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# The role of the socio-economic context in the spread of the first wave of COVID-19 in the Marche Region (central Italy)

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Eleonora Gioia, Alessandra Colocci, Cristina Casareale, Noemi Marchetti, Fausto Marincioni\*,

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[f.marincioni@univpm.it](mailto:f.marincioni@univpm.it)

Department of Life and Environmental Sciences, Università Politecnica Delle Marche, Via Brecce Bianche, 60131, Ancona, Italy

\*Corresponding author.

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## Abstract

The first wave of COVID-19 arrived in Italy in February 2020 severely hitting the northern regions and delineating sharp differences across the country, from North to South. The Marche Region (central Italy) is a good example of such uneven distribution of contagion and casualties. This paper discusses the spatial diffusion of COVID-19 during the spring of 2020 in the five provinces of Marche and discusses it by means of descriptive and quantitative analysis of local socio-economic variables. Results show that the high impact of COVID-19 in Pesaro and Urbino, the northernmost province of Marche, might be reasonably attributable to higher mobility of local residents, especially northbound. Similarly, the larger contagion among the elderly in the center and northern provinces, is possibly due to a high number of hospices and seniors' residential facilities. Finally, the North-to-South diffusion of the virus can be explained by the Region's transportation infrastructures and urban layout along the coastal area.

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## Keywords:

COVID-19, First wave, Socio-economic context, Spatial interactions, Multidimensional analysis, Central Italy

## Abbreviations

No keyword abbreviations are available

## Data availability

Data will be made available on request.

## 1 Introduction

In December 2019, the World learned that in Wuhan, the capital of the province of Hubei (China), a new Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) was detected [1]. This infectious disease spreads through droplets and virus particles scattered into the air when an infected person breathes, talks, laughs, sings, coughs, or sneezes [1]. The new disease, named “COVID-19” (Coronavirus Disease 2019), presents symptoms difficult to differentiate, at its onset, from those of an ordinary flu, it can however deteriorate very rapidly becoming life threatening, especially when affecting breathing ability [2]. Older people with frailties were found very vulnerable to the disease [3]. On March 11, 2020, the Director-General of the World Health Organization (WHO) declared the infection outbreak a global pandemic [4], with more than 10 million people infected and more than 500.000 deaths claimed as of June 30, 2020 [5].

Italy was among the first areas outside China heavily affected by the virus and the government effort to cope with such an emergency was paramount [6]. The first two cases of COVID-19 in Italy were confirmed on January 31, 2020, when two Chinese tourists in Rome tested positive. The numbers of identified cases climbed sharply after the hospitalization of a 30-year-old man in the Hospital of Codogno (Lombardy Region, northern Italy) on February 21, 2020. As a matter of fact, in the first weeks of the pandemic, most of the cases were detected in Lombardy and in the surrounding Regions of Veneto, Piedmont, Emilia-Romagna and, remarkably, in the more distant Marche (central Italy) [6]. At the same time, the other central Regions of Italy, the southern ones and the islands reported a rather low diffusion of contagions [7–9]. In the Marche Region, COVID-19 was detected at the beginning of March 2020 from the northernmost province of Pesaro and Urbino, an area included in the initial 26 Italian Provinces listed as ‘red zone’, within which movements inside and outside the respective administrative jurisdictions had been harshly reduced [10]. As of April 20, 2020, the number of contagions in Marche was still the highest of the regions of central Italy (i.e., Lazio, Tuscany, Umbria, Abruzzo) [2]. Over time, the virus spread southward all over the Italian peninsula. According to the data of the Italian Ministry of Health, on June 30, 2020, at the end of the first wave of COVID-19, Marche ranked the eighth most infected region, with the Emilia Romagna Region, at its northern border, ranking third, and the Abruzzo Region, at its southern border, ranking thirteenth [11].

Indeed, COVID-19 revealed how humankind is heavily exposed to and mostly unprepared for pandemics in terms of socio-economic resilience. Truth to be told the Sendai Framework for Disaster Risk Reduction (DRR) 2015–2030, though unheard, had been calling attention on the need of more dedicated actions to tackle underlying disaster risk drivers and prepare for consequences of pandemics and epidemics [12,13]. In recent years, a new research field named Health Emergency and Disaster Risk Management (Health-EDRM) has emerged as a multidisciplinary intersection of health and disaster risk reduction (DRR) [14]. In this framework, it is suggested that the DRR strategies such as disaster risk assessment can contribute to build the resilience to pandemics [15]. To achieve this goal, given the complex and systemic nature of such risks, there is a strong need of interconnected and pluralistic approaches [15,16].


The global literature on the spread of COVID-19 considers several perspectives (such as epidemiologic, demographic, socio-economic and environmental) and multiple scales (from global to local) [17–19]. Information about the availability of health facilities or contingency plans have been thoroughly explored to explain the crucial contribution to the impact and severity of the COVID-19 pandemic [19,20]. Likewise, spatial and demographic dimensions of the community appeared important factors of COVID-19 diffusion [17,21,22], especially in nowadays globalized lifestyle in which mobility is the essence [23–26]. Indeed, several studies have already analyzed how the lockdown, limiting people mobility and interactions, contained the diffusion of COVID-19 [10,27,28]. However, it is still unclear which factors are more relevant to lower vulnerability and resilience to infectious diseases, especially at the regional and local level [21,29,30]. Moreover, the available resources, the cultural habits (such as the mobility), but most of all, previous experiences with epidemics and pandemics change from place to place [31,32]. Very likely, these variabilities influence the choice of effective models of pandemic response [32,33].

With this study we purpose to analyze the socio-economic pattern that made the Marche Region (central Italy) exceptionally vulnerable to the contagion during the first wave of COVID-19 (February–June 2020). Particularly, we investigated, by means of both descriptive and quantitative analysis (statistic test of Kendall rank correlation coefficient), the significant connections between COVID-19 contagion and the local demographics, health services context, infrastructural and urban systems, as well as mobility habits.

## 2 Materials and methods

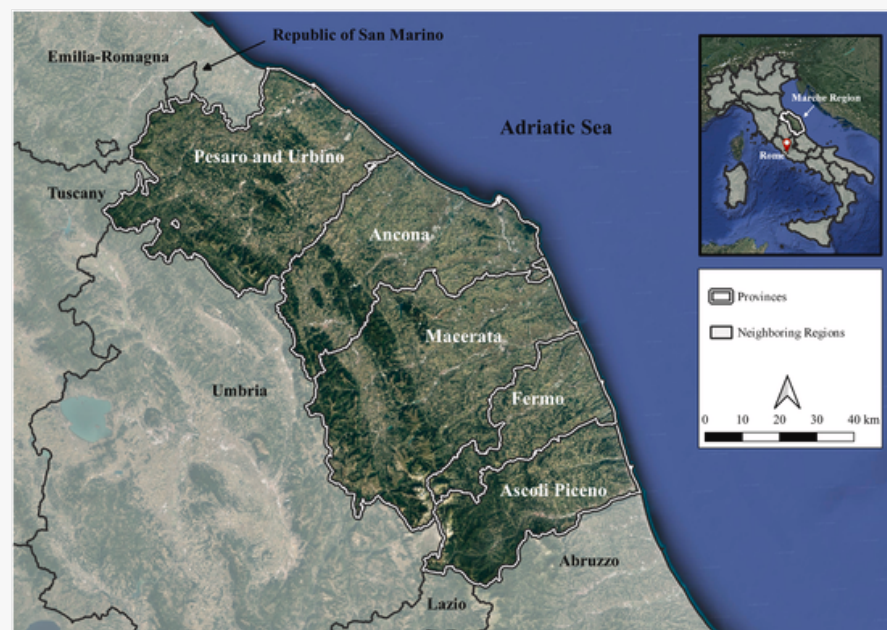
## 2.1 Study area

The Marche Region is located on the eastern side of the Italian peninsula with an area shaped like a bended rhomboid, extending mostly from North-West to South-East and with a surface of approximately 9401.18 km<sup>2</sup> (Fig. 1). The Region is limited by the Adriatic seaboard to the East and the Umbria-Marche Apennine range to the West (bordering with the Tuscany and Umbria Regions). To the North, Marche borders with the Emilia-Romagna Region and the Republic of San Marino, whereas to the South is bounded by the Abruzzo and Lazio Regions. From an administrative point of view, the Marche Region is subdivided into five provinces: Pesaro and Urbino, Macerata, Ancona, Fermo, and Ascoli Piceno (Fig. 1).

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alt-text: Fig. 1

Fig. 1



Location of the Marche Region within Italy. The figure shows, from North to South, the five provinces, Pesaro and Urbino, Ancona, Macerata, Fermo and Ascoli Piceno. The Region borders with Emilia Romagna and San Marino Republic to the North, with Tuscany and Umbria to the West, with Lazio and Abruzzo to the South, and with the Adriatic Sea to the East.

Among the 20 Italian Regions, Marche is 13th for number of citizens and 11th for population density (i.e., persons per square kilometer). The distribution and the demographic composition of the about 1.5 million residents of Marche are primary aspects upon which we developed our analysis. Ancona (Capital City of Marche) is the most populated

province (471,228), followed by Pesaro and Urbino (358,886), Macerata (314,178), Ascoli Piceno (207,179) and Fermo (173,800).

Data from the Italian National Institute of Statistics (Istat) show that Marche is among the top four Regions in Italy for life expectancy at birth for males (81.8 years compared to the Italian average of 81.0 years) and the top six for females (85.9 years compared to the Italian average of 85.3 years) [34]. The life expectancy influences the public spending of Marche which is currently primarily destined to the regional healthcare service [35].

In general, from a socio-economic point of view, the Region occupies a position just above the national average both in terms of per capita income and of limited conditions of poverty and deprivation, which is associated with a higher level of education [35]. However, the gross domestic product of Marche Region is lower than the national average, though it is increasing from 2016 [36]. A manifold of enterprises, about 3% of the overall Italian enterprises as of 2020, has traditionally been based in the Marche Region [37]. Quantitatively, most of the enterprises are related to national (in connection with the North of Italy) and international trading activities, followed by the primary sector (agriculture and fisheries), constructions and manufacturing activities [37]. The latter is illustrative of the overall productive sector and is characterized by small-sized enterprises [37], scattered throughout the Region and not concentrated in few heavily industrialized poles. Therefore, the local economy appears strongly rooted and interrelated with the local communities. Overall, the Marche Region still presents evident rural features, inherited from historical cultural trends.

## 2.2 Data sources and analyses

Our analysis on the influencing factors of COVID-19 diffusion considered data from heterogeneous sources:

- Official data of the number of deaths, infected people and performed swabs to monitor the contagion, was collected through daily bulletins (accessible at <https://www.regione.marche.it/>) made available by the Marche Regional Health Emergencies Operating Group (GORES) and the national Italian Institute of Health (ISS),
- Data on the health care system was collected from the Regional Observatory of Social Policies of the Marche Region (accessible at: <https://www.regione.marche.it/Entra-in-Regione/ORPS>) and the Italian National Institute of Statistics (accessible at <https://www.istat.it/>),
- Data on the infrastructure system, urbanization and mobility was collected from the Italian National Institute of Statistics.

Using the opensource desktop GIS software QGIS, we generated various thematic maps, describing the diffusion of COVID-19, the distribution of health and social facilities, infrastructures, urbanization and mobility. At the same time, using the cross-platform, open-source application ScapeToad®, anamorphic maps were drawn to highlight the role played by specific variables in the studied provinces.

Finally, because data on the evolution of the early contagion in Marche had not been made uniformly available at the municipal scale, the overall analysis was carried out at a provincial level. Consequently, all the discussed information refers to such geographical scale. We acknowledge that such a constraint might limit the localization and connection of specific trends and decrease the clearness on how the virus spread both spatially and temporarily within the studied provinces. However, since the focus of this study is to explore the factors behind COVID-19 diffusion within the Marche Region and its boundary role at the national level in Spring 2020, the provincial scale can be considered sufficient to reflect the complex dynamics of the pandemic.

Along with the main descriptive analyses, quantitative analyses were also performed. The objective was to investigate correlations among the studied socio-economic features of the Marche Region. To this purpose, the following proxies had been selected:

- a. Total number of infections (representing the diffusion of COVID-19 in the Marche Region),
- b. Total beds available in health and social structures (gauging the health care system),
- c. Housing dispersion index (portraying the infrastructural and urban system),
- d. Total extra-regional commuter flow toward the northern Italy regions of Piedmont, Aosta Valley,


In addition to these already mentioned sources, the Housing Dispersion Index (HDI) was retrieved from the Urban Indices made available by Presidency of the Council of Ministers of the Italian Government (accessible at <https://www.urbanindex.it/indicatori/indice-di-frammentazione-del-paesaggio-urbano/>). The HDI measures the rate of isolated houses on the overall number of houses in a certain area. The data in this case was available at the municipal scale, however, to maintain the uniformity with the previous analysis, the median HDI value was calculated for each studied province.

The quantitative analysis was performed using the Kendall rank correlation method. Also known as Kendall's  $\tau$  coefficient, this test is considered one of the best options when the population size is small, the number of variables is limited and their distribution is unknown [38]. The test relies on a bivariate non-parametric method, following a rank-based statistical process [39]. Using the IBM SPSS Statistic 19 software, the Kendall's  $\tau$ -b was calculated; it was chosen this specific coefficient because robust and not affected by eventual ties. The metric evaluates the rate of concordance (or discordance) between two sets of ordinated variables. The  $\tau$ -b coefficient assumes values between  $\pm 1$  and 0; the closer the coefficient is to  $\pm 1$  the stronger is the correlation, conversely the closer the coefficient is to 0 the weaker is the correlation (Table 1). Significantly, the positive or negative values indicate the direction of the relation. In terms of significance, the analysis is considered statistically significant with p values lower than 0.05, and highly significant with p values lower than 0.001.

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Source [40].

Table 1

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Relation between the values of Kendall's  $\tau$ -b and the strength of correlation.

Range of Kendall's $\tau$ -b value	Strength of correlation
0 and $\pm 0.10$	very weak
$\pm 0.10$ and $\pm 0.19$	weak
$\pm 0.20$ and $\pm 0.29$	moderate
$\pm 0.30$ and $\pm 1.00$	strong

## 3 Results and discussion

### 3.1 The first wave of COVID-19 in the Marche Region

As already mentioned, the first case of COVID-19 in Marche Region was detected at the end of February 2020 in the municipality of Pesaro. This patient zero for Marche was a resident of Pesaro who commuted to work in a factory near Codogno (Lombardy), the place of the first known COVID-19 outbreak in Italy (Fig. 2). Possibly, the diffusion of the virus in the Pesaro and Urbino province was also favored, inter-alia, by various public events such as the 2020 northerner carnival festivals (held in Pesaro, Urbino and Fano on 23 February, 20–25 February, 9–16–23 February, respectively) and the final tournaments of the 2020 Italian Basket Cup held in Pesaro from 13 to February 16, 2020. Due to the severity of the virus diffusion, the province of Pesaro and Urbino became the first 'red zone' of Marche [41].


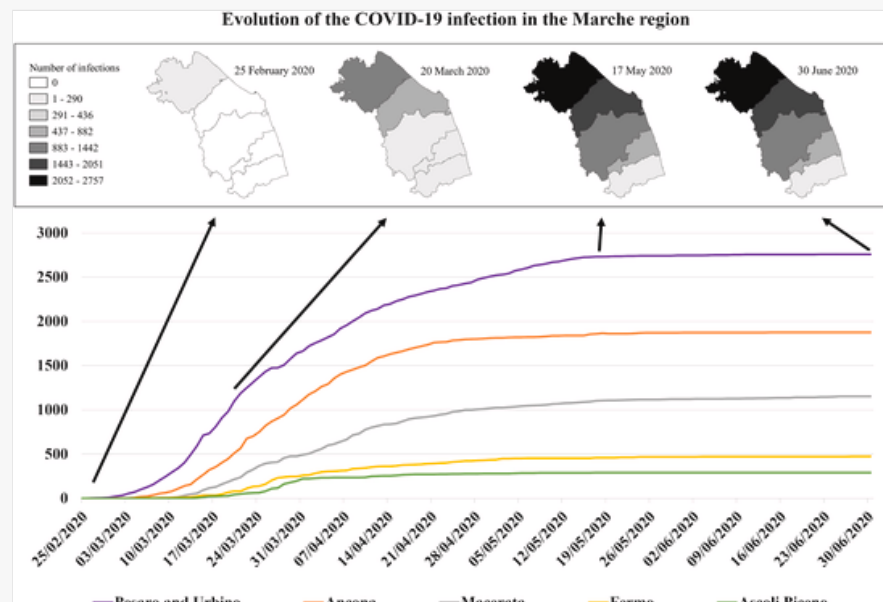
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Fig. 2



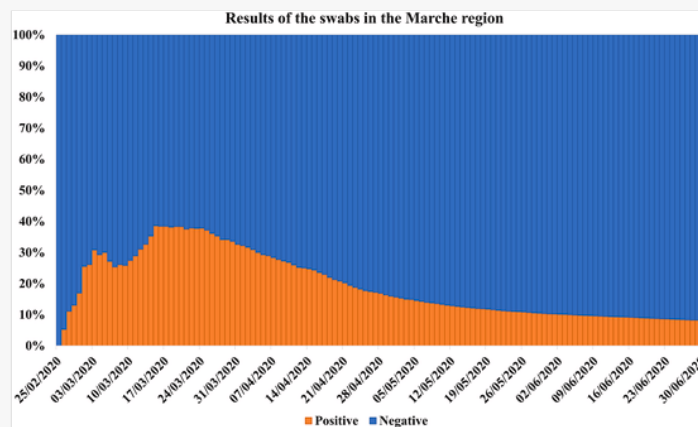
Evolution of the first wave of COVID-19 infection in the Marche Region, from February to June 2020. The colored lines in the graph indicate the temporal trend of the contagion in each province. The maps above the graph report noteworthy dates of the evolution in the spatial trend of the contagion: (from left to right) 25th February, when the first cases were detected in the province of Pesaro and Urbino; 20th March, when the number of cases kept growing in the province of Pesaro and Urbino and started to spread in the meridional provinces of Marche; 17th May, when the number of new infections started to stabilize; 30th June, when the first wave of the pandemic ended. (Source: elaboration of data of the regional daily bulletin, accessible at <https://www.regione.marche.it/>).

By the beginning of March 2020, COVID-19 was present across the entire Marche Region, with all provinces reporting cases except for the province of Ascoli Piceno. On 5th March, 100 cases were reported in the province of Pesaro and Urbino, 19 in the province of Ancona, 2 in the province of Macerata, 3 in the province of Fermo. The first case in Ascoli Piceno was registered a week later, on 11th March. However, the substantial disproportion of COVID-19 cases between the northern and southern provinces remained significant for the following weeks. As of 20th March, the province of Pesaro and Urbino exceeded a thousand cases, reaching 1099 people infected, with an increase in contagion throughout the Region (Ancona = 513 cases, Macerata = 476 cases, Fermo = 246 cases, Ascoli Piceno = 43 cases). As of April, the spread of the coronavirus was still relevant, especially in the northern part of the Region, but started to slow down in the southern part of Marche. Following the national trends, the percentage of the population testing positive in Marche rose until 17th May, when the circulation of coronavirus began to stabilize in each province consequently to the COVID-19 control measures. On 30th June, the total number of infections in Marche were distributed as follow: 2757 in the province of Pesaro and Urbino, 1857 in the province of Ancona, 1154 in the Province of Macerata, 473 in the province of Fermo and 290 in the province of Ascoli Piceno. Fig. 2 shows the evolution of the contagion in the region from 25th February to June 30, 2020, highlighting how the contagion worsened during the months of March and April, to then stabilize in the following two months. The consistent difference in the spread of the coronavirus among the provinces of the Marche Region defines the buffer/frontier function of the Marche Region in the North-South diffusion of the pandemic in Italy.

The results of the swabs administered in the Marche Region were also analyzed to confirm the temporal trend of the COVID-19 contagion. From the end of February to the end of June, after an initial shortage of medical devices, the total number of administered swabs increased on a weekly basis. In terms of positive vs. negative outcome, Fig. 3 highlights that in March 2020 the number of positive swabs was approximately half the number of the negative swabs (respectively 3684 and 7295 on 30th March). The contagion appeared to begin its deceleration in April with a noticeable decrease of the number of positive swabs in relation to the total number of administered swabs. The proportion in May became one positive every eight swabs administered (6785 positive against 76,165 negative swabs on 30th May). Such trend was substantially maintained through 30th June.

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Fig. 3




Results of the swabs performed in the Marche Region from February to June 2020. The percentage of positive swabs (in orange) compared to the total number of swabs (in blue) shows that, after the initial spike of March, the swabs testing positive started decreasing from April, keeping the percentage of infections stable until the end of June (Source: elaboration of data of the regional daily bulletin, accessible at <https://www.regione.marche.it/>). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Hence, starting with the month of April 2020, despite the increased number of administered swabs, the number of positive results decreased (Fig. 3). This results show on the one hand the successful containment of the virus over time and on the other hand the increased diagnostic capacity of the Region.

Another relevant result of the analysis of the diffusion of COVID-19 in Marche is related to mortality. During the first wave, the death toll linked to the COVID-19 virus tallied 996 people, of which 594 men and 402 women, with an average age of 80.5 years. 94.8% of the deaths carried pre-existing pathologies. Most of the losses occurred in the province of Pesaro and Urbino (527), followed by Ancona (217), Macerata (165), Fermo (66), and Ascoli Piceno (13). Eight casualties were residents outside the Region.

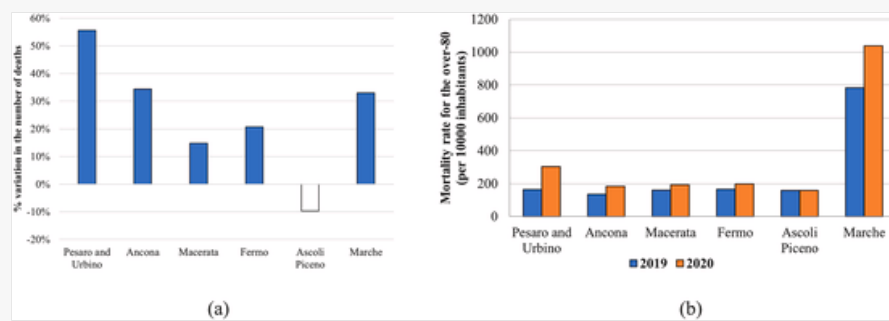
As a matter of fact, the change in the mortality rate between the provinces is rather evident when comparing 2020 with the period 2015–2019 (Pre COVID-19); the value of the mortality rates for the month of March 2020 was more than double in Pesaro and Urbino (+55.6%), while Ascoli Piceno was the province with the lowest mortality rate recording a negative mortality (−9.7%), further revealing that COVID-19 had not yet spread significantly across the province in March 2020 (Fig. 4a). The share of deaths in which COVID-19 was the direct cause, as described in a report of the Italian National Institute of Statistics and the Italian Institute of Health [42], varied according to age. The over-80 age group is the one that suffered most from the virus impact in all provinces (Fig. 4b). On the whole the mortality rate of 2020 was higher across all ages when compared to that of 2019, yet it decreased significance with the younger ages [43,44].

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Fig. 4





Change in mortality due to COVID-19 in the Marche Region and provinces: percentage changes in the number of deaths of March 2020, compared to the March average of the previous 5 years (a); comparison of the mortality rate per 10,000 inhabitants for the over-eighty in 2019 and 2020 (b). (Source: elaboration of data of the Italian National Institute of Statistics and the Italian Institute of Health, available at <https://www.istat.it/it/archivio/245573>).

### 3.2 The health care system

The social and health care system in the Marche Region is coordinated at regional level by the Marche Regional Health Agency (ASUR), which is divided into 5 “Vast Areas”, reasonably approximated, though not exactly corresponding, to the jurisdiction of the five provinces [45]. Within this framework, the assistance offered to the elderly of Marche is not limited to hospitals and nursing homes, but covers a broad range of services (Table 2) [46].

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Table 2

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Type of health and social structures that provide residential and semi-residential services for the elderly in the Marche Region. The services are ordered from top to bottom according to an increasing degree of self-sufficiency of patients.

Organizational area	Type of structure	Type of service
Health	Residential	IC – Intermediate Care
		NH – Nursing Home for not self-sufficient Elderly
Social	Residential	PRE – Protected Residence for Elderly
		PRD – Protected Residence for Dementia
		RH – Retirement Home
		CH – Community Housing for Elderly
		HH – House Hotel
Health	Semi-residential	DCD – Day Center for Dementia
Social	Semi-residential	DCE – Day Center for the Elderly

Health residential facilities include: i) Intermediate Care (IC), which host patients discharged from hospitals or in pre-hospitalization situations, and ii) the Nursing Homes (NHs), providing continuous nursing care in residential units for patients who are not self-sufficient and with pathologies that require high health protection (e.g., guests in artificial nutrition) [47]. Conversely, social residential structures include: i) Protected Residences for the Elderly (PREs) and Protected Residences for Dementia (PRDs), which host with high social-health integration patients respectively with physical-psychological pathologies and with cognitive deficits that cannot be cured at home; ii) Retirement Homes (RHs), accommodation with community services for self-sufficient elders; iii) Community Housing for the Elderly (CH), consisting of a set of small lodgings that allow an independent life; and iv) House Hotels (HHs), self-managed or semi-self-managed facilities for self-sufficient elderly people who choose a family life of cohabitation. Among the

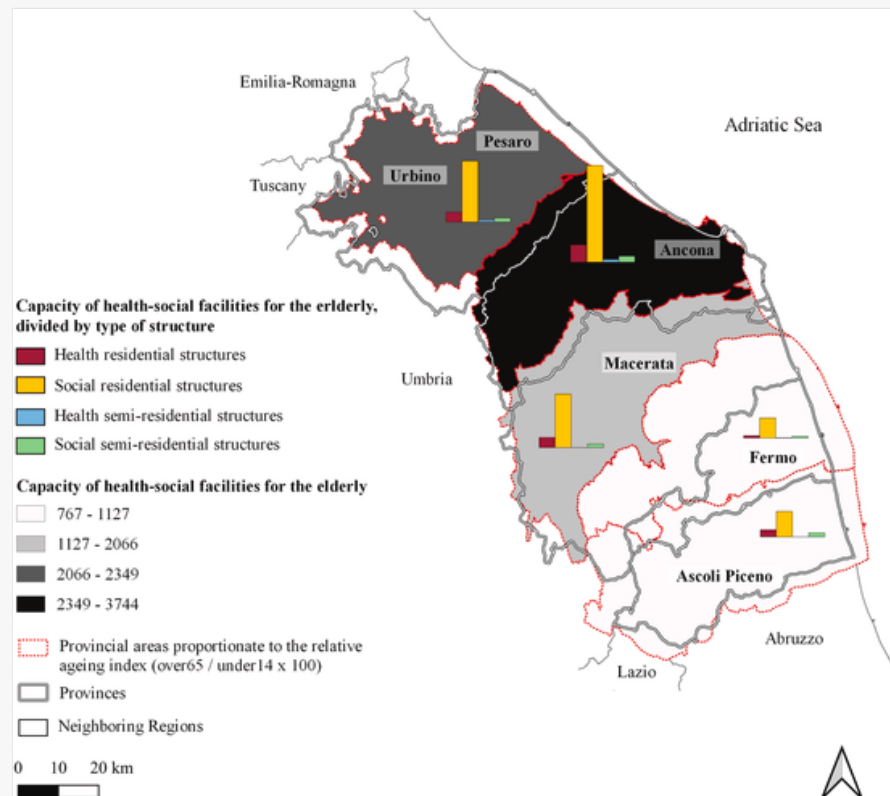
health semi-residential structures, the Day Centers for people with Dementia (DCDs) are intended to accommodate only occasionally elderly people with cognitive deficits but with a low level of behavioral disturbance and, among the social semi-residential ones, the Day Centers for the Elderly (DCEs) are intended for not self-sufficient elderly people with physical and psychological pathologies.

The distribution of the health and social structures in Marche for the year 2018 [46] shows a much greater capacity in the North-Central provinces of the Region (Fig. 5), with a peak of 3744 beds in the province of Ancona (7.9 beds per 1000 people), followed by 2349 in Pesaro and Urbino (6.5 beds per 1000 people), 2066 in Macerata (6.6 beds per 1000 people), 1127 in Ascoli Piceno (5.4 beds per 1000 people), and 767 in Fermo (4.4 beds per 1000 people). In terms of territorial distribution, the overall number of health and social structures are higher in the provinces of Ancona (134), Macerata (98), and Pesaro and Urbino (95), followed by Ascoli Piceno (45) and Fermo (41). Furthermore, considering the type of service provided, the most common structures are the social residential ones, particularly the PREs (152 facilities, 5185 beds) and the RHs (109 facilities, 1822 beds), followed at a considerable distance by the social semi-residential DCEs (42 facilities, 633 beds) and the health residential NHs (38 facilities, 1230 beds) (Fig. 6).


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Fig. 5

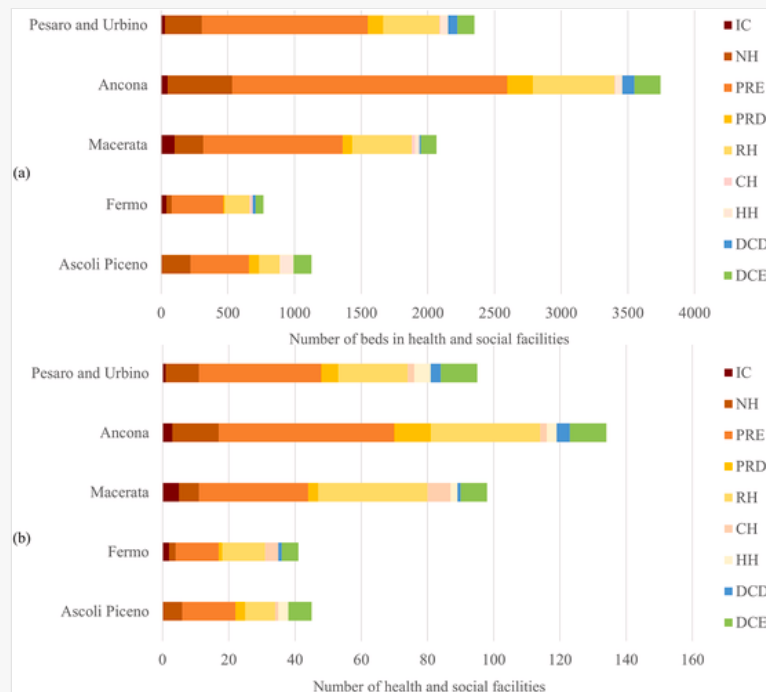


Capacity of the health and social facilities for the elderly by province and by type of structure. The area of the provinces is deformed proportionally to their aging index.

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alt-text: Fig. 6

Fig. 6




Distribution of beds in health and social facilities divided by type of service across the five provinces: (a) number of bed, (b) number of facilities. (Source: elaboration of data of the Regional Observatory of Social Policies, accessible at <https://www.regione.marche.it/>).

Data show two noteworthy patterns: a) the northern provinces tally the highest hosting capacity both in terms of total number of beds and number of beds per 1000 inhabitants; b) the northern provinces have the highest number of available structures. Therefore, the distribution of health and social structures in Marche is not proportional to the aging index (i.e., number of over-65s per 100 people), which in fact show an increasing aging index moving south (Fig. 5). If on the one side this anomaly could be explained by the distribution of the resident population (smaller in the south), or a symptom of unbalanced public health policies, yet on the other side, it may be simply the consequence of a socio-cultural tradition that sees the elderly being cared for in their own family. In support of this second hypothesis, the southerner provinces include the greatest percentage of health and social structures with semi-residential regime, which host the elderly only for a few hours during the day. On the other hand, the northerner provinces include proportionally more residential care facilities, which may be a consequence of a more urban lifestyle that sees the elderly transferred and taken care full time in these social and health structures. Such disparity of community life between the northerner and southerner provinces might have contributed to the highest diffusion of COVID-19 infections among the elderly residing in Marche. The elderly living in the in health and social facilities were more exposed to COVID-19 contagion; as documented, in the initial phases of the epidemic operators and employees, along with family members and visitors acted as vector for the diffusion of COVID-19 bringing the virus inside these “confined” facilities [48,49]. Eventually, the National Institute of Health passed rules that imposed progressive isolation of these residences from the surrounding context [50].

### 3.3 The infrastructural and urban systems

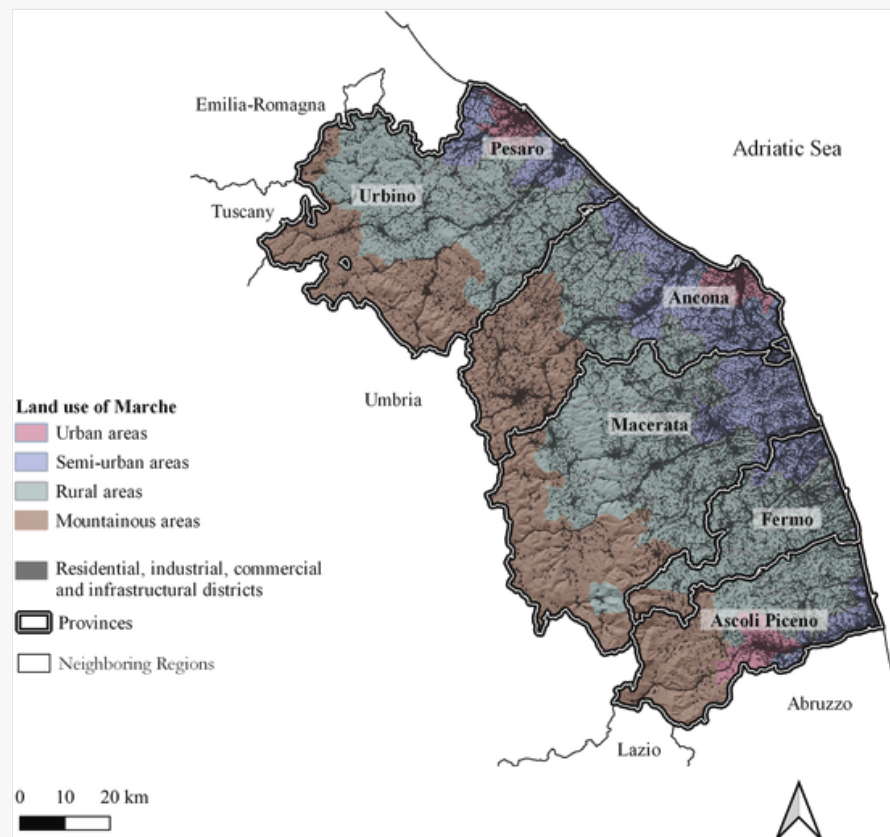
The built environment of Marche shows correspondences with its economic map, with a series of small centers distributed throughout the area. Such characterization results analogous over the five provinces. The urban landscape is that of a low-density residential development that is scattered outside villages, suburbs, and smaller cities. The

industrialized areas are narrow and clustered near the coastline, while the commercial strips are laid along arterial expressways leading into and out of villages, suburbs, and smaller cities. Activities in the five provincial territories gravitate around their major urban centers (from North to South: Pesaro, Ancona, Macerata, Fermo and Ascoli Piceno) (Fig. 7) [51]. In terms of land use, the Marche Region is divided in almost vertical bands of different where anthropization decreases moving from the eastern seaboard towards the Apennine mountains on the west (Fig. 7) [51]. These vertical bands, perpendicular to the coastline, are crossed by rivers near which are laid the roads connecting the main centers (near the coast) with the hinterland.

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alt-text: Fig. 7

**Fig. 7**




Land use of Marche, showing the distribution of the residential, industrial, commercial, and infrastructural built areas.

In general terms, then, it is reasonable to assume that where the rural tradition is more vivid and the centers are small and scattered, also due to the geomorphological features of the area, the relations, in social, economic and mobility terms, are limited to short distances, ensuing few exchanges of resources and people. This situation suggests that rural and less connected areas might have intrinsically prevented or slowed the COVID-19 contagion [52]. On the contrary, where urbanization and industrialization processes are more intense, so are the social interaction, and the probability of contagion [53]. It is also relevant to observe that the most developed areas, Urban and Semi-Urban Areas of Fig. 7, tend to be concentrated in the northern half of the Region, while the southern half is dominated by low density development, Rural and Mountainous Areas of Fig. 7. Simply put to a high social, urban, and economic dynamism along the northern seashores, is juxtaposed a more reserved and autochthonous lifestyle to the south, and such difference might have played a significant role with virus dynamics and diffusion of the pandemic in the Marche Region.

### 3.4 Mobility

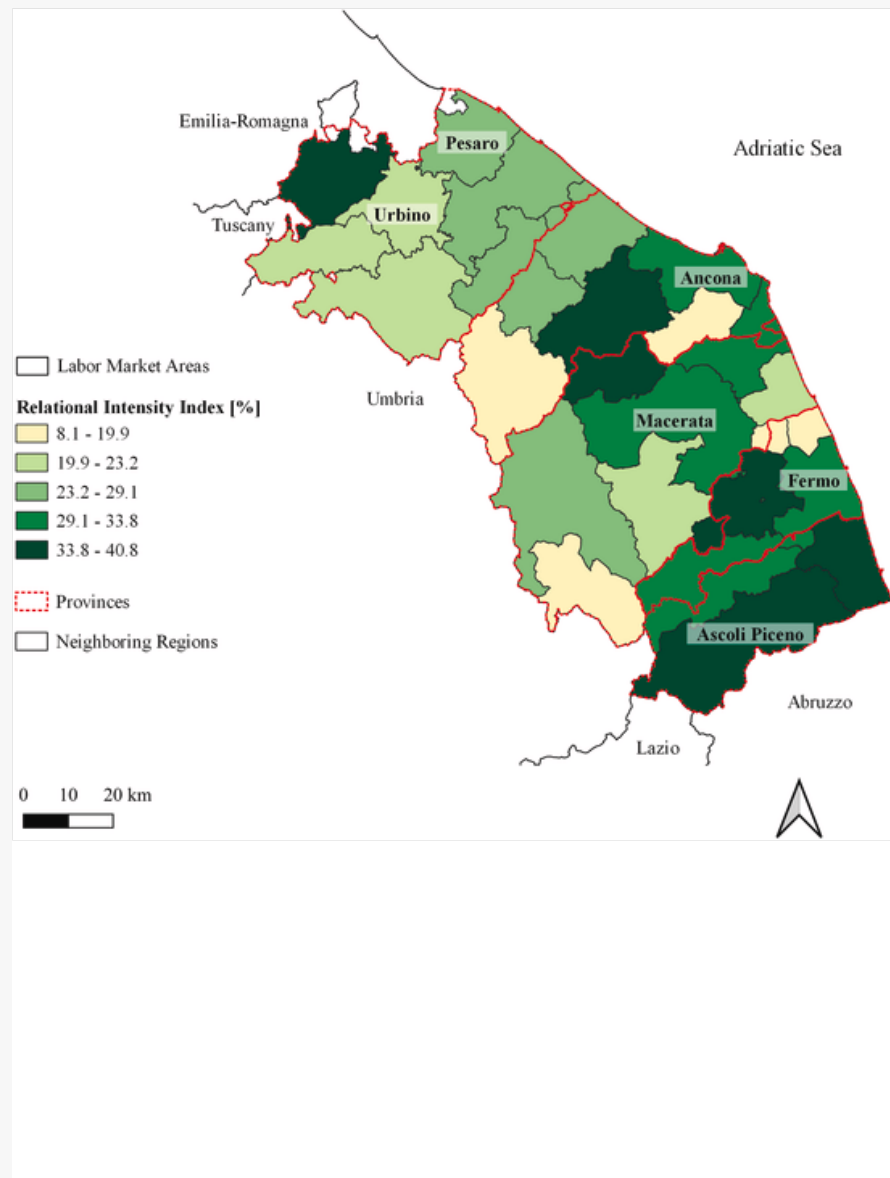
The interaction of individuals with the surrounding social and natural environment necessarily happens through various and complex forms of mobility. Indeed, mobility alters the community itself, favoring flow of people, goods and idea

inside and outside locales. In particular, people mobility is considered a key driver for the emergence and spread of diseases [54]. Consequently, exploring the way in which mobility re-defines boundaries might provide insights on how local communities interact with their surroundings and how this might have influenced COVID-19 spreading dynamics. For this analysis it was important gathering information about the Labor Market Areas (LMAs) and the associated Relational Intensity Index (RII) (Fig. 8). The Italian National Institute of Statistics (Istat) oversees the definition of the LMAs for the Italian municipalities and attributes the related RII values. In particular, a Labor Market Area assembles a group of neighboring municipalities within which the inhabitants reasonably fulfil the majority of their social and economic relations [55]. It is an area where social and economic needs are substantially met, independently of the administrative boundaries. The Relational Intensity Index is a percentage gauging the ratio of the fluxes of workers that connect different municipalities to the overall fluxes of workers occurring within a LMA [55]. The RII considers the interconnection for working reasons among municipalities, excluding inhabitants who live and work within the same municipality. Consequently, high values of RII (ideally closer to 100) translate into a high rate of exchanges across the municipalities of a LMAs.

 Images are optimised for fast web viewing. Click on the image to view the original version.

alt-text: Fig. 8


Fig. 8



Labor Market Areas (LMA) and Relational Intensity Index (RII) of the Marche Region. An LMA, delineated by black boundaries, is the area in which the population fulfill the majority of their social and economic relations. The RII, differentiated by the different color filling, ranks the intensity of the relations occurring inside an LMA. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

As a preliminary consideration, it should be pointed out that the boundaries of LMAs sometimes trespass the administrative ones. For example, in the northern section of the Region, some municipalities of Marche are associated to LMAs pertaining to the bordering Region of Emilia Romagna. Similarly, along both the North and the South borders, some municipalities belonging to Emilia Romagna or Abruzzo Regions, fall within Labor Market Areas pertaining to Marche. This setting highlights strong connections between Marche and the bordering Regions. These relations are particularly strong for the northernmost province of Pesaro and Urbino, deeply interconnected with the processes and dynamics occurring in the southern provinces of Emilia-Romagna. The differences between administrative and LMAs boundaries suggest that local communities' socio-economic footprint extends beyond the Regions' boundaries, creating a complex web of interconnections among locales. This is further confirmed when analyzing the trend of the Relational Intensity Index (RII). In the Marche Region it is possible to observe a general low RII in the western strip, suggesting that the mountainous areas are less able to satisfy the needs of the local communities, who therefore need to move far past the boundaries of their municipalities and Labor Market Area. Apart from this singularity, in Marche the RII shows progressively higher values moving southward. Because this index represents the rate of exchanges among a strict circle of neighboring municipalities, such growing values suggest that the liaison of the local populations with their closest surrounding area tends to become progressively stronger moving from North to South. The map in Fig. 8 Shows that in the southernmost areas of Marche residents are more able to fulfill the majority of their social and economic needs within their own Labor Market Area; the daily activities, including work, here is mostly performed within a small, circumscribed area, thus restraining the exchanges with the outside. Conversely, the scarcer exchanges among bordering municipalities within a LMA (suggested by low RII) seem to confirm a stronger tendency of northern residents to stretch over higher distances, beyond the Region's borders. This finding appear relevant to understand the pattern of diffusion of COVID-19 in Marche. Indeed, where there is a high mobility, the probability of virus transmission is high. Certainly, the economic connections of the northernmost provinces of Pesaro and Urbino with Emilia-Romagna and Northern Italy dangerously reduced the distance/buffer with some of the Italian Regions first ravaged by the COVID-19 pandemic [56].

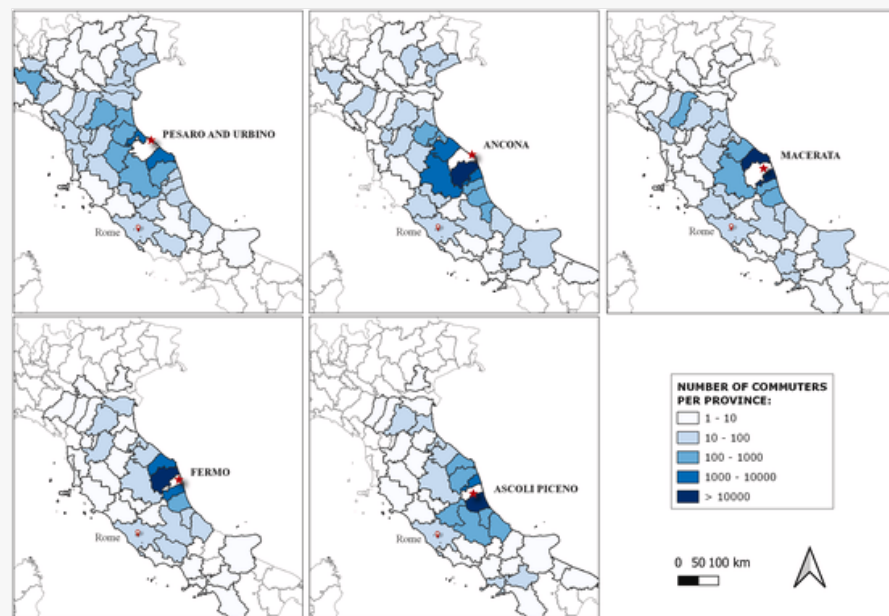
Another crucial characteristic of mobility, that could related to spread of the virus, is the daily commuting to work or school, especially through public transport [56]. In this regard, the spatial analysis of mobility of the residents of Marche shows widespread commuting across the five provinces and with the other Italian Regions [57] (Fig. 9). Commuter flows stretch in two primary directions, North-South and East-West, fitting the distribution of the Region's main urban centers and transport infrastructures (Fig. 7). The province of Pesaro and Urbino shows movements that exceed the administrative regional borders, especially with the neighboring northern province of Rimini (Emilia-Romagna Region) and the southern province of Ancona. These patterns most likely played a catalytic role in the North-South cascading spread of the COVID-19 contagion in Marche. Conversely, commuter patterns in the southern provinces of Macerata, Fermo and Ascoli Piceno show strong east-west movements along the river valleys cutting across the Apennine Mountain range. They show strong connection with the western Regions of Umbria e Lazio, whereas the connections with the northern Regions are weak. These described flows convey a regional intertwined mobility composed of threads [56], not necessarily originating from large urban centers, which gradually intersect each other, and reaching beyond the administrative boundaries. Reasonably, once found a point of entry in the Province of Pesaro and Urbino, the spread of COVID-19 in Marche rode along the Region's heterogeneous mobility patterns.

 Images are optimised for fast web viewing. Click on the image to view the original version.

alt-text: Fig. 9

**Fig. 9**





Daily commuting inward and outward the five Provinces of Marche: Pesaro and Urbino, Ancona, Macerata, Fermo, and Ascoli Piceno. The blue shades represent the number of commuters (for study or work) per examined province (indicated by a red star). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)


### 3.5 Tests of correlation

As explained in the methodology section, the influence of the above discussed socio-economic features on the pattern of diffusion of COVID-19 in the Marche Region have been further gauged through quantitative correlations. The Kendall's  $\tau$ -b coefficient of correlation was calculated to verify the possible link between the total number of infections and:

- total beds in health and social facilities,
- housing dispersion index,
- total extra-regional commuter flow to northern Italy.

These three values are used as proxies for elderly exposure to virus, aggregation, and movement of people (potential vectors of the virus vectors). Not surprisingly, [Table 3](#) show a trend of declining values moving from the northern to the southern provinces of Marche for “total beds in health and social facilities” and for the “total extra-regional commuter flow to and from northern Italy.” As visible in [Table 3](#), high values are found in the northern province of Pesaro and Urbino (2757 infections, 2349 beds, and 11,033 extra-regional commuters). Conversely, the “housing dispersion index” increases moving from the north to south. This trend was also expected; when the density and intensity of urbanization is higher (urban setting), the housing dispersion index is lower. Vice versa when the density and intensity of urbanization is lower (rural setting), the housing dispersion index is higher. As visible in [Table 3](#), the lowest value of the housing dispersion index was found in the province of Pesaro and Urbino (0.1673) while the highest (0.2868) was found in the southern province of Fermo.

Table 3

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Values of total number of infections, total beds available in the health and social facilities, the housing dispersion index, and the total extra-regional commuter flow to and from northern Italy, for each of the five provinces of Marche.

Province	Total number of infections	Total beds in health and social structures	Housing dispersion index	Total extra-regional commuter flow to and from northern Italy
Pesaro and Urbino	2757	2349	0.1673	11,033
Ancona	1857	3744	0.1716	903
Macerata	1154	2066	0.1972	372
Fermo	473	767	0.2868	91
Ascoli Piceno	290	1127	0.2345	75

Results of the Kendall's  $\tau$ -b test (Table 4) show a strong correlation between all tested pair of variables ( $\tau$ -b > 0.600 for all tests), confirming a potentially important role of the examined features in the diffusion of COVID-19 in Marche. Also, the statistical significance of all tests appears strong, except for the total beds ( $p = 0.142$ ). In this case, the limited dimension of the population might have weakened the results, though it is still possible to detect a specific influence of this variable, despite lacking a large probability of occurrence. In any case, the housing dispersion index and the extra-regional commuter flow exhibit a more solid picture. The housing dispersion index shows a strong, negative correlation ( $\tau$ -b =  $-0.800$ ,  $p = 0.05$ ) with the total infections, suggesting that the higher the dispersion, the lower the possibility of contagion. For the extra-regional commuter flow the correlation is even stronger ( $\tau$ -b =  $1.000$ ,  $p < 0.05$ ), meaning that a high mobility of daily commuters with the northern Italian Regions increased the probability of infections in the Marche Region.

alt-text: Table 4

Table 4

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Values of Kendall's  $\tau$ -b and related  $p$  for the correlation between the total number of infections and: total beds in health and social facilities, housing dispersion index, and total extra-regional commuter flow to and from northern Italy.

		Total beds in health and social facilities	Housing dispersion index	Total extra-regional commuter flow to northern Italy
Total number of infections	$\tau$ -b	0.600	$-0.800$	1.000
	$p$ value	0.142	0.05	<0.05

In synthesis, this quantitative analysis substantiated, also in statistical terms, the role of the discussed socio-economic features for the diffusion of COVID-19 in the Marche Region. To begin with, there seems to be a correlation, though not very robust, between the aggregation of elderly people in health and social facilities and the spread of COVID-19, possibly due to the interactions among guests, operators, and family members. Another feature that appeared solidly related to the diffusion of the virus was the local urbanization pattern; a scattered urban settlement appear to naturally isolate the communities. Such effect appeared particularly significant in the southern provinces of Marche. Finally, the role of commuter flows toward and from the northern Italian Regions strongly related with the contagion; such link was

possibly the virus' main access route to the Marche. As a matter of fact, the lower number of northbound commuters from southern Marche appeared to have protected the local population.

## 4 Conclusions

Italy was among the first countries severely affected by the COVID-19 pandemic, and the diffusion dynamics of the contagion were not homogeneous across its districts. This paper discussed, through qualitative and quantitative analysis, how a series of socio-economic factors, such as demographic aspects, public health and sanitary context, infrastructural and urban systems, as well as mobility patterns, might have affected the spread of the first wave of COVID-19 (over the period February–June 2020) within the Marche Region in central Italy. Results of this study shed some light on the key aspects that might have governed the diffusion of COVID-19 throughout Italy.

The spread of the new coronavirus in Marche began in the northernmost province of Pesaro and Urbino and followed a decreasing trend from North to South, somewhat replicating the patterns of diffusion at the Italian national level. Comparing data from 2019 to 2020, the study revealed a steep increase of mortality rate among the elderly people of Marche, especially in the richer northern province of Pesaro and Urbino. Among the factors that most likely contributed to this outcome was the type and organization of the social-health services offered to the elderly. For example, the Region's strong focus on the “social-health integration” of fragile guests with healthier ones, certainly positive in terms of social interaction for the elderly (inclusion vs. isolation), unfortunately became a source of vulnerability during the epidemic. Despite appearing “confined”, these retirement facilities are in fact in a continuous osmotic exchange with the outside World; the modality for family and friends' visits, as well as the employees switching procedures at the end of their work shifts, became conduits for the virus to get inside the facilities. To this extent, the elderly living at home with their family, practice more diffused in the South of Marche, were less exposed to the virus, especially during the 2020 quarantine periods when the entire family was confined at home.

Another reason for the North-to-South direction of the contagion appeared to be the Region's land use. The built environment of Marche is the result of an economic framework based on small enterprises scattered throughout the region. This condition translates into deep and rooted interrelations among people and their surrounding environment. Where the rural culture and framework is still vivid, especially in the southern and inland districts, strong bonding appear to limit exchanges and mobility outside the locales, bestowing them an inherent form of isolation and protection from the dynamics of the COVID-19 contagion. Reverse processes were true for the other half of Marche, the coastal strip, and the industrialized North, characterized by greater interconnections with the bordering territories heavily affected by COVID-19. Here, a socio-economic paradigm shifted towards wider circles and longer distance interactions increased the probability of contagion.

At last, and perhaps more importantly, the Region's mobility patterns played a crucial role in steering the virus diffusion, especially the daily commute for work or study, which direction and intensity appear consistent with those of the contagion. Results showed high mobility and exchanges, especially directed northward, and over a longer distance in the center and northern provinces of Ancona and Pesaro and Urbino. Conversely, the populations of southern Marche maintained stronger interrelation with their labor market area, with which they were able to fulfill most of their socio-economic needs.


In conclusion, the results of our spatial and statistical analysis highlighted the most important local socio-economic characteristic that significantly affected the spread dynamics of COVID-19 in the Marche Region. These findings provide important insights calling for new ways of individual and community interaction to lower vulnerability and increase resilience to infectious diseases. We hope to have contributed new insights to the ongoing debate and lessons learned, highlighting issues and opportunities, better to manage future epidemic emergencies.

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## Declaration of competing interest

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 The corrections made in this section will be reviewed and approved by a journal production editor. The newly added/removed references and its citations will be reordered and rearranged by the production team.

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## Highlights

- Boundary regions in the first wave of COVID-19 in Italy.
  - North-South trend of COVID-19 diffusion in Italy.
  - Socio-economic factors appear to have facilitated COVID-19 spread in the Marche Region.
  - The study provides significant insights for future prevention of pandemic diffusion.
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