A Tool for Evaluating Depopulation Policies: Age-Sex Population Projections of Spanish Rural Areas (2022-2050)

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Highlights:

1. Cohort-component population projections.
2. Policy evaluation in order to address possible demographic challenges.
3. Identify depopulation tendencies in Spanish rural areas.

Abstract: Rural depopulation in Spain, reflecting broader European trends, presents a complex challenge with far-reaching economic, social, and ecological consequences. Population decline and ageing, compounded by imbalanced sex ratios characterised by masculinisation, contribute to a shrinking labour force, increased pressure on healthcare systems, and diminished generational renewal. Despite numerous policy attempts over past decades, these trends have persisted. Recently, Spain launched a more ambitious initiative, the Demographic Challenge, aimed at reversing rural depopulation. This study uses the cohort-component model to construct counterfactual demographic projections—unaffected by the new policy—as a benchmark for future evaluation of the age-sex distribution of the population residing in Spanish rural municipalities. Estimates are obtained by instrumentally projecting demographic rates under two alternative frameworks: constant rates and ARIMA-based models. Results from both approaches anticipate continued population decline and ageing in rural areas by 2050, with a progressively narrower base in the age pyramid if current trends are not reversed. These results underscore the urgency of effective policy interventions to address the ongoing demographic crisis in rural Spain.

Keywords: Cohort-component projections; Demographic Challenge; Policy evaluation; Rural depopulation.

Una herramienta para evaluar políticas de despoblación: proyecciones demográficas edad-sexo de la España rural (2022-2050)

Ideas clave:

1. Proyecciones demográficas por el método cohorte-componente.
2. Evaluación de políticas para afrontar los posibles desafíos demográficos del siglo XXI.
3. Identificación de futuras tendencias de la despoblación rural en España.

Resumen: La despoblación rural en España, en línea con tendencias más amplias observadas en Europa, constituye un desafío complejo con consecuencias económicas, sociales y medioambientales. El declive y envejecimiento de la población, agravado por una proporción de sexos desequilibrada, caracterizada por la masculinización, contribuyen a la reducción de la fuerza laboral, una mayor presión en el sistema sanitario y a una limitada renovación generacional. A pesar de los numerosos intentos de política pública implementados en las últimas décadas, estas tendencias han persistido. Recientemente, España introdujo una iniciativa más ambiciosa, el denominado Reto Demográfico, con el objetivo de revertir la situación. Este estudio utiliza el modelo cohorte-componente para construir proyecciones demográficas contrafactuales, no afectadas por las nuevas políticas, que sirvan como referencia para futuras evaluaciones de las distribuciones por edad y sexo del conjunto de la población residente en los municipios rurales españoles. Las estimaciones se obtienen proyectando, como paso intermedio, las tasas de variación de los componentes demográficos bajo dos marcos alternativos: tasas constantes y modelos ARIMA. Los resultados con ambos enfoques apuntan a una continuidad del declive demográfico y del envejecimiento de las áreas rurales hasta 2050, con una base de la pirámide de población progresivamente más estrecha si no se revierten las tendencias actuales. Estos resultados ponen de relieve la urgencia de implementar políticas eficaces para hacer frente a la crisis demográfica que afecta al medio rural español.

Palabras clave: Proyecciones cohorte-componente; desafío demográfico; evaluación de políticas; despoblación rural.

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1. Introduction

According to the Spanish Ministry of Territorial Policy, between 2001 and 2018, a total of 5,120 Spanish municipalities experienced population decline, with 4,000 of them having fewer than 1,000 inhabitants (Ministerio de Política Territorial y Función Pública, 2020). Almost all municipalities with fewer than 1,000 inhabitants are experiencing depopulation and face significant challenges in returning to their former population levels. Indeed, in 2022, according to the Spanish National Statistical Agency (INE), just 3 % of the Spanish population lived in municipalities with fewer than 1,000 inhabitants (INE, 2022), even though these areas accounted for 61.3 % (4,991 in total) of all Spanish municipalities and covered over 40 % of the Spanish territory.

Depopulation in Spanish rural areas is characterised by sustained out-migration, and a masculinised and ageing population. Young people often migrate to larger municipalities in search of better labour and educational opportunities (Recaño, 2017), with women being more likely to leave, resulting in a higher proportion of male residents (Camarero and Sampedro, 2016; Serrano and Pitarch-Garrido, 2023). This demographic imbalance negatively affects fertility rates and population renewal, leading to communities that are primarily composed of older residents.

Ageing and depopulation not only alter the demographic composition of rural areas but also have economic, social, and environmental repercussions. The labour force shrinks while demands for healthcare and dependency support increase, posing significant challenges to social inclusion and exacerbating regional inequalities (Gómez-Valenzuela and Holl, 2024). Rural residents often express dissatisfaction with the lack of services, generating frustration and potentially influencing decisions about whether—and where—to move. Furthermore, as the primary sector remains the main economic foundation of rural regions—where most livestock farms are concentrated—ageing and depopulation often leads to the abandonment of agricultural activities and land, with ecological consequences such as increased soil erosion, loss of biodiversity, and desertification (Rodrigo-Comino et al., 2022).

It is not surprising, therefore, that at the beginning of the 21st century, social movements began to raise awareness about depopulation in certain Spanish provinces. Examples include *Teruel Existe*, which originated as a citizens' committee seeking to address inequalities in the distribution of resources in the province of Teruel, and *Soria ¡Ya!*, another grassroots movement that emerged to highlight the lack of services and advocate for increased investment in the province of Soria. Today, both are officially registered as political parties. Initiatives to address the risk of depopulation initially began at the smallest territorial level, as local and regional governments were often the first to understand the scope and urgency of the problem. However, designing and implementing effective policies at such a granular territorial level can be challenging, especially given that higher-level government institutions typically have greater resources to address these risks (Sáez et al., 2016). As a result, initiatives have been developed at both European and national levels.

The European Union has launched medium- and long-term strategies to reverse the trend of depopulation. Examples include the rural development programme *LEADER*—which began as a pilot project in 1991 and was integrated into the EU's broader policy framework in 2007 (Peralta, 2017)—and the *Smart Villages* initiative, introduced in 2017 with the goal of revitalizing rural services by boosting digital and social innovation (ENRD, 2018). The Spanish government started in 2008 to regulate the composition, functions, and operation of different commissions and councils related to depopulation in rural areas (Tornos, 2021). Nearly a decade later, in 2017, the project known as *Demographic Challenge* (*Reto demográfico* in Spanish) was launched, but it was not until 2019 when policies started to be developed, leading to the creation of the *National Strategy to Address the Demographic Challenge* and the approval of 130 measures to tackle the issue. This programme aims to ensure that small villages are included in a green, digital and inclusive recovery, with the objective of eliminating inequalities between rural and urban areas and promoting greater territorial cohesion across Spain. Both European and national strategies represent ambitious initiatives.

Given the importance of both policy design and continuous evaluation, this research aims to establish a benchmark against which the effectiveness of depopulation policies can be assessed. To this end, the study extrapolates and projects current demographic trends to produce age-sex population forecasts for the Spanish population living in municipalities with fewer than 1,000 inhabitants, treating this population as a single aggregate. That is, projections are produced at an aggregated level rather than separately for each municipality. These forecasts can serve as a reference baseline for future analysis, enabling comparative examinations to evaluate the effectiveness of the implemented policies in the mid-to-long term. By tracking changes in population composition over time, it will be possible to assess whether these policies successfully mitigate depopulation or whether further social research is needed to better understand its underlying causes.

Specifically, this study projects age-sex population composition of Spanish rural areas up to 2050 using data from 2010 to 2021, defining rural areas as municipalities with fewer than 1,000 inhabitants.

It should be noted that the definition of *rural area* varies across institutions and contexts. For instance, the Spanish Ministry of Agriculture defines rural areas as municipalities with fewer than 30,000 inhabitants and a population density below 100 inhabitants per square kilometre (Subsecretaría General de Análisis, Coordinación y Estadística, 2021). This encompasses 82 % of all municipalities in Spain. Eurostat and INE rely on the Degree of Urbanisation (DEGURBA) classification, which defines rural areas as municipalities where more than 50 % of the population resides in one-square-kilometre grid cells classified as non-urban. A cell is considered rural if it has fewer than 300 inhabitants per square kilometre and a lower urban and service development. This definition captures 99.45 % of municipalities with fewer than 1,000 residents but also includes approximately 1,800 municipalities with populations above this threshold. Alternative definitions have also been proposed. Goerlich et al. (2016) suggest combining densities with minimum population thresholds, land use and accessibility to identify rural areas, while Recaño (2017) proposes characterise typologies of rural areas employing multivariate statistical methods. In this study, we adopt a more restrictive definition based on municipal population size.

The data used in this project consist of both public statistics and detailed microdata obtained from INE, following the signing of an ad-hoc confidentiality agreement with advance payment. Although individual data cannot be shared, aggregated projections can be, as available in the supplementary material. The microdata include population stock and birth statistics from 2010 to 2021 and migration flows from 2012 to 2021. Population stocks are combined with estimates of age-specific fertility and migration rates, derived from INE's microdata, and projections of death rates by sex and single year of age, as obtained by Sifre-Armengol et al. (2025). Fertility and migration rates for municipalities with fewer than 1,000 inhabitants are obtained from microdata, while death rates correspond to municipalities with fewer than 10,000 inhabitants—the smallest population group for which detailed public statistics of mortality probabilities are available in Spain, and thus the closest proxy to rural areas.

We would like to emphasize that population projections using municipal level data, particularly for municipalities with fewer than 1,000 inhabitants, are rarely produced. Projections are typically conducted at the national level (for example, see the World Population Prospects (WPP) website, https://population.un.org/wpp/), benefiting from comprehensive datasets and larger populations, which lead to more robust conclusions. However, considering that small municipalities in Spain account for nearly 1.5 million people and face a significant risk of ageing and depopulation, it is relevant to investigate these areas more specifically.

The rest of the paper is structured as follows. Section 2 provides theoretical and empirical background, with a focus on Spain. Section 3 describes the data used and their sources. Section 4 details the methodology employed for producing the population projections. Section 5 analyses the recent evolution of mortality, fertility and migration flows in rural Spain. Section 6 presents and analyses the main outcomes. Section 7 concludes, summarising the main results, discussing limitations and suggesting future research directions. Supplementary material accompanies the paper, providing the complete list of municipalities with fewer than 1,000 inhabitants considered in this study, along with the population projections disaggregated by age, sex, and year.

2. *Background*

Population projections are valuable tools for decision-making across various fields, including education, healthcare, regional policy, and insurance (Diamond et al., 1990). The effectiveness of such decision-making processes is closely linked to data quality, with finer levels of disaggregation generally being preferable (Keilman, 2001). However, working with smaller populations typically implies a limited number of observations, which increases variability and uncertainty in the estimates. For this reason, population projections are most commonly produced at the national level. This limitation is also present in Spain, where the smallest units provided by INE for population projections correspond to provincial capitals (González et al., 2015), and although some regional statistical institutes (e.g., IDESCAT in Catalonia, IVE in the Valencian region, or ICANE in Cantabria) generate projections at smaller levels, including municipalities, they typically lack detailed age- and sex-specific breakdowns (Parra-Rodríguez and Campo-Moreno, 2017). Against this background, this research focuses on generating single-year age and sex projections by aggregating Spanish rural municipalities with fewer than 1,000 inhabitants, using the cohort-component method (Smith et al., 2013).

A review of the literature identifies a relevant study that provides population projections for 180 Galician rural municipalities, although for municipalities with populations between 311 and 9,556 inhabitants (Toxo and López, 2024). The methodology employed in that study is based on analysing population trends and detecting significant changes using joinpoint regression. Once trends are classified, municipalities exhibiting a linear trend are projected using linear regression, while those with non-linear trends are projected using the Cohort Change Ratio (CCR) method (Hamilton and Perry, 1962). This method calculates the variation over two specific time periods, t_0 and t_1, and then applies the resulting ratio to the population stock at a time t to estimate the stock at time $t + (t_1 - t_0)$. We adopt a different methodological approach, and also differ in how projections are offered. Toxo and López (2024) present municipality-level projections aggregated across ages and sexes, whereas this study produces age- and sex-specific projections aggregated across municipalities.

One of the most widely used techniques for population projections is the cohort-component population projection method (Smith et al., 2013), which is based on the assumption that future population changes are driven by the interactions of fertility, migration flows, and mortality within specific age-sex cohorts. This method allows for detailed projections by explicitly modelling how each age-sex cohort evolves over time, accounting for changes in each of these demographic components. Since each component follows distinct patterns and is influenced by different factors, projecting the total population without accounting for their individual trends can obscure underlying demographic processes.

Fertility has been widely studied, with extensive research dedicated to understanding the factors shaping its evolution over time (Leasure, 1963; Easterlin, 1966; Pavía-Miralles et al., 2003; Burillo et al., 2020; Lozano et al., 2024). In terms of fertility prediction, two recent studies in the Spanish context are particularly noteworthy. The first is a review of the most influential fertility predictors, using the sum of age-specific fertility rates for women of reproductive age (15–49 years) as the response variable (Llorente-Marrón et al., 2022). The second study projects the total fertility rate (TFR) using Bayesian statistical methods (Caro-Barrera et al., 2022). Similar predictive studies have been conducted in other countries, including a review comparing different time-series techniques to forecast age-specific fertility rates (Bell, 1997).

The analysis of migration flow determinants in Spain has attracted growing interest in recent years (e.g., Izquierdo et al., 2016; Hierro et al., 2019; Sanchis et al., 2025). However, despite the equivalent of one quarter of the Spanish resident population having changed municipalities between 2012 and 2021, internal migration flows across different habitat sizes have received relatively limited attention. Some studies, nonetheless, have been conducted over the last few decades, highlighting that these flows have been driven not only by rural depopulation but also by a form of urban exodus—referred to in the literature as 'counterurbanisation' (Dean et al., 1984; Cloke, 1985; Fielding, 1986). Although this process occurred somewhat later in Spain than in other developed countries, major Spanish cities have experienced a loss of residents in favour of surrounding smaller urban areas offering better quality of life, cheaper housing, or the opportunity to live further from large cities due to remote working.

Regarding external migration flows, the literature identifies three main types of international 'counterurbanisation' in Spain: retirement migration (Rodríguez et al., 2004), return migration (individuals returning to their hometowns) (Oliva, 2011), and relocations in search of better job opportunities (Bayona-i-Carrasco and Gil-Alonso, 2013; Hierro, 2016), with foreign migration flows playing a crucial role in shaping the demographic landscape of Spanish rural areas. While the number of foreign-born residents in Spain increased by a factor of 2.9 between the 2001 and 2021 censuses at the national level, the increase was even more pronounced—3.2 times—in municipalities with fewer than 1,000 inhabitants. Foreign immigration is helping to mitigate the risks of depopulation in rural Spain.

To address all these migration trends, a number of studies have developed national-level migration forecasts (e.g., Fernández-Huertas and López-Molina, 2018). However, these forecasts struggle to incorporate sudden shifts caused by political decisions or global crises. For instance, the COVID-19 pandemic significantly altered migration patterns worldwide (González-Leonardo et al., 2024). Recent studies have started examining its effects on internal Spanish migration flows (Molina et al., 2020; González-Leonardo et al., 2022), particularly in rural areas, where depopulation trends may have been temporarily disrupted.

Regarding mortality, Sifre-Armengol et al. (2025) recently constructed age-sex life tables for Spain by income level, climate area and habitat size for the period 2010-2050. They estimate life tables from observed data for the period 2010–2019 and generate projections, using the generalized Age-Period-Cohort models (Villegas et al., 2018), up to the year 2050. Other institutions also provide life tables (e.g., United Nations, 2024; Human Mortality Database, 2024), however, not disaggregated by habitat size.

The ultimate goal of our research is to provide a tool for analysing the impact of public policies aimed at reversing the depopulation risk in rural areas. In this context, a recent study on policies and investments in the Molina de Aragón-Alto Tajo region of Guadalajara (Spain) offers valuable results (Núñez-Martí and Goycoolea-Prado, 2024). It examines depopulation and its effects on local economies, utilising both demographic data (population size and composition) and economic data (income, labour force, and registered labour contracts), along with surveys of local inhabitants. The literature also includes studies that evaluate the failures of market and government policies in rural areas, comparing local and regional policy responses and other relevant factors (Sáez et al., 2011).

We expand the research to date on depopulation in small municipalities (fewer than 1,000 inhabitants) in Spain by projecting their population composition. For fertility, we rely on age-specific fertility rates estimated from microdata. Mortality is incorporated using death rates forecasted for municipalities with fewer than 10,000 inhabitants—the smallest population group for which such statistics are published. Migration flows are analysed with particular attention to movements to and from rural municipalities, based directly on the raw data relevant to our study.

3. Data

All databases used in this study were directly or indirectly provided by INE. Individual population stock data as of 1 January—containing each resident's date of birth and census section of residence—and birth statistics, which include the municipality of residence of each mother, were obtained under ad-hoc confidentiality agreements. Both datasets cover the period from 2010 to 2021. INE further provided individual records of residential changes (in- and out-migrations) by municipality, including the date of birth and the date of the move, for the period 2012 to 2021, also under a confidentiality agreement. These agreements were granted following a formal research request and a pre-approved payment process, in accordance with INE procedures (https://ine.es/infoine/). Finally, sex- and age-specific life tables by habitat size were obtained from Sifre-Armengol et al. (2025), who derived them using INE microdata.

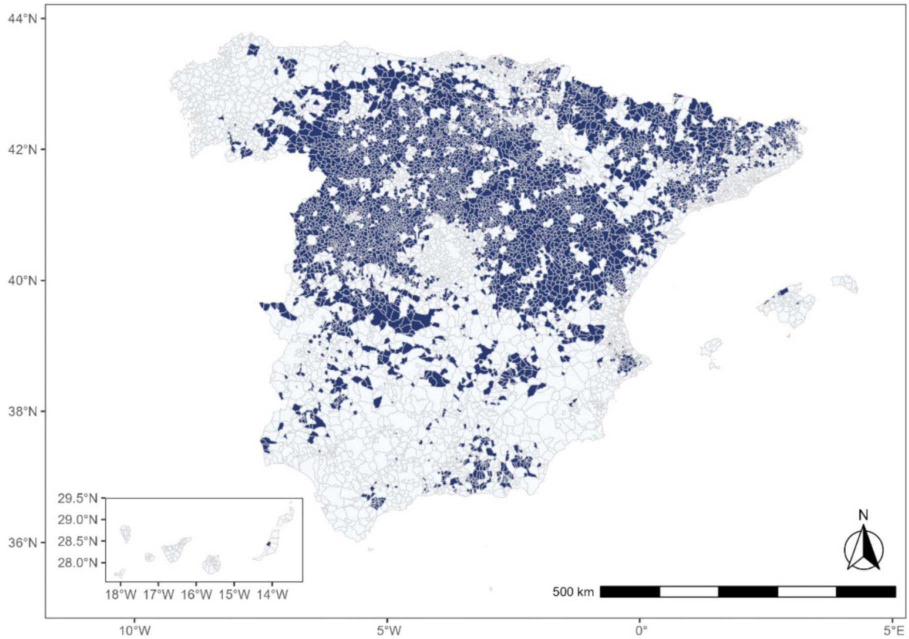
Microdata provided by INE contain more detailed information than what is typically available through the open statistics on its website. On INE's website, the number of residents by municipality is omitted in queries using five-year or one-year age groups when the count is fewer than five individuals (INE, 2024a). For small municipalities, complete population stocks are only available in broad age categories (0–16, 16–64, and 65 or older). In contrast, our datasets include detailed statistics at the census section level.

Similarly, public information on migration flows is incomplete. Identifiers for municipalities involved in migration flows are omitted when these include villages with fewer than 10,000 residents (INE, 2024b). This information is, however, available in the provided microdata. Starting in 2021, data on registrations and de-registrations by municipality have begun to be publicly released, disaggregated by sex and grouped age categories (0–15; 16–24; 25–34; 35–44; 45–54; 55–64; 65 or older).

The birth statistics we received are also significantly more detailed than those available in public releases. The microdata cover all mothers who gave birth in Spain and include both the municipality code of the mother's residence and her age. In contrast, public data group together all municipalities with fewer than 10,000 inhabitants, identifying them only with a general indicator (INE, 2024c). In short, INE implements logical, physical, and administrative safeguards to ensure the effective protection of data it considers confidential, from the point of collection through to publication (INE, 2024a).

The sex-age life tables estimated by Sifre-Armengol et al. (2025) were also derived from INE microdata. According to the authors, the tables—segmented by various mortality risk factors, including habitat size—were constructed using individual records on population stocks, births, residential variations, and deaths provided by INE. The authors produced life tables for the period 2010–2019 and projected them up to 2050. These tables, including those specific to populations residing in municipalities with fewer than 10,000 inhabitants, are publicly available in a Mendeley repository (Lledó et al., 2024).

Figure 1.
Geography of Spanish municipalities, with villages with fewer than 1,000 inhabitants in 2021 highlighted in blue dark



Source: own elaboration.

Figure 1 highlights in dark blue the Spanish municipalities with fewer than 1,000 inhabitants as of 1 January 2021, providing a geographical representation of the area under study. Most of these municipalities are concentrated in the northern half of Spain. With exceptions such as Madrid and its surrounding areas, some provincial capitals, the Ebro Valley, and coastal zones, where population density is generally higher due to greater urbanisation and economic activity, much of this area of Spain consists of small villages. The proportion of highlighted municipalities in the southern half of the country, Galicia, and in the islands is significantly lower.

4. Methodology

Starting from an initial population stock, future population levels are determined by the evolution of births, deaths, and residential movements. This study aims to project the population of Spanish rural areas annually up to 2050, providing a baseline for assessing the effectiveness of depopulation policies. Both the size and composition of the future population in the area under study are shaped by its fertility, mortality, and migration dynamics. The cohort-component method is the most widely used approach for producing population projections (Smith et al., 2013). It is both flexible and powerful, allowing adaptation to different assumptions. In addition to projecting overall population levels, it can generate projections of demographic subgroups and be applied at any geographical level, from highly aggregated to highly disaggregated units.

This method is based on an accounting equation, according to which the total population stock at time moment $t + 1$, P_{t+1}, equals the population stock available in the previous time period, P_t, minus the number of deaths (D_t) and emigrants (E_t) plus the number of births (B_t) and immigrants (I_t) recorded during the period between t and $t + 1$:

$$P_{t+1} = P_t - D_t + B_t + I_t - E_t$$

Rather than focusing on the total population stock, it is more relevant to express the accounting equations for the population stocks by age x and sex s. These equations can be mathematically represented in a relatively concise way, under a few assumptions. Specifically, assuming a uniform distribution of demographic events over calendar and age years, and that t and $t + 1$ correspond to 1 January of years $t + 1$ and $t + 1$, respectively, it can be demonstrated—with the aid of the Lexis diagram (Lexis, 1875)—that the population aged $x + 1$ (last birthday) and sex s at time $t + 1$, denoted $P_{x+1,s}^{t+1}$, is, for $x > 1$, approximately equal to:

$$P_{x+1,s}^{t+1} \approx P_{x,s}^{t} - P_{x,s}^{t}\left(\frac{1}{2}\left(q_{x,s}^{t} + q_{x+1,s}^{t}\right)\right) - \frac{1}{2}\left(E_{x,s}^{t} + E_{x+1,s}^{t}\right) + \frac{1}{2}\left(I_{x,s}^{t} + I_{x+1,s}^{t}\right)$$

where $P_{x,s}^{t}$ represents the population stock at age x for sex s at moment t, $q_{x,s}^{t}$ denotes the probability of dying at age x for sex s during year t, and $E_{x,s}^{t}$ and $I_{x,s}^{t}$ represent the number of emigrants and immigrants, respectively, with age x and sex s during year t.

Note that these relationships apply to populations aged over 1 and are approximate, as some immigrants may die during year t before reaching moment $t+1$, and some emigrants who die after leaving have already been counted as resident deaths. The expected discrepancy, however, is negligible. Under the additional assumption that that immigrants face the same mortality risk as residents, the exact formula is:

$$P_{x+1,s}^{t+1} = P_{x,s}^{t} - \frac{1}{2}P_{x,s}^{t}\left(q_{x,s}^{t} + q_{x+1,s}^{t}\right) - \frac{1}{2}\left(E_{x,s}^{t} + E_{x+1,s}^{t}\right) + \frac{1}{2}\left(I_{x,s}^{t} + I_{x+1,s}^{t}\right) +$$
$$\frac{1}{6}\left(E_{x,s}^{t} - I_{x,s}^{t}\right)\left(q_{x,s}^{t} + q_{x+1,s}^{t}\right) + \frac{1}{6}\left(E_{x+1,s}^{t} - I_{x+1,s}^{t}\right)q_{x+1,s}^{t}.$$

The formulas for ages 0 and 1 differ slightly from the general formula, as the base for $P_{0,s}^{t+1}$ is not a previous stock but births, and because mortality risks in the first moments (days) of life are significantly higher (Lledó et al., 2025). As a result, for age 0, a larger number of deaths are expected for newborns of year t compared to those born in the previous year, implying a higher death probability coefficient for newborns. Hence, the populations aged 1 and 0 for sex s at time $t+1$ are, respectively, approximately equal to:

$$P_{1,s}^{t+1} \approx P_{0,s}^{t} - P_{0,s}^{t}\left(\frac{2}{5}\,q_{0,s}^{t} + \frac{1}{2}q_{1,s}^{t}\right) - \frac{1}{2}\left(E_{0,s}^{t} + E_{1,s}^{t}\right) + \frac{1}{2}\left(I_{0,s}^{t} + I_{1,s}^{t}\right)$$

and

$$P_{0,s}^{t+1} \approx B_{0,s}^{t} - B_{0,s}^{t}\frac{3}{5}\,q_{0,s}^{t} - \frac{1}{2}\,E_{0,s}^{t} + \frac{1}{2}\,I_{0,s}^{t},$$

where $B_{0,s}^{t}$ represents the number of newborns with sex s during year t.

Denoting by t_0 the last year for which observed population stocks are available, projections can be obtained recursively for $t = t_0 + 1, t_0 + 2$, using the above equations and projected values for death probabilities, births, immigrants and emigrants. Specifically, denoting by $i_{x,s}^{t}$, $e_{x,s}^{t}$, and b_x^t the projected immigration, emigration, and fertility rates for age x, sex s and year t, we project the number of immigrants, emigrants and births as follows:

$$\frac{1}{2}\left(I_{x,s}^{t} + I_{x+1,s}^{t}\right) = \frac{1}{2}P_{x,s}^{t}\left(i_{x,s}^{t} + i_{x+1,s}^{t}\right),$$
$$\frac{1}{2}\left(E_{x,s}^{t} + E_{x+1,s}^{t}\right) = \frac{1}{2}P_{x,s}^{t}\left(e_{x,s}^{t} + e_{x+1,s}^{t}\right),$$
$$B_0^t = \sum_{x=15}^{49}\frac{1}{2}\Big[\left(1 + i_{x,w}^{t} - e_{x,w}^{t} - \tfrac{1}{2}q_{x,w}^{t}\right)\Big(P_{x,w}^{t}$$
$$+ \left(1 + i_{x-1,w}^{t} - e_{x-1,w}^{t} - \tfrac{1}{2}q_{x-1,w}^{t}\right)P_{x-1,w}^{t}\Big)\Big]\,b_x^t,$$

where stands for women and the estimation of births implicitly assumes that immigrant women have the same likelihood of becoming pregnant as resident women. Births are distributed between males and females in proportions of 0.516 and 0.484, respectively, as estimated using data from newborns in 2021.

Interested readers who compare this methodology with the one employed by INE to produce projections (INE, 2024d) will note some differences that merit clarification. The INE adopts a time-based approach, producing annual projections and defining the reference population as the mean population between years t and $t + 1$. In contrast, our projections are structured around age- and sex-specific cohorts. Nevertheless, the greatest differences reside in how migration flows are operationalised. In the INE methodology, internal migration is modelled through detailed age- and sex-specific origin-destination rates that govern the redistribution of population between territorial units, while international migration is introduced through projected net migration balances subsequently distributed by age and sex. By contrast, our methodology applies age- and sex-specific migration rates directly to the projected cohorts of the aggregated rural population. These differences simply reflect alternative operational choices within the same cohort-component framework.

5. *Demographic trends in rural Spain*

As stated in the previous section, population projections can be generated conditional on having projected rates for immigration, emigration, and fertility, as well as death probabilities. In this section, we analyse the recent evolution of births and migration flows in Spanish rural municipalities to project their corresponding rates into the future. These projected rates constitute an intermediate input that is subsequently integrated within the classical cohort-component model through the recursive estimation of births, immigrants, and emigrants, as detailed above. Rate extrapolation is performed under two alternative approaches: constant rates and ARIMA-based models. Importantly, the ARIMA models are used exclusively to extrapolate demographic rates and do not replace the cohort-component structure of the population projections. They serve solely as an alternative approach for extending observed dynamics into the future, acting as a mechanical extrapolation of recent trends in demographic rates rather than as a structurally richer or more robust estimation strategy. In this sense, ARIMA-based projections provide an additional degree of flexibility by offering an alternative benchmark to the constant-rate scenario, based on the continuation of recent patterns. For mortality, we rely on life table projections produced by Sifre-Armengol et al. (2025).

5.1. Mortality

Sifre-Armengol and colleagues estimate and project life tables for Spain by incorporating not only age and sex but also regional characteristics, including habitat sizes categorized into four groups based on population: fewer than 10,000; between 10,000 and 50,000; between 50,000 and 250,000; and more than 250,000. Drawing on a large dataset of over 2 billion microdata events from 2010 to 2019, they first estimate raw central death rates by age and sex, which are then smoothed to remove irregularities. Subsequently, they project death probabilities from 2020 to 2050 by applying several standard longevity models—namely, the Lee-Carter, Renshaw-Haberman (Renshaw and Haberman, 2006), and Plat models (Plat, 2009)—supplemented with modelling for older ages and smoothing splines to correct remaining random fluctuations. For our rural population projections, we use the 2021–2050 life table projections obtained with the Lee-Carter model (Lee and Carter, 1992) corresponding to populations residing in municipalities with fewer than 10,000 inhabitants, as this represents the closest available disaggregation to smaller rural municipalities, allowing us to account—at least partially—for habitat-size differences in mortality while avoiding less representative country-level averages.

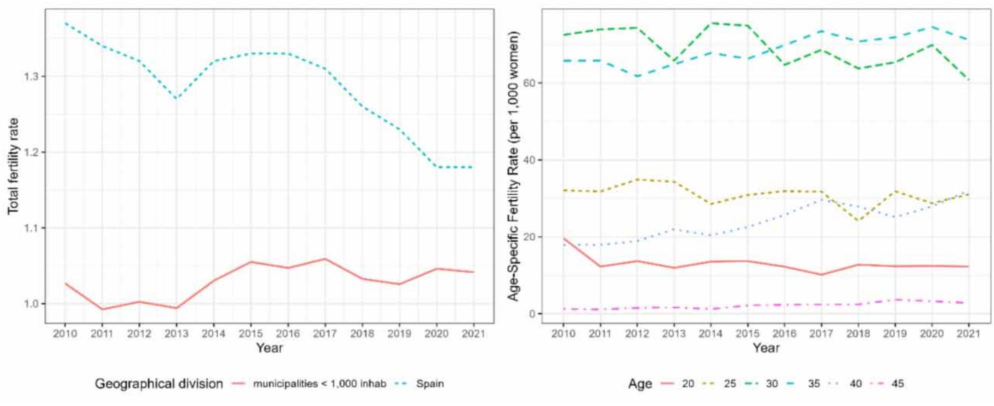
5.2. Fertility

The term fertility refers to the occurrence of births within an individual, a group, or an entire population. We estimate fertility rates for municipalities with fewer than 1,000 inhabitants using birth statistics from the Statistical Birth Bulletin, which covers all mothers who gave birth in Spain, along with their age and municipality of residence.

A basic measure of gross fertility is the general fertility rate, defined as the number of births divided by the number of females aged 15–49. This metric, however, treats all reproductive ages equally, despite well-documented heterogeneity in fertility behaviour across age groups (e.g., Pavía-Miralles et al., 2003). This is clearly illustrated in the right panel of Figure 2, which displays age-specific fertility rates (AFR_x) for selected ages in rural Spain from 2011 to 2021. For example, in present-day Spain, women are more likely to give birth in their 30s than in their 20s. Consequently, fertility is more commonly synthesised using the total fertility rate (TFR), which relates the number of births to the number of females in their prime childbearing years and is obtained by aggregating the AFR_x for x (see left panel of Figure 2).

Importantly, as shown in the left panel of Figure 2, substantial differences persist between the TFR of Spanish municipalities with fewer than 1,000 inhabitants and that of Spain as a whole. Hence, we rely on rural age-specific fertility rates for our projections. Specifically, we project fertility rates by age using two distinct approaches. First, since the rates shown in the right panel of Figure 2 exhibit no significant temporal trends, we consider AFR_x^t to be constant over time, setting it equal to the average value observed from 2010 to 2021. The second approach consists in fitting an ARIMA model (Box et al., 2015) to each observed series of AFR_x^t ($t = 2010, \ldots, 2021$) and using the resulting forecasts for extrapolation. Once $b_x^t = \widehat{AFR}_x^t$ are available for $t = 2022, \ldots, 2050$ (see supplementary material for details), the projected number of births by year and sex is computed as described in the methodology section.

Figure 2.
Evolution of fertility in rural Spain between 2010 and 2021. The left panel displays the total fertility rates (TFR) corresponding to municipalities with fewer than 1,000 inhabitants, as well as for Spain as a whole. The right panel shows age-specific fertility rates for selected ages. Age-specific fertility rates are expressed as births per 1,000 women



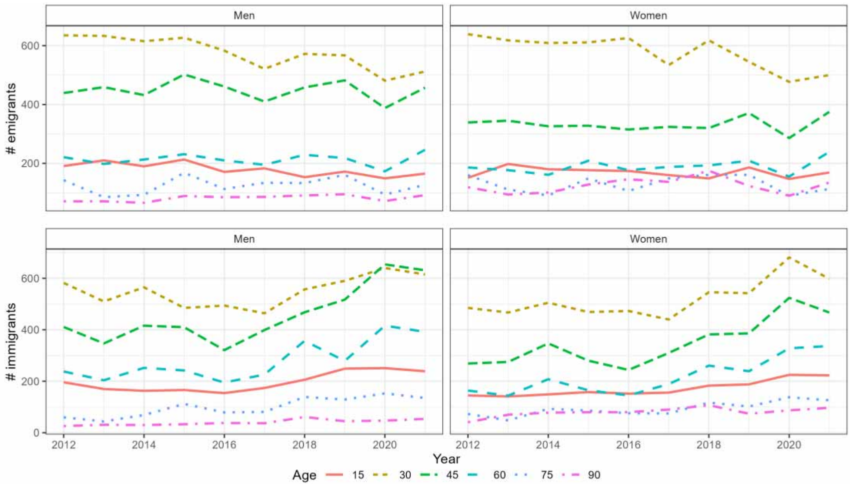
Source: own elaboration.

5.3. Migration

The term migrant refers to a person who changes their place of usual residence from one political or administrative area to another (Smith et al., 2013). In this study, municipalities are taken as the political or administrative reference areas. Accordingly, a migrant is defined as someone who moves from one municipality to another, arrives from another country to a Spanish municipality, or relocates from a Spanish municipality to a foreign country.

We consider the years 2012 to 2021 as the period of analysis. This includes the first two years of the COVID-19 pandemic. During this time, lockdowns led to a 2.5 % decline in internal migrations in Spain. Following the lifting of restrictions, cities experienced net migration losses, while rural areas recorded gains (González-Leonardo et al., 2022). These trends for rural areas are evident in Figure 3, which shows the number of emigrants (upper panels) and immigrants (lower panels) from and to Spanish rural areas by sex and selected ages from 2012 to 2021. As observed, the number of migrants relocating to rural areas increases towards the end of the period, especially in 2020, when the urban exodus to rural areas intensified as people sought greater social distancing and more space due to the pandemic and lockdowns.

Figure 3.
Number of emigrants (upper panels) and immigrants (lower panels) from and to Spanish rural areas—defined as municipalities with fewer than 1,000 inhabitants—by sex and selected ages, from 2012 to 2021



Source: own elaboration.

Although it cannot be ruled out that these end-period trends in immigration may prove temporary—the impact of COVID-19 on emigration from rural areas was significantly smaller—we apply the same two approaches utilised for projecting fertility rates (constant rates and ARIMA-based extrapolation) to project migration rates.

The process starts by calculating the immigration and emigration rates by age (x) and sex (s) for each year ($t = 2012, \ldots, 2021$), using net in- and out-migration flows to and from rural municipalities, as a proportion of the corresponding age-sex-year population group. This approach does not account for internal movements between rural municipalities. Specifically, the rates are calculated as follows:

$$i_{x,s}^{t} = \frac{I_{x,s}^{R,t}}{P_{x,s}^{R,t}},$$

$$e_{x,s}^{t} = \frac{E_{x,s}^{R,t}}{P_{x,s}^{R,t}},$$

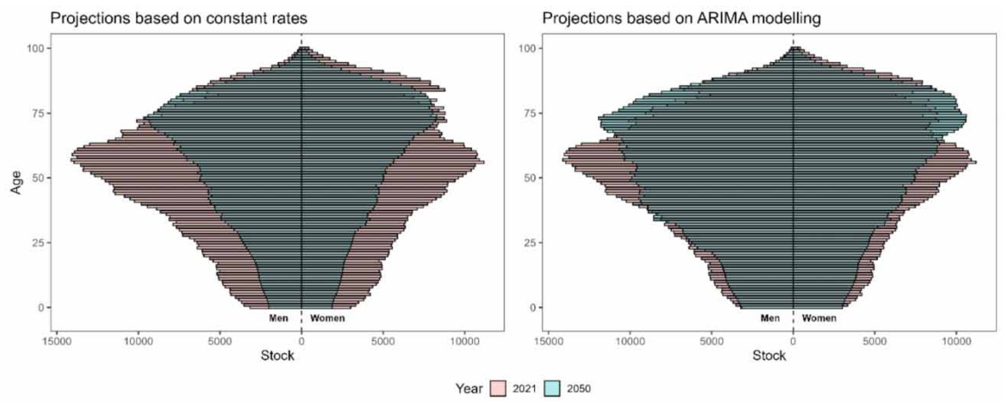
where $I_{x,s}^{R,s}$ and $E_{x,s}^{R,s}$ denote, respectively, the number of migrants to and from rural areas with age x and sex s during year t, and $P_{x,s}^{R,s}$ is the corresponding rural population stock at the beginning of the year.

Once the projected migration rates, $\hat{\imath}_{x,s}^{t}$ and $\hat{e}_{x,s}^{t}$ for $t = 2022, \ldots, 2050$, are obtained using either the constant-mean or ARIMA-based extrapolation approach (see supplementary material for the values), the projected numbers of immigrants and emigrants by year and sex are computed as described in the methodology section.

6. Results

This section summarises the population projections for rural areas (municipalities with fewer than 1,000 inhabitants) up to the year 2050, obtained using the cohort-component method described in the methodology section and the projected demographic components detailed above. All projected population counts by age, sex, and year, as well as the rates used, are available in the supplementary material accompanying this paper.

Figure 4.
Projected population pyramids for rural areas in 2050 (sky blue bars), by sex and age, using the cohort-component methodology, under two demographic rate extrapolation scenarios: constant rates (left panel) and ARIMA-based projections (right panel). For reference, the 2021 population structure is also shown (pale pink bars)



Source: own elaboration.

Figure 4 displays the projected population pyramids for rural areas in 2050 (sky blue bars) by sex and age under two alternative scenarios: one based on constant mean rates (left panel) and the other on ARIMA-based extrapolation (right panel). For reference, the population structure in 2021 is also shown (pale pink bars). Both scenarios exhibit a marked ageing process, with a notable increase in the relative and absolute size of the population aged 65 and over. The base of the pyramid narrows considerably, mainly in the constant-mean scenario, indicating a persistent decline in younger cohorts. Overall, the projections point to significant demographic ageing and a contraction of the younger population in rural areas by mid-century. Nonetheless, the two scenarios diverge in important ways, reflecting the different demographic dynamics captured by each rate projection method.

The constant-mean scenario projects a more pronounced ageing process and a sharper decline in the younger population than the ARIMA-based scenario. It anticipates a population loss of over half a million residents in the study area. This decline is accompanied by a substantial increase in the elderly population, intensifying the demographic challenges associated with ageing and depopulation. The realisation of this scenario would represent a clear failure of current depopulation policies pursued at both European and national levels.

The ARIMA extrapolation scenario—which mechanically projects the most recent demographic trends observed over the past decade—paints a less pessimistic, though still not optimistic, picture. The lack of optimism is explained by the fact that most estimated trends are not statistically significant, implying little evidence of systematic change. At the same time, the relatively less pessimistic outlook stems from the fact that, among the few statistically significant trends, the majority display positive slopes. When analysing fertility rate trends, only 11.4 % of the estimated coefficients are statistically significant; however, 75 % of these significant coefficients are positive. A similar pattern is observed for migration flows. In the case of immigration, only 3.47 % of the trend coefficients are statistically significant, yet all of them are positive. For emigration, no ARIMA model produces a statistically significant trend coefficient.

Despite sustaining the post-pandemic increase in immigration for more than 30 years, this scenario also projects a net loss of population by the end of the period—this time exceeding one hundred thousand people. As with the constant-mean scenario, the decline is accompanied by a substantial increase in the elderly population. However, the decreases among middle-aged and younger cohorts are smaller, placing comparatively less pressure on local economies and social systems. Still, the scenario makes it clear that the challenges of ageing and depopulation would remain, also showing a possible failure of current European and Spanish depopulation policies.

We end the presentation of results by analysing the distributions by sex. Table 1 shows the projected distributions for 2030, 2040, and 2050, along with the observed values for 2021 as a reference. Sex ratios, measured as the number of men per 100 women, are also displayed. As a rule, the sex ratio increases in both scenarios, although the trajectories differ. With the constant-mean approach, the sex ratio rises modestly from 112.7 in 2021 to 114.7 in 2030, before gradually declining to 111.0 by 2050. This suggests a slight narrowing of the gender imbalance over time, with male and female populations decreasing at a similar pace in the later decades.

By contrast, the ARIMA-based scenario projects a continuous rise, from 112.7 in 2021 to 115.9 by 2050. This indicates that, although both male and female stocks decline more slowly than in the constant-mean case, the male population is projected to remain consistently larger, widening the relative gender gap.

Table 1.
Observed (2021) and projected sex distributions and sex ratios in Spanish rural areas for 2030, 2040, and 2050 under the constant-mean and ARIMA-based extrapolation scenarios

	Men stock		Women stock		Sex ratio	
Year	Mean	ARIMA	Mean	ARIMA	Mean	ARIMA
2021	767,854		681,466		112.68	
2030	685,760	753,441	597,698	654,786	114.73	115.07
2040	596,309	740,833	523,309	640,821	113.95	115.61
2050	497,487	717,250	448,009	618,844	111.04	115.90

Source: own elaboration.

Overall, these projections suggest that the demographic imbalance between men and women would persist—and even intensify under the ARIMA-based scenario—driven by a comparatively slower decline in the male population. It is worth noting that these figures contrast sharply with the national sex ratio, which stood at 96.3 men per 100 women in 2021, underscoring the persistent and distinctive male surplus in rural areas.

7. Conclusions and limitations

The phenomenon of depopulation and its impact on rural areas in Spain—as well as in other European regions—has become a complex issue driven by a variety of factors that directly affect these territories and carry significant, far-reaching interrelated economic, social, and ecological consequences. Population decline and ageing result in a shrinking labour force and greater pressure on healthcare systems—a particularly serious concern for small municipalities, which are often located in areas with already limited access to services. If current trends in depopulation and ageing persist, the gap between rural areas and larger urban centres could widen further, exacerbating existing social and economic inequalities.

Beyond ageing, rural population structures are also characterised by imbalanced sex ratios, with a marked masculinisation. This imbalance reduces the number of births relative to populations of the same size, further accelerating population ageing and increasing the risk of depopulation, as generational renewal becomes increasingly difficult. It should be noted, however, that the high magnitude of masculinisation observed in this study is closely linked to the definition of rural areas adopted here, namely municipalities with fewer than 1,000 inhabitants. Under alternative definitions, such as that proposed by DEBURGA, the sex ratio imbalance also emerges but is notably less pronounced.

Given the problematic population composition and demographic trends in rural areas, it is not surprising that governments at various levels have made repeated attempts over the past decades to reverse these patterns. However, the policies implemented thus far have largely failed to achieve their objectives. More recently, a new and more ambitious initiative—known as the Demographic Challenge—has begun to be rolled out in Spain. In light of the need for continuous policy evaluation, this research constructs a counterfactual scenario that projects existing trends—still unaffected by the new policies—into the future, providing a benchmark against which the effectiveness of the new rural depopulation measures can be assessed during the coming years.

Based on recent demographic trends, we derive—using the cohort-component methodology—two alternatives for counterfactual projections: one using constant rates and another relying on ARIMA extrapolations. While both approaches diverge in key aspects—thereby providing an indication of the uncertainty surrounding the projections—they also share important similarities. In both cases, a decline in the number of inhabitants is anticipated, with projections based on ARIMA extrapolations suggesting a less alarming trajectory. The ARIMA-based estimates, however, should be interpreted with caution, as they mechanically extend recent demographic trends. Given the relatively short length of the available time series and the presence of exceptional events—most notably the COVID-19 pandemic-induced migration toward rural areas—these ARIMA-based projections may amplify temporary fluctuations and short-term anomalies rather than capture longer-term structural dynamics. As highlighted by González-Leonardo et al. (2022) and more recently by Recaño and Marbán (2024), post-pandemic migration patterns appear more heterogeneous than initially suggested.

Population ageing is also expected under both projections: by 2050, the most populous age cohorts, compared to 2021, would shift to the oldest age groups. If the new policy fails to reverse current trends, both sets of projections point to a continued deterioration in population structure, with a significantly narrower base in the age pyramid, indicating reduced generational renewal.

The constructed projections are intended to serve as a benchmark for comparison to assess, over the coming years and decades, the effect of the new policy, functioning as a counterfactual that illustrates what might have occurred if the Demographic Challenge policy had not been implemented. However, these projections are inherently limited, as other factors not considered—and unrelated to the policy—could also influence the future evolution of population size and composition in rural areas of Spain. Population projections could change drastically as a result of new political, health, or economic shocks. They could also be affected by other nationwide policies, such as a potential initiative aimed at increasing fertility rates, which currently remain below replacement levels. Furthermore, even sustained extreme weather events could trigger forced migration and alter the geographical distribution of the population.

Likewise, a different assessment of demographic trends could have produced alternative projections. For instance, this study considers only the mother's age as a fertility factor, although it is well established that socioeconomic factors also influence fertility (Devolder and Bueno, 2011; Carioli et al., 2021). Including these additional factors could help create more homogeneous cohorts, potentially leading to different projections. Similarly, diverging operationalization decisions regarding migration flows may also affect the results. For instance, the INE projects foreign net migration by setting assumptions on the evolution of the net migration balance and interpolating these balances linearly over time, based on the number of movements. In contrast, our approach models immigration and emigration separately using age-specific rates that depend on the rural population stock.

Another important limitation stems from the simplification of grouping more than 4,900 municipalities into a single category, despite the significant heterogeneity among rural areas. Municipalities with fewer than 1,000 inhabitants vary widely in characteristics (Gutiérrez-Posada et al., 2017). Factors such as proximity to economic centres, tourism appeal, and infrastructure development will affect each municipality differently; however, this study treats all such municipalities as a single entity. The projections should be therefore interpreted as a macro-rural estimate and should not be applied to individual municipalities. This approach is consistent with the main objective of the study, which is to provide a tool for evaluating depopulation policies in general terms rather than at the local level. Nevertheless, future research should explicitly account for heterogeneity across rural areas. For instance, incorporating dimensions such as geographical isolation, dominant economic activity, or the current intensity and trajectory of depopulation could help define more homogeneous groups of municipalities and yield more nuanced projections.

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10. References

Bayona-i-Carrasco, J., & Gil-Alonso, F. (2013). Is foreign immigration the solution to rural depopulation? The case of Catalonia (1996–2009). *Sociologia Ruralis*, *53*(1), 26-51. https://doi.org/10.1111/j.1467-9523.2012.00577.x

Bell, W. R. (1997). Comparing and assessing time series methods for forecasting age-specific fertility and mortality rates. *Journal of Official Statistics*, *13*(3), 279-303.

Box, G. E. P., Jenkins, G. M., Reinsel, G. C., & Ljung, G. M. (2015). *Time Series Analysis: Forecasting and Control* (5th ed). Wiley.

Burillo, P., Salvati, L., Matthews, S. A., & Benassi, F. (2020). Local-scale fertility variations in a low-fertility country: evidence from Spain (2002–2017). *Canadian Studies in Population*, (47), 279-295. https://doi.org/10.1007/s42650-020-00036-6

Camarero, L., & Sampedro, R. (2016). Exploring female over-migration in rural Spain—Employment, care giving and mobility. In: K. Wiest (eds.), *Women and Migration in Rural Europe: Labour Markets, Representations and Policies* (pp. 189-208). Palgrave Macmillan. https://doi.org/10.1007/978-1-137-48304-1_10

Carioli, A., Recaño, J., & Devolder, D. (2021). The changing geographies of fertility in Spain (1981-2018). *Investigaciones Regionales*, (50), 147-167.

Caro-Barrera, J. R., García-Moreno García, M. B., & Pérez-Priego, M. (2022). Projecting Spanish fertility at regional level: A hierarchical Bayesian approach. *PLOS One*, *17*(10), e0275492. https://doi.org/10.1371/journal.pone.0275492

Cloke, P. (1985). Counterurbanisation: a rural perspective. *Geography*, *70*(1), 13-23. https://doi.org/10.1080/20436564.1985.12451924

Dean, K. G., Brown, B. J. H., Perry, R. W., & Shaw, D. P. (1984). The conceptualisation of counterurbanisation. *Area*, *18*(1), 9-14.

Devolder, D., & Bueno, X. (2011). Effects of migration on fertility patterns of non-native women in Spain. *Papers de Demografía*, (382), 1-26.

Diamond, I., Tesfaghiorghis, H., & Joshi, H. (1990). The uses and users of population projections in Australia. *Journal of the Australian Population Association*, (7), 151-170.

Easterlin, R. A. (1966). On the relation of economic factors to recent and projected fertility changes. *Demography*, (3), 131-153.

ENRD (2018). Smart villages, revitalising rural services. *EU Rural Rev*, *26*(8), 1-52.

Fernández-Huertas, J., & López-Molina, G. (2018). Predicting Spanish emigration and immigration. *AIReF Working Paper Series*, 8.

Fielding, A. J. (1986). Counterurbanisation. In: M. Pacione (eds.), *Population Geography: Progress & Prospect (Routledge Revivals)* (pp. 224-256). Routledge.

Goerlich, F. J., Reig, E., & Cantarino, I. (2016). Construcción de una tipología rural/urbana para los municipios españoles. *Investigaciones Regionales*, (35), 151-173.

Gómez-Valenzuela, V., & Holl, A. (2024). Growth and decline in rural Spain: An exploratory analysis. *European Planning Studies*, *32*(2), 430-453. https://doi.org/10.1080/09654313.2023.2179390

González, M. L. A., Vázquez, E. F., & Morollón, F. R. (2015). A methodological note for local demographic projections: A shift-share analysis to disaggregate official aggregated estimations. *Rect@: Revista Electrónica de Comunicaciones y Trabajos de ASEPUMA*, *16*(1), 43-50.

González-Leonardo, M., López-Gay, A., Newsham, N., Recaño, J., & Rowe, F. (2022). Understanding patterns of internal migration during the COVID 19 pandemic in Spain. *Population, Space and Place*, *28*(6), e2578. https://doi.org/10.1002/psp.2578

González-Leonardo, M., Rowe, F., Potančoková, M., & Goujon, A. (2024). Assessing the differentiated impacts of COVID-19 on the immigration flows to Europe. *International Migration Review*, online available. https://doi.org/10.1177/01979183241242445

Gutiérrez-Posada, D., Rubiera-Morollon, F., & Viñuela, A. (2017). Heterogeneity in the determinants of population growth at the local level: Analysis of the Spanish case with a GWR approach. *International Regional Science Review*, *40*(3), 211-240. https://doi.org/10.1177/0160017615589009

Hamilton, C. H., & Perry, J. (1962). A short method for projecting population by age from one decennial census to another. *Social Forces*, *41*(2), 163-170.

Hierro, M. (2016). Latin American migration to Spain: Main reasons and future perspectives. *International Migration*, *54*(1), 64-83. https://doi.org/10.1111/imig.12056

Hierro, M., Maza, A., & Villaverde, J. (2019). Internal migration dynamics in Spain: Winners and losers from the recent economic recession. *Population, Space and Place*, *25*(2), e2176. https://doi.org/10.1002/psp.2176

Human Mortality Database (2024). University of California, Berkeley (USA) and Max Planck Institute for Demographic Research (Germany). Retrieved from: www.mortality.org and www.humanmortality.de

INE (2022). *Avance de la Estadística del Padrón Continuo a 1 de enero de 2022. Datos provisionales* [Comunicado de prensa]. Retrieved from: https://www.ine.es/prensa/pad_2022_p.pdf

INE (2024a). *Estadística del Padrón Continuo*. Informes Metodológicos Estandarizados. Retrieved from: https://goo.su/fgiZo

INE (2024b). *Estadística de variaciones residenciales*. Resultados. Retrieved from: https://goo.su/F1TlGLz

INE (2024c). MNP: *Estadística de Nacimientos*. Resultados. Retrieved from: https://goo.su/BRfB2r

INE (2024d). *Proyecciones de la Población de España 2024-2074*. Metodología. Retrieved from: https://goo.su/Cx7I

Izquierdo, M., Jimeno, J. F., & Lacuesta, A. (2016). Spain: From massive immigration to vast emigration? *IZA Journal of Migration*, (5), 10. https://doi.org/10.1186/s40176-016-0058-y

Keilman, N. (2001). Data quality and accuracy of United Nations population projections, 1950-95. *Population Studies*, *55*(2), 149-164.

Leasure, J. W. (1963). Factors involved in the decline of fertility in Spain 1900–1950. *Population Studies*, *16*(3), 271-285.

Lledó, J., Pavía, J. M., & Sifre-Armengol, C. (2024). Database of estimates and forecasts of Spanish sex-age death rates by climate area, income level, and habitat size (2010-2050). Mendeley Data, V3, https://data.mendeley.com/datasets/jbtwjbgx5f/3

Lledó, J., Pavía, J. M., & Simó-Noguera, C. (2025). Anomalous distributions of birthdates across days of the month: An analysis using Spanish statistical records. *Population Studies*, *79*(1), 167-185. https://doi.org/10.1080/00324728.2024.2393622

Lee, R., & Carter, L. (1992). Modeling and forecasting U.S. mortality. *Journal of the American Statistical Association*, *87*(419), 659-671. https://doi.org/10.2307/2290201

Lexis W. (1875). Einleitung in die Theorie der Bevölkerungsstatistik. Karl J. Trübner.

Llorente-Marrón, M., Díaz-Fernández, M., & Méndez-Rodríguez, P. (2022), Ranking fertility predictors in Spain: A multicriteria decision approach. *Annals of Operations Research*, *311*(2), 771-798. https://doi.org/10.1007/s10479-020-03669-7

Lozano, M., Esteve, A., Boertien, D., Mogi, R., & Cui, Q. (2024). Lowest low fertility in Spain: Insights from the 2018 Spanish Fertility Survey. *Demographic Research*, (15), 625-636. https://doi.org/10.4054/DemRes.2024.51.19

Molina, A., de Pablo, J., Milán, J., & Caparrós, J. L. (2020) COVID-19. ¿Oportunidad para el mundo rural en España? Una reflexión. *Economistas*, (170), 167-182.

Ministerio de Política Territorial y Función Pública (2020). *Diagnóstico Estrategia Nacional Frente al Reto Demográfico. Eje Despoblación*. Available at: https://mpt.gob.es/dam/es/portal/reto_demografico/Indicadores_cartografia/Diagnostico_Despoblacion.pdf

Núñez-Martí, P., & Goycoolea-Prado, R. (2024). Evaluación de las políticas e inversiones en desarrollo local en la España vaciada. Comarca Molina de Aragón-Alto Tajo, Guadalajara, 2000-22. *Hábitat y Sociedad*, (17), 219-239. https://doi.org/10.12795/HabitatySociedad.2024.i17.10

Oliva, J. (2010). Rural melting-pots, mobilities and fragilities: reflections on the Spanish case. *Sociologia Ruralis*, *50*(3), 277-295. https://doi.org/10.1111/j.1467-9523.2010.00516.x

Parra-Rodríguez, F., & Campo-Moreno, L. (2017). *Proyecciones de población de los municipios de España 2016-2037*. ICANE, 2.

Pavía-Miralles, J. M., Vila-Lladosa, L. E., & Cabrer-Borras, B. (2003). Declining fertility: Implications for regional education planning. *Environment and Planning A*, (35), 59-73. https://doi.org/10.1068/a3534

Peralta, J. L. (2017) El enfoque LEADER y los Grupos de Acción Local ante la nueva programación estratégica. *Fundación de Estudios Rurales*, 110-117.

Plat, R. (2009). On stochastic mortality modeling. *Insurance: Mathematics and Economics*, *45*(3), 393-404. https://doi.org/10.1016/j.insmatheco.2009.08.006.

Recaño, J. (2017). La sostenibilidad demográfica de la España vacía. *Perspectives Demogràfiques*, (7), 1-4. https://doi.org/10.46710/ced.pd.cat.7

Recaño, J., & Marbán, L. (2024). ¿Éxodo urbano y renacimiento rural? Las migraciones de las ciudades y el mundo rural durante la pandemia de Covid-19 en España. *Estudios Geográficos*, *85*(297), 1216-1216. https://doi.org/10.3989/estgeogr.2024.1216

Renshaw, A., & Haberman, S. (2006). A cohort-based extension to the Lee-Carter model for mortality reduction factors. *Insurance: Mathematics and Economics*, *38*(3), 556-570. https://doi.org/10.1016/j.insmatheco.2005.12.001

Rodrigo-Comino, J., Salvia, R., Egidi, G., Salvati, L., Giménez-Morera, A., & Quaranta, G. (2022). Desertification and degradation risks vs poverty: A key topic in Mediterranean Europe. *Cuadernos de Investigación Geográfica*, *48*(1), 23-40. https://doi.org/10.18172/cig.4850

Rodríguez, V., Fernández-Mayoralas, G., & Rojo, F. (2004). International retirement migration: Retired Europeans living on the Costa del Sol, Spain. *Population Review*, *43*(1), 1-36. https://doi.org/10.1353/prv.2004.0009

Sáez, L. A., Ayuda, M., & Pinilla, V. (2011). Public intervention against depopulation as a local policy: Justifications from Spain. *CEDDAR Documentos de Trabajo*, (6), 1-18. Retrieved from: https://www.roldedeestudiosaragoneses.org/wp-content/uploads/DT2011-6.pdf

Sáez, L. A., Ayuda, M., & Pinilla, V. (2016). Pasividad autonómica y activismo local frente a la despoblación en España: El caso de Aragón analizado desde la Economía Política. *AGER. Journal of Depopulation and Rural Development Studies*, (21), 11-47. https://doi.org/10.4422/ager.2016.04

Sanchis, A. G., Remoaldo, P., & Martinez-de-Ibarreta, C. (2025). Migrations in Spain: Econometric models with demographic and economic variables (1950–2021). *The Annals of Regional Science*, (74), 41. https://doi.org/10.1007/s00168-025-01370-w

Serrano, J., & Pitarch-Garrido, M. D. (2023). Recent demographic trends in Spanish rural areas: Poverty and inequality with gender perspective (1999–2020). In: R. de Miguel González & M. L. de Lázaro y Torres (Eds.), *Sustainable Development Goals in Europe: A Geographical Approach* (pp. 91-112). Springer International Publishing.

Sifre-Armengol, C., Pavía, J. M., & Lledó, J. (2025). A comprehensive database of estimates and forecasts of Spanish sex–age death rates by climate area, income level, and habitat size (2010–2050). *Demographic Research*, (52), 1-24. https://doi.org/10.4054/DemRes.2025.52.1

Smith, S. K., Tayman, J., & Swanson, D. A. (2013). *A Practitioner's Guide to State and Local Population Projections*. The Springer Series on Demographic Methods and Population Analysis, (37). Springer, Dordrecht. https://doi.org/10.25336/P61883

Subsecretaría General de Análisis, Coordinación y Estadística (2021). *Demografía de la población rural en 2020*. AgrInfo 31. Ministerio de Agricultura, Pesca y Alimentación. Retrieved from: https://goo.su/FTKeNnq

Tornos, J. (2021). La lucha contra la despoblación en España. Marco normativo. *Cuadernos de Derecho Local*, (56), 55-83.

Toxo, R., & López, E. (2024). El despoblamiento en las áreas rurales de Galicia, España: Proyecciones demográficas a nivel municipal usando el método joinpoint y modelos extrapolativos (2023-2052). *AGER. Revista de Estudios sobre Despoblación y Desarrollo Rural*, (39), 287-338. https://doi.org/10.4422/ager.2024.09

United Nations (2024). *Methodology of the United Nations population estimates and projections*. World population prospects 2024: UN DESA/POP/2024/DC/NO. 10, July 2024 [Advance unedited version]. Department of Economic and Social Affairs, Population Division. UN.

Villegas, A., Millossovich, P., & Kaishev, V. (2018). StMoMo: An R package for stochastic mortality. *Journal of Statistical Software*, *84*(3), 1-38. https://doi.org/10.18637/jss.v084.i03

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Conceptualization	0 %	100 %	0 %
Data curation	50 %	0 %	50 %
Formal analysis	50 %	50 %	0 %
Funding acquisition	0 %	50 %	50 %
Investigation	50 %	0 %	50 %
Methodology	50 %	0 %	50 %
Project administration	0 %	50 %	50 %
Resources	0 %	50 %	50 %
Software	50 %	0 %	50 %
Supervision	0 %	50 %	50 %
Validation	0 %	50 %	50 %
Visualization	50 %	0 %	50 %
Writing – original draft	50 %	0 %	50 %
Writing – review & editing	0 %	100 %	0 %

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