Geographical and Sex Heterogeneity in Temperature Related Deaths in Europe

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Introduction

Climate change-induced increases in summer temperatures present new health risks for affected populations. Over the past decade, Europe has experienced record-breaking heatwaves, most notably in 2018, 2020, and 2022. Mean and maximum temperatures, frequencies of warm days and nights, and heatwaves have increased since 1950, while the corresponding cold indices have decreased (Forster et al., 2023). The human body can cope with exposure to temperature extremes via thermoregulatory functions. However, exposure to extremes temperatures for prolonged periods of time endangers human health and determines excess deaths in the affected population (Barreca et al., 2016). Numerous studies report important temperature-related mortality effects in populations emphasizing geographic heterogeneities in vulnerabilities in the population (Díaz et al., 2015; Tobías et al., 2021).

Although it is unequivocal that changing surface temperature affects human health, it remains challenging to accurately estimate the scale, the impact, and the geographical disparities of many temperature-sensitive health risks. Importantly, the lack of comprehensive scientific knowledge about how extreme temperatures impact human mortality in different parts of Europe makes it difficult to identify vulnerable locations where policy interventions are necessary.

In this article, we investigate the temperature-mortality relationship in Europe leveraging a novel dataset comprising monthly deaths from 2014 to 2022 on total death counts at a fine-grained territorial unit (NUTS3). Consequently, we contribute to the existing literature providing estimates on the effect of temperature on mortality on individuals aged above 65 in Europe in recent years and at finer geographical resolution. Additionally, we analyze geographical differences in vulnerability to cold and heat to better understand and identify, among the European areas, the most at risk. Although it is well-identified that people aged above 65 are most prone to temperature-related mortality, there is no academic consensus on the effect of sex (Folkerts et al., 2022). Ultimately, the present study examines if sex differences in temperature-related mortality exist and if they are similar across the geographical regions in the European Areas.

Conceptual Framework

Extreme Temperature and Mortality

Global literature on extreme temperature and human mortality identifies cold-extreme temperatures as the most impactful for human health (Chen et al., 2018; Zhao et al., 2021). This general trend is due in part to the fact that cold temperatures facilitate the spread of flu and virus, increasing the mortality rates in the colder months (Son et al., 2019). Heatwaves become increasingly investigated from the heatwaves of summer 2003, which generated 70.000 additional deaths across Europe (Robine et al., 2008). July 2023 sees multiple global temperature records broken, including ocean temperature (Copernicus, 2023). Among the effects modifier of temperature-related mortality identified by the academia can be mentioned: demographic characteristics, socio-economic factors, geographical location, and climate aspects. Researchers found, for both heat and cold extreme temperatures, mortality is most marked among people above 65+ years old (Masselot et al., 2023; Raimi, 2021). Instead, it has to be clarified the relationship between sex and mortality-related temperature (Van Steen et al., 2019). Some studies have identified woman as the most vulnerable to heat and cold (Donaldson et al., 2019; Folkerts et al., 2022), other have identified man at higher risk (Achebak et al., 2019), other have found no significant differences (Marí-Dell'Olmo et al., 2019). Examining the socio-economic conditions, the major risks for heatwaves mortality are considered: the absence of air conditioning, live in a high-density area, live lonely, have a low education level, income, and an adverse health status (Bakhtsiyarava et al., 2023; Chen et al., 2018; Liu et al., 2020). In particular, research conducted in South Korea found a U-shaped association between population density and heat-mortality risk. The highest risk was evident in rural populations, while in urban areas the risk increased with increasing population density (Lee et al., 2022). The risks for cold-related mortality are mainly identified in rural areas, where individuals may have limited access to healthcare facilities, heating infrastructure, and difficult financial situations. Indeed, rural areas often house more vulnerable populations, such as the elderly and very young (Lal et al., 2011; Zhang et al., 2020). Nevertheless, urban areas are not immune to the risks associated with cold-related mortality, as exemplified by findings in Scotland (Wan et al., 2022).

Although a lot of studies have been conducted, only less than 25% take simultaneously into account demographic characteristics, socio-economic factors, geographical location, and climatic aspects (Cole et al., 2023). This can be considered as a great gap in literature.

Geographical differences

Climate and temperature risks diverge across the World spatially, but also in terms of hazards, exposure, vulnerability, and capability to adaptation (European Environment Agency. & European Topic Centre for Air Pollution and Climate Change Mitigation., 2018). There can be various reasons why some geographical areas are more affected than others by mortality caused by temperature extremes, which are becoming more and more extreme. Firstly, in some regions the frequency, intensity, and duration of heatwaves or cold spells is more severe (Xu et al., 2016). Secondly, every country has a specific demographic structure that can be less or more vulnerable to extreme temperatures (Muttarak et al., 2016). For example, the European area is characterized by a high population magnitude and an aging demographic structure: on 1st January 2023 448,4 million individuals lived in the EU, of which 98 million are over 60 years old (Eurostat, 2023). Last, but not least, some countries are less adapted or have fewer tools to adapt to extreme temperatures (Carleton et al., 2022). These differences exist not only between countries, but also within countries. Hence our choice to operate at NUTS 3 level, to better capture differences between provinces of Europe. Our paper aims to investigate the heterogeneity in the European country considering there is a lack of paper into recent data that take into account geographic, demographic and socioeconomic variation at NUTS 3 level, that consider both urban and rural area. Our choice fell on Europe also because average warming have increased at more than twice the global average over the past 30 years (*Temperatures in Europe Increase More than Twice Global Average*, 2022). The Intergovernmental Panel on Climate Change (IPCC) defined the European area as a hotspot for multiple risks of increasing temperatures and extreme heat (Intergovernmental Panel On Climate Change (Ipcc), 2023). Specifically, the IPCC identifies the largest winter warming in Northern-Europe and East-Europe, and largest summer warming in the Mediterranean area (Sánchez et al., 2004). From the Sixth Assessment Report (AR6) released in 2022, the IPCC considers for the first time the Mediterranean region as an entity, started dedicating an entire chapter to investigate the multiple mechanism which occurring in this Area (Ali et al., 2023). We also consider it equally important to carry out the analysis for the entire Mediterranean Area, not only for the European ones. Increasing temperatures and more intensive heatwaves in the basin threaten human well-being, economic activities, and many ecosystems on land and in the ocean. In future studies we aim to include all the Mediterranean countries, not only the European ones, to better understand possible changes in temperature-related mortality, trend, seasonality and have a more complete view.

Data, Variables, and Methods

Data and variables

We leverage four main sources of data. The death counts are provided by Eurostat (for all European countries. Specifically, this data counts deaths by week, sex, 5-year age group and NUTS3 region (DEMO_R_ MEEK3 grouped by month). We consider the data particularly valuable as it allows us to measure the impact on the population in rural areas compared to most of the existing studies carried out that consider only the urban areas, due to the magnitude of population at risk and the availability of data (Gasparrini et al., 2015; Guo et al., 2016). Moreover, we sum the weekly counts to monthly values to make our estimates comparable with previous studies (Barreca et al., 2016). Secondly, we collect data on yearly population counts provided by Eurostat to construct person-years of exposure (DEMO_R_PJANGRP3). In particular, the EU Database offers the counts of population on 1 January by age group, sex and NUTS3 region and we divide these values by the 12 for the months of exposure. Thirdly, the mortality data is matched to the daily temperature supplied by E-OBS (Copernicus Data Store), aggregated at the NUTS3 - monthly level, for the 2014 – 2022 period. The E-OBS daily gridded meteorological data for Europe derived from in-situ observation downloaded, provides ensemble mean information with a spacing of 0.1° x 0.1° from 2011 to 2022 at 25.0e version (Copernicus Climate Change Service, 2020). Specifically, for the construction of temperature exposures, we utilized the daily average temperature recorded in each NUTS3 region. The bins of daily average temperature were created based on percentiles derived from the temperature distribution specific to each NUTS3 unit over the study period and count the number of days in a month and NUTS3 area that fall within a temperature range. We established 9 temperature bins and these include days with temperature: 1) equal to or below the 1st percentile; 2) between the 1st and 5th percentile; 3) between the 5th and 10th percentiles; 4) between the 10th and 25th percentiles; 5) above the 25th percentile but below the 75th percentile; 6) between the 75th and 90th percentiles; 7) between the 90th and 95th percentiles; 8) between the 95th and 99th percentiles; 9) above the 99th percentile. The category encompassing temperatures between the 25th and 75th percentiles is considered the comfort zone and will be excluded from the analysis. Lastly, from the assumption that climate risk diverges across Europe not only spatially, but also in terms of hazards, exposure, vulnerability, and capability to adaptation (Field et al., 2014), we chose to analyze the European data using 8 climatic regions defined by the European Environment Agency (EEA) developed through the

RESIN project (H2020) (*RESIN Risk Typology — European Environment Agency*, 2020). The "European Climate Risk Typology" subdivision, accorporate the NUTS3 regions which share similar human risk characteristics concerning the climate hazards, the levels of exposure of population and infrastructure, vulnerability of the population, GDP and adaptive capacity of the areas (Carter et al., 2018).

Methods

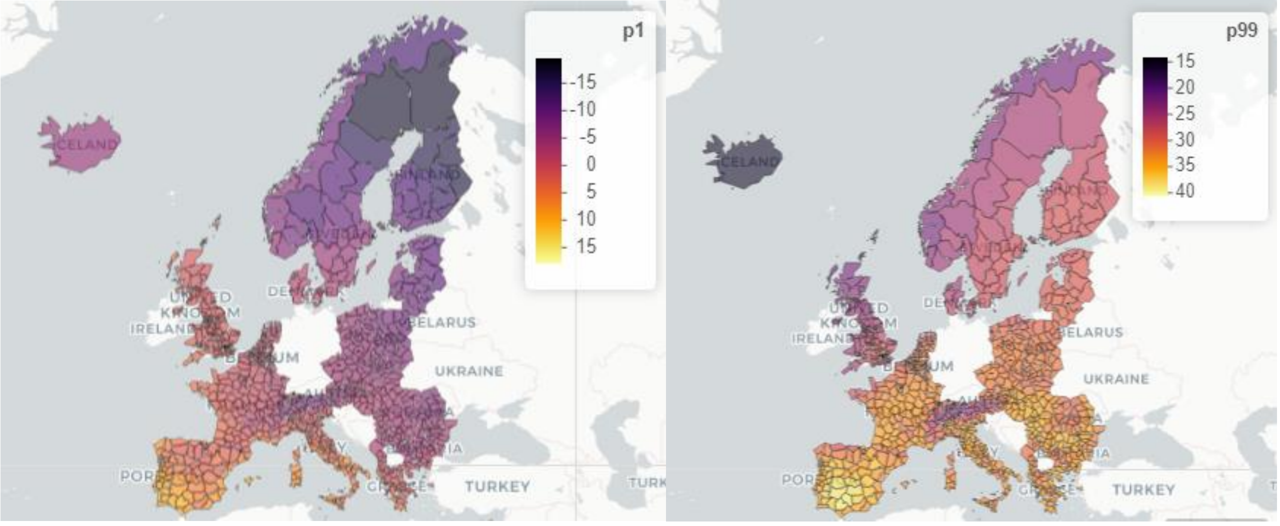
In our analytical approach, we employ a Poisson regression with Fixed Effects described in Equation (1):

$$1.\quad \log(Y_{nt}) = \log(E_{nt}) + \sum_j \Theta_j TEMP_{nt}^{j} + X_{nt}\beta_{nt} + \alpha_{nw} + \delta_{yw} + e_{tn}$$

In Equation (1), Y_{nt} is our outcome variable, the death count in month-year t and Nuts region n. E_{nt} is an offset term capturing the exposure to the risk of death in the NUTS3 region n and month-year t. *TEMP* captures the number of days in temperature range j in month-year t and NUTS3 region n. The coefficients Θj is the effect on mortality of exchanging one day in the comfort zone for a day in the j-th bin. We included into the analysis as control variables: the solar radiation, the relative humidity, the wind speed, the gender, and the age groups, identifiable in the formula (1) by the covariates $X_{nt}$with associated coefficients β_{nt}. Also, we added α_{nw} to capture NUTS3 region by month fixed effects and δ_{yw} to account for year by month fixed effects. In the analysis, we cluster standard errors at the NUTS3 level.

Preliminary Results

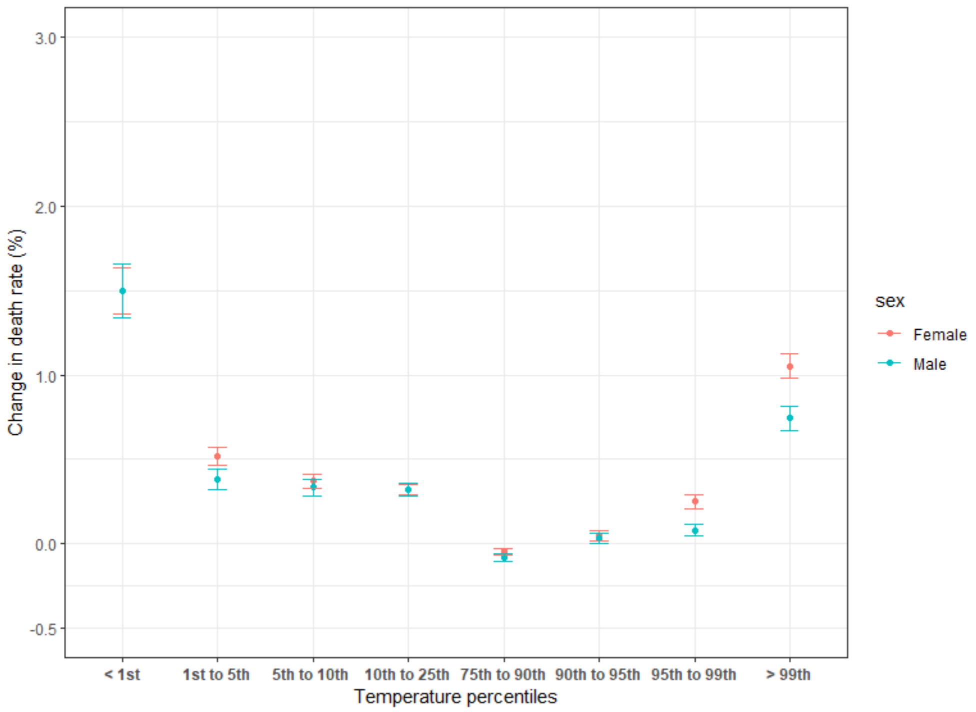
Figure 1. 99th and 1st percentile of temperature in the Nuts3 regions



Note: the figure presents the 99th and 1st percentile in each NUTS3 temperature distribution in the study period, 2014-2020.

In figure 1, we show the 99th and 1st percentile in each NUTS3 region in our period of analysis. We can observe the expected regional differences. Notably, in Spain the 99th percentile is in several regions above 35°C and in Sweden the 99th percentile is mostly below 30°C.

Figure 2. Extreme temperature and mortality in Europe (65+ per sex)



Note: in the figure we present results of the model exposed in Equation (1). 95% confidence intervals.

In figure 2, we expose the results of the model based on Equation (1). We observe a U-curve in the relationship between heat and cold exposure. Specifically, considering the sex differences, the mortality rate increases by 1.5% both for men and women for extreme cold exposure (<1st percentile), the mortality rate seems to be different, with an increase in death rate by 1.05 % for women and 0.74% for men for extreme heat (>99th percentile).

In figure 3, we analyze the interaction between temperatures and 3 risk climatic regions as preliminary case studies: Southern Europe, Urbanized Europe, and Northern Europe (defined by the European Environment Agency (EEA) through the RESIN project (H2020)). In general, we observe the extreme cold (1st percentile) to be the most detrimental. This result is in line with the literature and previous studies. Nevertheless, the impact of extreme heat (>99th percentile) seems to exacerbate sex differences more than extreme cold temperature (<1st percentile).

Figure 3. Extreme temperature-related mortality in Southern Europe (65+ by sex)

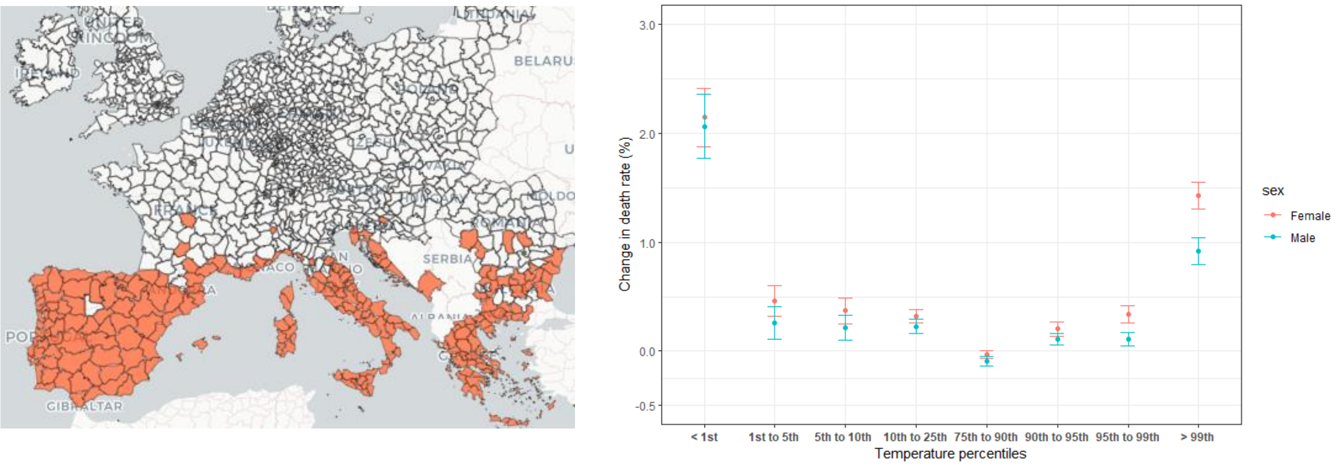


Figure 4. Extreme temperature-related mortality in Urbanized land of Europe (65+ by sex)

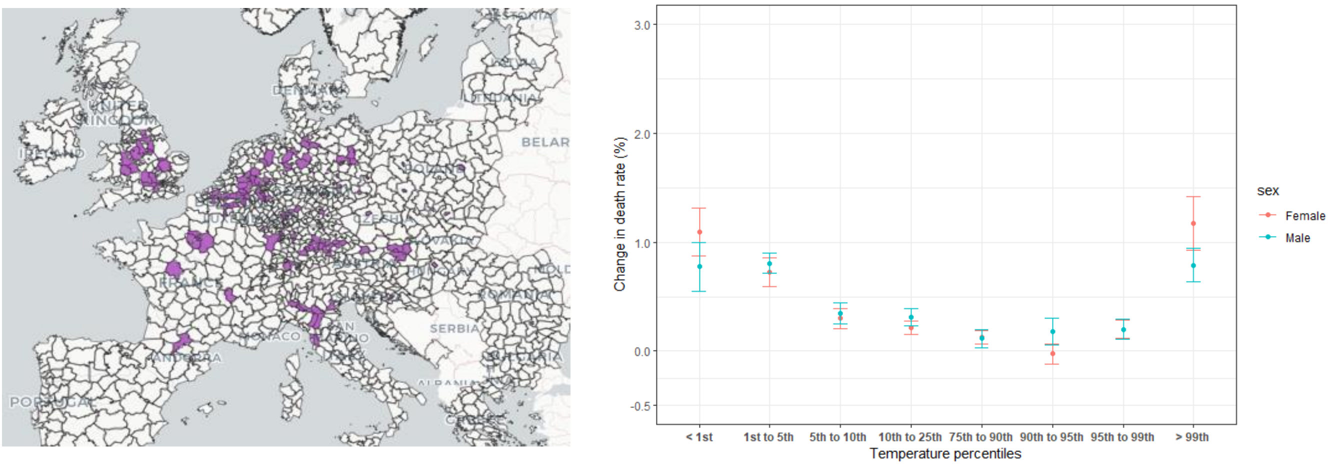
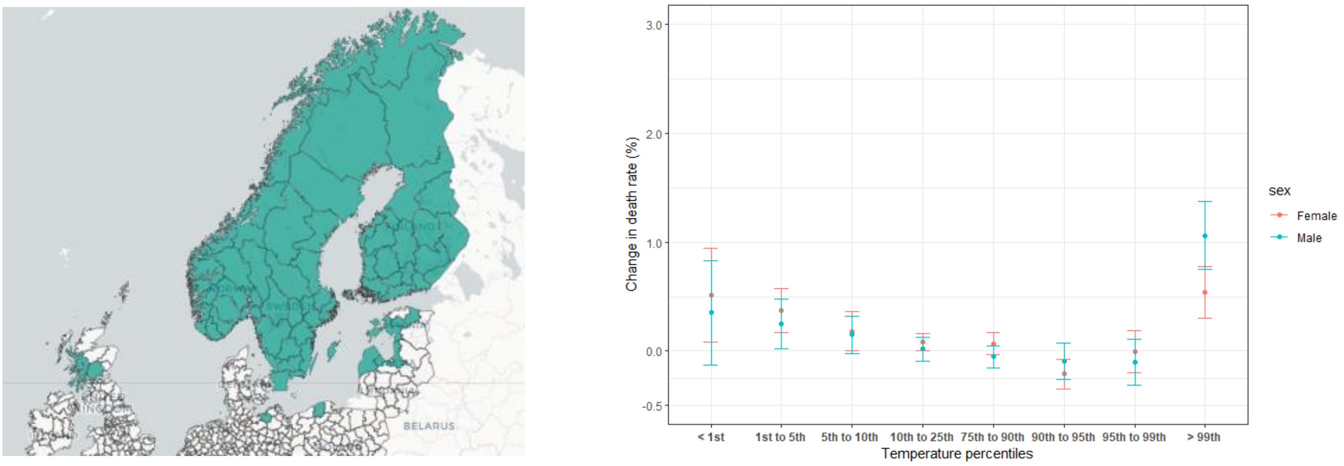


Figure 5. Extreme temperature-related mortality in Northern Europe (65+ by sex)



Note: the figure presents the results of Equation (1) run separately by climatic regions. 95% confidence intervals.

Discussion and Further steps

The geographical subdivision of southern land provided by EEA is characterized by high climate risks such as high temperatures, droughts, wildfires, and floods. It is a densely populated area, with old infrastructure, and a GDP that is lower than the European average. The estimated temperature-mortality curve of southern land displayed by sex, show an increase in mortality rate of 2.06% for men and 2.14% for women for extreme cold (<1st percentile), while for the extreme heat there is a significant discrepancy between women and men with an increase in mortality rate of 0.9% for men and 1.42% for women (>99th percentile). The urbanized European land provided by the EEA is a high-density area characterized by climatic hazards such as floods, heavy precipitation, and heat island effect. This area has critical infrastructure but also has a high innovation level. In the period investigated the change in death rate show for both cold and heat temperatures a higher increase in death rate for women than for men. The northern Europe subdivision is a low-density area with green cities and small rural settlements, characterized by climatic hazards such as coastal hazards, heavy precipitation, high and cold temperatures. This area has critical infrastructure but also a high innovation level. The estimated temperature-mortality curve seems to show that northern countries are more adapted to dealing with cold temperatures than for heat. Indeed, we see a higher pick in extreme-heat temperature. Specifically per sex, for the extreme-cold, there is almost no differences between women and men, instead for the extreme hot temperatures there is an increase in death rate of 1% for men in respect of 0.54% for women.

Some considerations are necessary: our model is able to capture through the offset term E_{nt} the magnitude of population per sex, consequently the general occurrence of more women than men over the age of 65, but it does not consider the health status of the individuals. As the literature acknowledges, specifically women that reach higher age, are in a fragile health condition and alone as widows (Case & Paxson, 2005). Furthermore, individuals of advanced age with health problems (which are especially women) tend to stay close to the city and/or hospitals (Steptoe et al., 2013). This can partially explain the higher increase in death rate for women than for men in the southern and urbanized subdivision considered. Concerning the northern land, the discrepancy between the percentage of men and women at an advanced age, start to be meaningful from the age category of 70, slightly later than the Sothern (United Nations, 2023). This can partially clarify the higher increase in death rate for men than for women. Moreover, we denote the southern Europe exhibits the higher increase in death rate at cold temperatures. This prompts some new inquiries: is it due to the lack of heating or energy poverty that is particularly widespread in Eastern, Central, and Southern Europe (Bouzarovski, 2014)?

Furter analysis will be conducted to better understand the mechanisms which can determine sex and geographical heterogeneity in Europe. In particular in future steps, we will leverage information on death counts by age categories as well as gender, analyzing more specifically the geographical subdivisions, to test if our results on the geographical heterogeneities observed were biased by differences in the population structure between European countries. This analysis will allow us to explore which age group with correspondent gender are the most vulnerable to the exposure to heat and cold, and in which area. Furthermore, we will add control variables on the socioeconomic characteristics of each NUTS3 region collecting data on GDP per capita and population density.

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