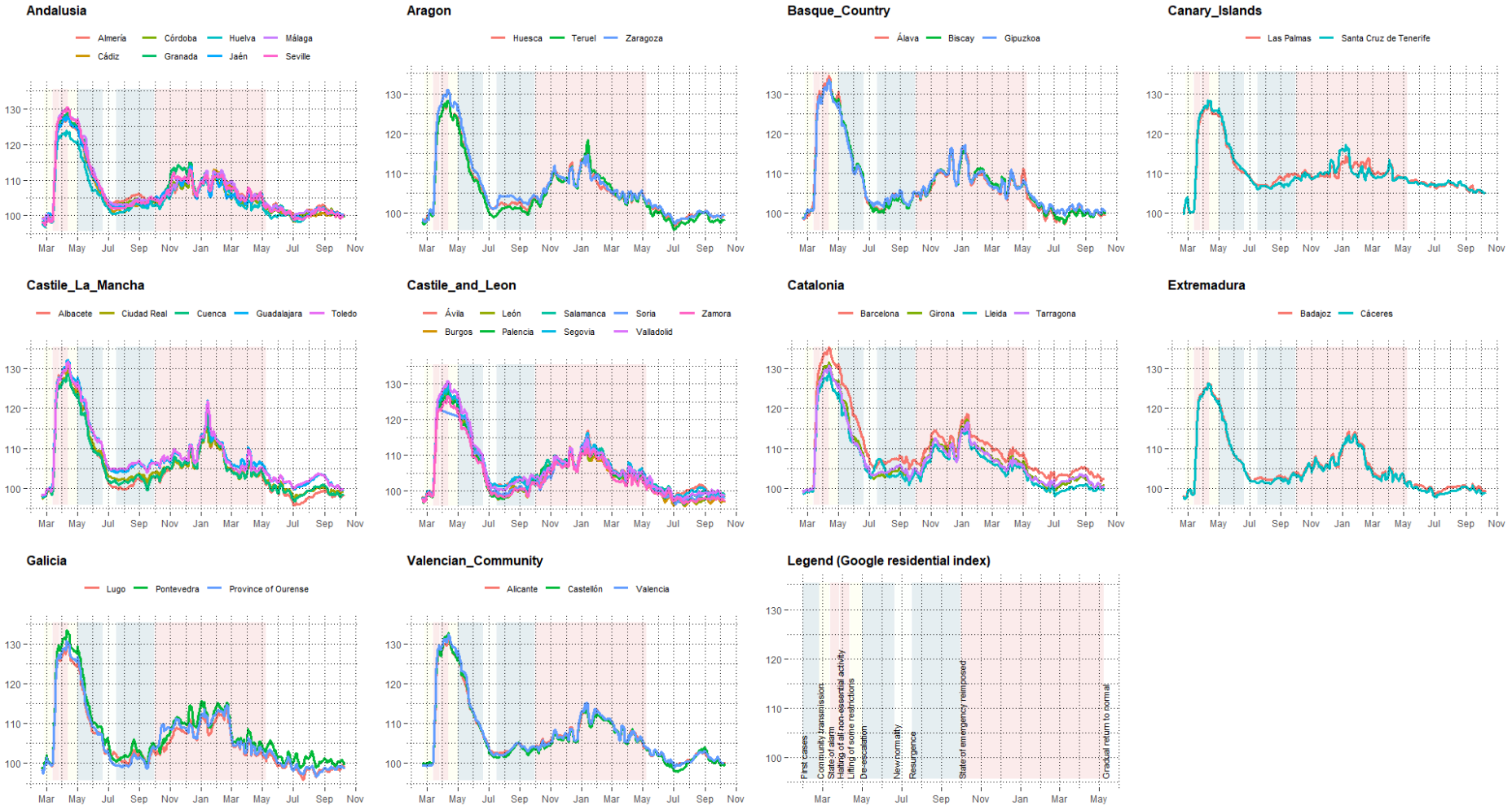
Source: JRC analysis (Google 2021a)

Figure 36. The charts show how **Google workplaces index** for provinces of the selected autonomous communities [base=100] changed since the beginning of the pandemic. The background colours describe to the different phases of the pandemic (see Legend and section 6.1)



Source: JRC analysis (Google 2021a)

Figure 37. The charts show how **Google residential index** for provinces of the selected autonomous communities [base=100] changed since the beginning of the pandemic. The background colours describe to the different phases of the pandemic (see Legend and section 6.1)



Source: JRC analysis (Google 2021a)

In general, it can be concluded that the share of urban population of provinces has low correlation with the number of infections. However, the volume of interprovincial trips has a higher but still moderate correlation with the number of cases. Further analysis would be necessary to analyse the causal relation of the two. A feasible approach to assess the impact of population mobility on the spread of infections would be the application of the mobility associated risk index developed by Ponce-de-Leon et al. (2021) It should be recalled that non-essential interregional trips were restricted between regions during the state of alarms and in many cases even between provinces belonging to the same region. Therefore, the analysis should be carried out with a finer geographical granularity.

6.4 Comparing MITMA mobile and macro model data

To see how the distribution of interprovincial trips was affected by the pandemic, the share of trips for each origin-destination pair compared to the annual total was calculated between 2017 (MITMA macro model data) and 2020 (MITMA mobile data). Only provinces on the Peninsula are included in the analysis, islands and autonomous cities are excluded. Due to the nature of the two data sources, the number of trips of 2017 and 2020 cannot be compared directly, the following equations describe the calculations that make the data from the two years comparable.

Following the same matrix structure as presented in section 5, the total number of trips can be calculated for 2017 (sum^{2017}) as described by the formula below where i,j represent the provinces and x_{ij} the number of annual trips between i and j provinces according to the origin-destination matrix of the MITMA macro model. The annual total of the trips in 2020 (MITMA mobile data) is sum^{2020}, where i,j represent the provinces and y_{ij} the number of annual trips (examined period: 01.03.2020 – 01.03.2021) between i and j provinces.

$$sum^{2017} = \sum_{i=1,j=1}^{i=52,j=52} x_{ij} \quad (5)$$

$$sum^{2020} = \sum_{i=1,j=1}^{i=52,j=52} y_{ij} \quad (6)$$

The following matrix describes how the variation from 2017 to 2020 is calculated for each origin-destination pair (these values are used for further analyses and visualization).

Figure 38. Explanation of the calculation

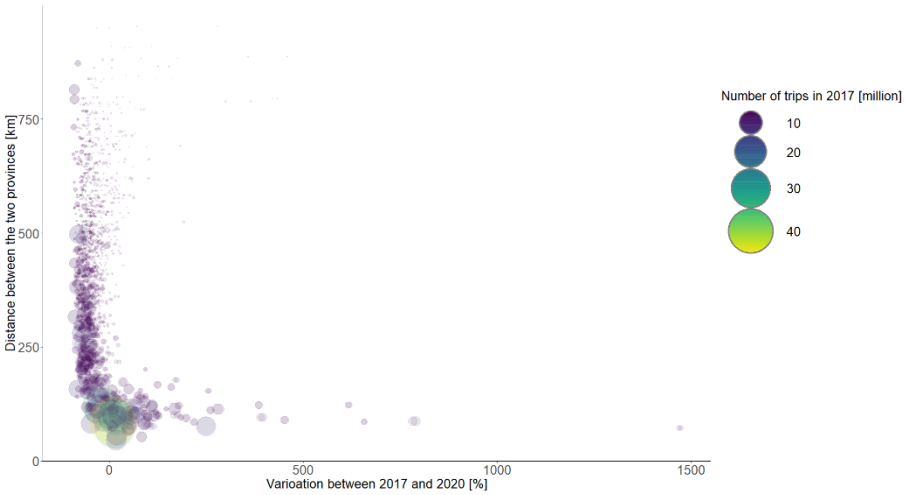
		Destinations					
		1	2	…	j	…	n
Origins	1	$\frac{\frac{y_{11}}{sum^{2020}}}{\frac{x_{11}}{sum^{2017}}}$	$\frac{\frac{y_{12}}{sum^{2020}}}{\frac{x_{12}}{sum^{2017}}}$	…	$\frac{\frac{y_{1j}}{sum^{2020}}}{\frac{x_{1j}}{sum^{2017}}}$	…	$\frac{\frac{y_{1n}}{sum^{2020}}}{\frac{x_{1n}}{sum^{2017}}}$
	2	…	…		…		…
	…	…			…		
	i	…	…		$\frac{\frac{y_{ij}}{sum^{2020}}}{\frac{x_{ij}}{sum^{2017}}}$	…	
	…	…					
	n	$\frac{\frac{y_{n1}}{sum^{2020}}}{\frac{x_{n1}}{sum^{2017}}}$	…		…	…	$\frac{\frac{y_{nn}}{sum^{2020}}}{\frac{x_{nn}}{sum^{2017}}}$

Source: JRC

The graph below (*Figure 39*) shows the results, how the distribution of interprovincial trips changed during the pandemic (01.03.2020 – 01.03.2021) compared to 2017 (MITMA macro model annual data). It shows that for the great majority of origin-destination pairs the share decreased compared to the annual total. The number of trips between provinces that are farther away is generally lower than for those provinces which are closer to each other. The weight of connections with the highest number of trips slightly increased.

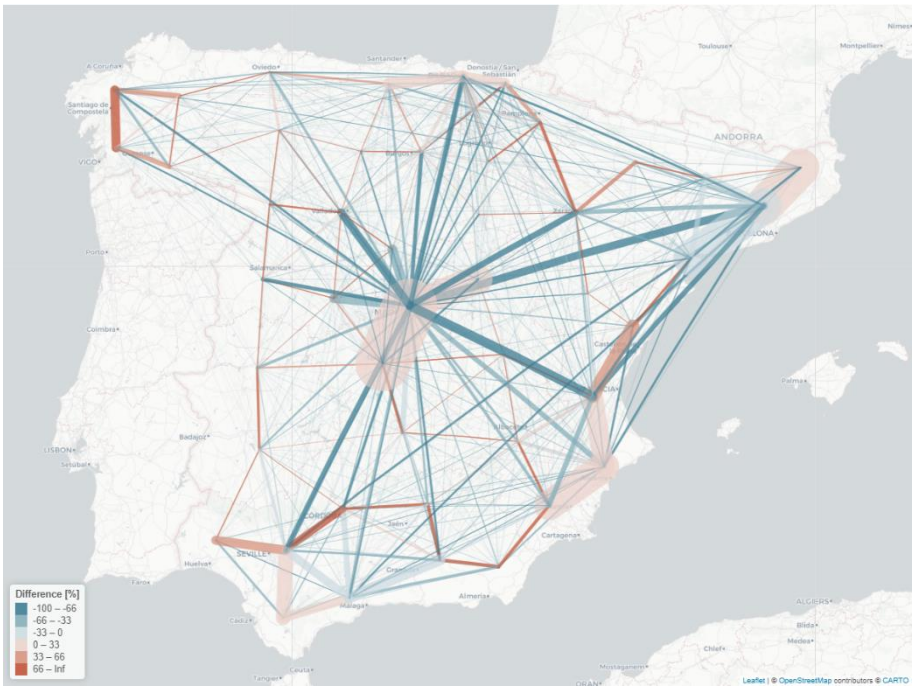
The results are visualized on a map as well where the colours represent the differences from 2017 to 2020 (the cells of the result matrix) and the size of the lines represent the volume of the movements in 2017. The map shows that interprovincial connections that originally had higher volumes of trips in 2017 kept their dominance and their weight slightly increased. Movements on longer distances decreased more significantly than on shorter distances.

Figure 39. Distribution of total annual interprovincial mobility variation between 2017 (MITMA macro model) and 2020 (MITMA mobile data)



Source: JRC analysis (MITMA 2021b, 2021c)

Figure 40. Total annual interprovincial mobility variation between 2017 (MITMA macro model) and 2020 (MITMA mobile data)



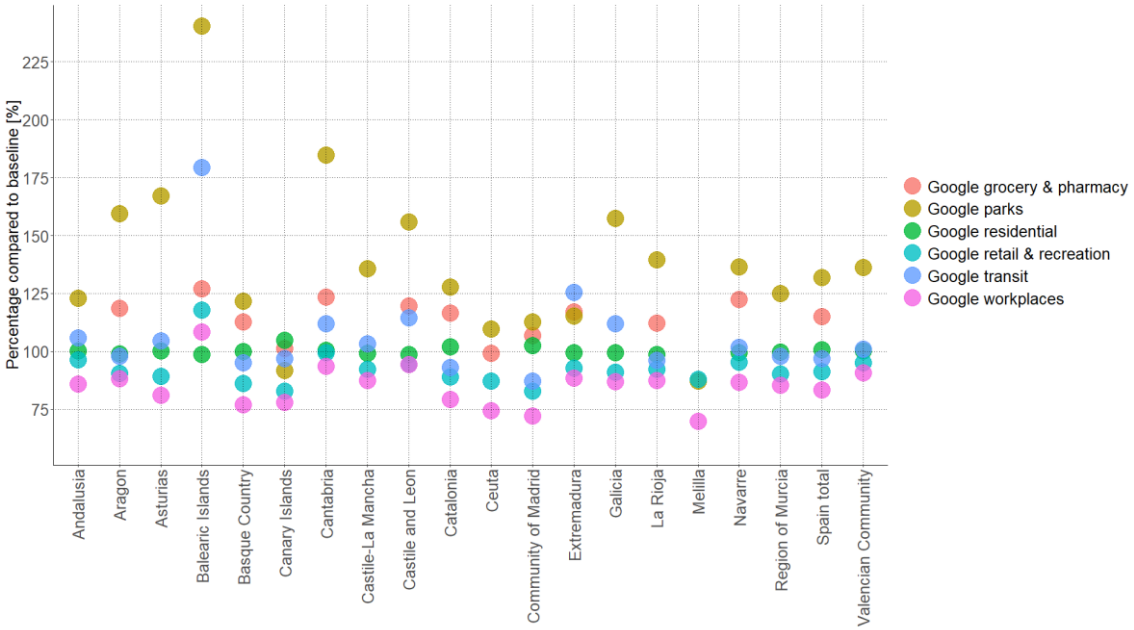
Source: JRC analysis (MITMA 2021b, 2021c)

Long-distance interregional and in some cases even interprovincial trips were restricted during the two states of alarm, for the great majority of the examined period, therefore, it can be stated that the results of the comparison meet the preliminary assumptions as long-distance trips decreased drastically. The weight of interprovincial trips within regions increased in many cases, which is an unexpected result.

6.5 September 2021

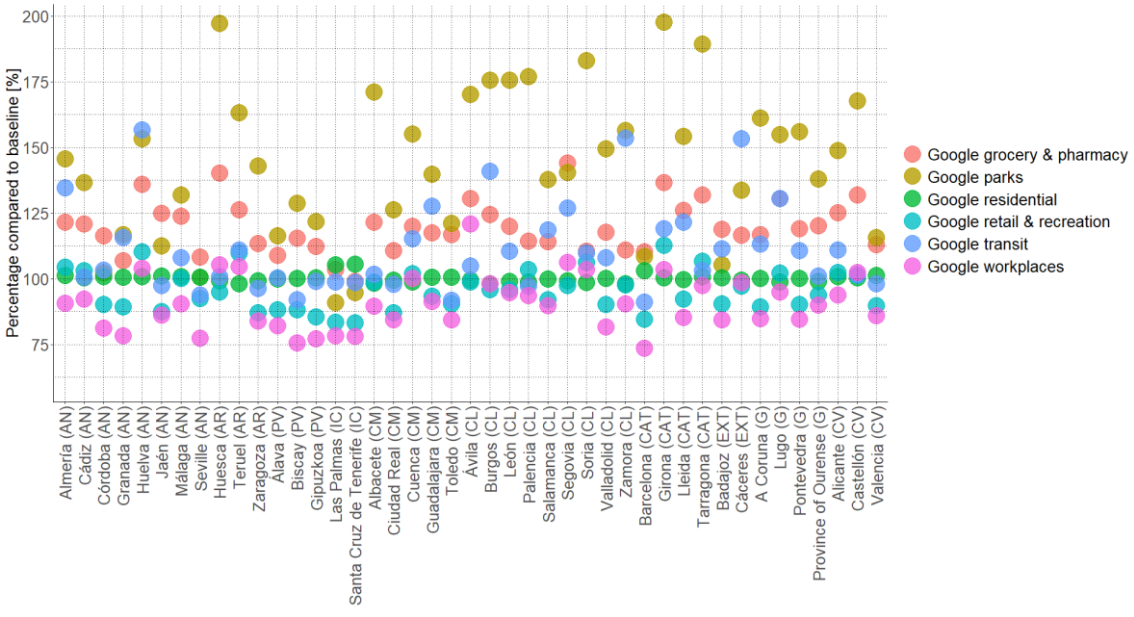
In this section it is summarized whether Google indices seem to recover after the summer of 2021 choosing the period of September 13-27 and calculating the mean value for each index for the two-week period (see Figure 41 for all autonomous communities and Figure 42 for provinces that belong to autonomous communities consisting of more than one province).

Figure 41. Google indices of autonomous communities in September 2021



Source: JRC analysis (Google 2021a)

Figure 42. Google indices of provinces in September 2021



Source: JRC analysis (Google 2021a)

Google parks index reaches the highest values (the national average is 132%). This result occurs probably due to the dates of the baseline, January – February 2020, when spending time in the nature was less common than in September. Besides that, September is still part of the summer in many parts of Spain.

Google retail & recreation index remains below the baseline in all provinces except the Balearic Islands (the national average is 91%), while **Google grocery & pharmacy index** reaches 100-125% levels compared to baseline in all provinces (the national average is 115%). Although online shopping is reaching higher shares in general and the e-commerce grocery sector has grown dramatically during the pandemic, department stores, clothing and electronics still dominate e-commerce purchases (the latter belongs to Google retail & recreation) (CNMC 2021; INE 2021b). Besides seasonal influence, this could be the reason why Google grocery & pharmacy index exceeds the baseline value. However, far-reaching conclusions cannot be drawn from these two indices, especially from retail & recreation index, as they include different activities and only part of them is related to e-commerce.

Google residential index is around the baseline value in most provinces, the Canary Islands and Barcelona are slightly above the rest of Spain (the national average is 101%), but the difference is only 3-5%. People stay at home as much as before the pandemic, in the examined period there was no curfew in place.

Google transit stations index indicates that public transport usage has still not recovered (although the national average is 97%). Some provinces reach or even exceed pre-pandemic levels, while eight out of the nineteen regions remain below the baseline. Only four out of the ten biggest cities' provinces reach at least pre-pandemic levels (Malaga, Murcia, Alicante and Cordoba) and the top five cities' provinces (Madrid, Barcelona, Valencia, Seville and Zaragoza, values vary between 88% and 98%) remain below pre-pandemic levels.

Except a few provinces, **Google workplaces index** remain below pre-pandemic levels, the national average is around 83% compared to the baseline. The biggest cities' provinces belong to the ones with lowest levels (after Barcelona, the provinces of the Basque Country, Seville and Madrid, 72%-78%), Valencia is an exception with slightly higher values (78%). According to the Spanish Statistical Office, around 15% of the workplaces applied teleworking before the pandemic, while this share raised to almost 50% during the state of alarm (INE 2021d). Google workplaces index suggests higher levels of teleworking in comparison to pre-pandemic times. Lower employment rate could be a reason for lower levels of the index, but employment rate on national level recovered by Q3 2021 and reaches pre-pandemic levels (INE 2021c). More common teleworking can be one of the main reasons why Google transit remains below pre-pandemic levels.

These findings are only based on Google indices and should be validated with other data sources to check whether Google indices describe the real situation (for example with public transport usage data).

7 Discussion on the results

In this section those circumstances are discussed that limited the research.

The baseline period used both for Google and MITMA mobile data is relatively short compared to the length of the examined timeframe. For this reason, it is difficult to determine what changes are due to the pandemic and what are due to seasonal changes (for example when summer is compared to the baseline in winter). Overall, it can be concluded that for such a long timeframe of analysis a more suitable baseline should be chosen, if available, that covers a longer period and facilitates more the observation of seasonal effects. In our case, the baseline was given and could not be extended; however, the data sources used for the present report illustrate the dynamics of the changes in a sufficient manner.

In addition, new active coronavirus cases might not be the best indicator for representing the severity of the pandemic as sampling across Spanish provinces might have differed and the number of identified cases might not represent the real attack rate of the pandemic. For eliminating this uncertainty, the number of hospitalized persons and deaths could be used that do not rely on sampling. However, for the purpose of this analysis, the number of daily new cases was a sufficient indicator that describes the dynamics of infections well.

A major limitation is related to the lack of well-structured data on movement restrictions across Spain. Data availability limited the analysis on how restricting measures affected mobility and the initial research questions turned out to be too demanding. Although it can be concluded that strict measures and uncertainty in the beginning of the pandemic were powerful enough to make people stay at home, after the first state of alarm, the effects of the restricting measures are not evident as data is available only on national level. Collecting data and compiling official gazettes for all regions and provinces would have been too demanding (but doable). Such a data collection could be less demanding for a smaller area, when a well-defined location is analysed (for example a city). A well-structured database on government responses to the pandemic would facilitate the impact assessment of the applied measures for evidence-based decision making. The discussed international examples in section 4.2 are good examples for such a database and assessment.

Open mobility data enables relatively quick and complex analysis on the effects of the pandemic. Although some further questions might be raised about the accuracy and comparability of the data sources, they describe the trends in a suitable manner.

8 Conclusions

This report analyses how the pandemic affected mobility in Spain at national, autonomous community and provincial levels. The timeframe of the analysis is March 1, 2020 – October 1, 2021 and is based on publicly available data sources. Cell information based mobility data, Google (COVID-19 Community Mobility Reports) and Apple (Mobility trends reports) mobility data were analysed. It was found that Google data is a more reliable data source than Apple to analyse the mobility situation in Spain as Apple follows a different approach for calculating the indices. The data sources, the methodology and the results were presented in the report. Besides that, an online dashboard was delivered that can be used for further analysis to complement the results discussed in this report.

Since the beginning of the COVID-19 pandemic, five waves of infection can be observed in almost every region of Spain; however, the severity of the waves differ. As a reaction to the pandemic, the first state of alarm was imposed on March 13, 2020 with hard lockdown prohibiting all non-essential movements. Due to the restrictions and unpredictable consequences of the coronavirus disease, the number of all movements dropped drastically in all Spanish autonomous communities to 40-50 % compared to baseline regardless the number of reported coronavirus cases. The number of trips related to retail, workplaces or public transport journeys dropped to under 25% compared to baseline according to Google data. After most of the restrictions were lifted, mobility levels returned to 70-80% compared to baseline by the summer of 2020. Although the number of coronavirus infections and deaths of the subsequent waves exceeded the first wave, mobility levels remained relatively high compared to baseline (above 75%). Differences across provinces in terms of mobility levels were more dominant during the summer of 2020 and 2021 when attractive tourist destinations reached higher levels and cities which residents tend to leave their residence dropped to lower levels. Out of the holiday seasons, during the two states of alarm the trends were less scattered across Spain and mobility levels dominantly remained below pre-pandemic levels.

Besides movement restrictions that had obvious impacts on mobility, seasonality of infections and mobility had great impact on the number of trips, especially as the two summer holiday seasons and lower infection rates, as well as higher levels of vaccination in 2021 coincided. When autonomous communities or provinces are compared, seasonality and tourism caused greater differences in terms of mobility than local movement restrictions or local breakouts in infections. The first lockdown caused a dramatic decrease in the number of trips all over Spain, while during the second lockdown most provinces followed a similar trend maintaining a 70-90% compared to pre-pandemic levels.

Although data availability on restrictions limited the possibilities of analysing in-depth the effects of restrictive measures on mobility, national level data shows that government decisions in the beginning were somewhat delayed, then followed the evolution of infections. The results of a windowed time lagged cross correlation analysis shows that despite a few exceptions, restrictions had an immediate result on the number of trips, especially during the first state of alarm when restrictions were highly enforced. Limited data availability on government responses to the pandemic turned out to be a barrier that hindered impact assessment. A well-structured, detailed database on government measures would be necessary to evaluate the impacts of the movement restrictions and conclude evidence-based policy proposals.

An important question for the future is the long-term effects of the pandemic on mobility and the take-up of teleworking, online shopping, home delivery and other means that have become the norm since the beginning of the pandemic to reduce movements and contacts. Google workplace index shows that in greater cities people in overall tend to work more from home. Visits of workplaces in September 2021 on national level reaches 83% compared to pre-pandemic values, while even lower levels in great cities' provinces. Google transit index shows that public transport has not recovered either. Although the national average is 97% when whole Spain is considered, provinces of major cities remain below baseline. A possible future research line would be a prediction on how sustainable mobility could be affected in long term by the changes due to the pandemic.

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List of abbreviations

MITMA	Ministerio de Transportes, Movilidad y Agenda Urbana (Spanish Ministry of Transport, Mobility and Urban Agenda)
OxCGRT	Oxford Covid-19 Government Response Tracker

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Table 3. Data on population and the number of confirmed coronavirus cases per 100,000 inhabitants Spain

Autonomous community	**Province**	**Population**	**Share of population in cities with more than 50,000 inhabitants**
Spain		**47,450,795**	**53 %**
Andalusia (AN)		**8,464,411**	**51 %**
	Almería	727,945	53 %
	Cádiz	1,244,049	69 %
	Córdoba	781,451	42 %
	Granada	919,168	32 %
	Huelva	524,278	27 %
	Jaén	631,381	27 %
	Málaga	1,685,920	70 %
	Seville	1,950,219	49 %
Aragon (AR)		**1,329,391**	**55 %**
	Huesca	222,687	24 %
	Teruel	134,176	0 %
	Zaragoza	972,528	70 %
Asturias (AST)		**1,018,784**	**61 %**
Balearic Islands (IB)		**1,171,543**	**45 %**
Basque Country (PV)		**2,220,504**	**47 %**
	Álava	333,940	76 %
	Biscay	1,159,443	46 %
	Gipuzkoa	727,121	35 %
Canary Islands (IC)		**2,175,952**	**54 %**
	Las Palmas	1,131,065	60 %
	Santa Cruz de Tenerife	1,044,887	48 %

Autonomous community	Province	Population	Share of population in cities with more than 50,000 inhabitants
Cantabria (C)		**582,905**	**39 %**
Castile and León (CL)		**2,394,918**	**44 %**
	Ávila	157,664	37 %
	Burgos	357,650	49 %
	León	456,439	41 %
	Palencia	160,321	49 %
	Salamanca	329,245	44 %
	Segovia	153,478	34 %
	Soria	88,884	0 %
	Valladolid	520,649	57 %
	Zamora	170,588	36 %
Castile-La Mancha		**2,045,221**	**27 %**
	Albacete	388,270	45 %
	Ciudad Real	495,045	15 %
	Cuenca	196,139	28 %
	Guadalajara	261,995	33 %
	Toledo	703,772	24 %
Catalonia		**7,780,479**	**54 %**
	Barcelona	5,743,402	65 %
	Girona	781,788	13 %
	Lleida	438,517	32 %
	Tarragona	816,772	30 %
Ceuta		**84,202**	**100 %**
Community of Madrid		**6,779,888**	**86 %**
Extremadura		**1,063,987**	**29 %**

Autonomous community	Province	Population	Share of population in cities with more than 50,000 inhabitants
	Badajoz	672,137	31 %
	Cáceres	391,850	25 %
Galicia		**2,701,819**	**37 %**
	A Coruna	1,121,815	37 %
	Lugo	327,946	30 %
	Pontevedra	945,408	40 %
	Province of Ourense	306,650	34 %
La Rioja		**319,914**	**48 %**
Melilla		**87,076**	**100 %**
Navarre		**661,197**	**31 %**
Region of Murcia		**1,511,251**	**56 %**
Valencian Community		**5,057,353**	**45 %**
	Alicante	1,879,888	52 %
	Castellón	585,590	39 %
	Valencia	2,591,875	42 %

Source: (INE 2021a)

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