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UNDERSTANDING AND MANAGING DEPOPULATION WITH SYSTEM DYNAMICS: A CASE STUDY IN WESTERN SPAIN (VITIGUDINO)

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Abstract: SPANDAM is a system dynamics model designed to examine the causes of depopulation in a given area and simulate the effects of policies aimed at addressing or mitigating depopulation dynamics and their consequences. Three scenarios have been simulated for the Vitigudino region: a baseline scenario, a moderate policy scenario, and a more aggressive policy scenario. Other measures are implemented at varying levels of intensity depending on the scenario. The simulation results show that the region's attractiveness significantly increases as a result of the implemented policies and the improved quality of life for residents. However, this improvement is not sufficient to reverse the depopulation dynamics. The increase in net migration, which turns positive in the highest-intervention scenario, does not offset the negative natural population growth. Nevertheless, the depopulation process slows down considerably, and although it is not fully reversed, the improvement in residents' quality of life is, in itself, a result that justifies political intervention in the area.

Key words: depopulation, system dynamics, Spain, Vitigudino, model, policy scenarios

Resumen: **Comprender y gestionar la despoblación mediante Dinámica de Sistemas: Un estudio de caso en el oeste de España (Vitigudino).** SPANDAM es un modelo de dinámica de sistemas diseñado para examinar las causas de la despoblación en un área determinada y simular los efectos de las políticas dirigidas a abordar o mitigar la dinámica de la despoblación y sus consecuencias. Se han simulado tres escenarios para la región de Vitigudino: un escenario de referencia, un escenario de políticas moderadas y un escenario de políticas más agresivas. Se aplican otras medidas con distintos niveles de intensidad según el escenario. Los resultados de la simulación muestran que el atractivo de la región aumenta considerablemente gracias a las políticas aplicadas y a la mejora de la calidad de vida de los residentes. Sin embargo, esta mejora no es suficiente para invertir la dinámica de despoblación. El aumento de la migración neta, que se vuelve positiva en el escenario de mayor intervención, no compensa el crecimiento natural negativo de la población. Sin embargo, el proceso de despoblación se ralentiza considerablemente y, aunque no se invierte por completo, la mejora de la calidad de vida de los residentes es, en sí misma, un resultado que justifica la intervención política en la zona.

Palabras clave: despoblación, dinámica de sistemas, España, Vitigudino, modelo, escenarios políticos

Highlights

- System Dynamics model (SPANDAM) applied to rural depopulation in Spain.
- Three policy scenarios simulated for the Vitigudino region.
- Policies improve attractiveness but do not reverse population decline.
- Net migration turns positive only under high-intensity interventions.
- Quality of life improvements justify political action despite continued decline.

1. Introduction

Depopulation is a demographic and territorial phenomenon that is increasingly studied, although it lacks a unified definition (Rodríguez-Soler et al., 2020; Stèbe et al., 2024). Broadly speaking, it refers to a decline in the number of inhabitants in a given territory compared to previous periods, caused by negative natural population growth, a negative migration balance, or a combination of both factors (Mladenov & Ilieva, 2012). This process is particularly significant in developed countries, where migration has become a key driver of change in human settlement patterns (Coleman & Rowthorn, 2011; Del Rey Poveda & Ortega Osona, 2011; Rees et al., 2017).

Depopulation transcends the demographic dimension, affecting social, economic, political, and cultural aspects, and requires interdisciplinary analyses to understand its causes and effects (García et al., 2024; Maeztu Redín, 2020; Makkonen & Inkinen, 2023). Globally, authors such as Li et al. (2019) emphasized that this phenomenon stems from an increasing dependence of rural areas on urban economies and their exclusion from the knowledge economy, leading to their abandonment (Camarero, 2020). Furthermore, the development model based on agglomeration and density economies exacerbates this issue, favouring metropolitan centres while relegating rural areas to the periphery, with limited development and access to basic services (Ayuda Bosque et al., 2001; Rodríguez-Soler et al., 2020).

These territorial inequalities have led to social demands related to the lack of resources, public and private services, as well as financial exclusion, highlighting the need for public policies to address the issue (Ayuda Bosque et al., 2001; Lozynskyy et al., 2024; Servillo et al., 2012). Similarly, rural areas face challenges such as unemployment, underemployment, social decapitalization, and demographic profiles characterized by aging, dependency, and a predominance of men – factors that intensify their reliance on urban areas (Camarero, 2020). Addressing depopulation, therefore, requires analysing it as a reflection of existing territorial inequality.

In Europe, the process of depopulation has persisted from the 19th century to the present, with varying rhythms and intensities across countries. In the United Kingdom and France, the phenomenon began in the second half of the 19th century, whereas in Southern European countries such as Spain, Portugal, and Italy, it gained momentum after World War II. In countries like Poland and Romania, this phenomenon is more recent (Collantes & Pinilla, 2020; Pinilla & Saez, 2021; Stèbe et al., 2024).

At present, Spain represents one of the most severe cases of depopulation in Europe. Beginning in the 1950s, the country underwent a socioeconomic structural change that spurred rural exodus, driven by modernization, urban-industrial development, and the growth of the service economy (Camarero, 2020; Recaño, 2017). However, it was not until the late 1970s that rural emigration, primarily involving young people and women, significantly intensified as they sought educational and employment opportunities in urban areas (Camarero et al., 1992).

Until the late 1980s, natural population growth in rural areas, partially offset migration losses. However, declining fertility rates and population aging reversed this trend, leaving migration as the primary factor sustaining population levels (Bernardi & Requena y Díez de Revenga, 2003; Coleman & Rowthorn, 2011; Collantes, 2019; Palacios et al., 2022). Foreign immigration, particularly in the final decades of the 20th century, helped mitigate the decline in natural population growth due to the younger and more fertile demographic profile of immigrants, in contrast to the reproductive patterns of the native population (Martín & Rosero-Bixby, 2011).

The 2008 crisis worsened the situation with a reduction in immigration, an increase in youth emigration, and, for the first time, a simultaneous negative migration and natural population balance in 2012, accentuating the loss of rural population (Camarero, 2020). In absolute terms, Spain has grown from 41.1 million in 2001 to 48.9 million in 2024 (INE, 2024a), but territorial distribution has become even more imbalanced. According to the Spanish Ministry for the Ecological Transition and the Demographic Challenge (MITECO, 2020), nine autonomous communities and 6,232 municipalities have lost population in the last decade, with smaller municipalities being the most affected: 86% of municipalities with fewer than 1,000 inhabitants have experienced depopulation.

Low population density exacerbates the problem, affecting the provision of basic services. With an average of 93 inhabitants per km², below the European average (120/km²), nearly 50% of Spanish territory has densities below 12.5 inhabitants per km². Additionally, aging is concentrated in small municipalities, where up to 30% of the population is over 65 years old. Since 2015, negative natural population growth has affected 80% of municipalities and is expected to persist in the coming decades, solidifying the demographic challenge in rural areas (MITECO, 2020).

This article focuses on analysing the challenges of depopulation and potential solutions in the Vitigudino region, an area located on Spain's western border, in the province of Salamanca. Figure 1 highlights the Vitigudino region in green on a map of the regional divisions of peninsular Spain.

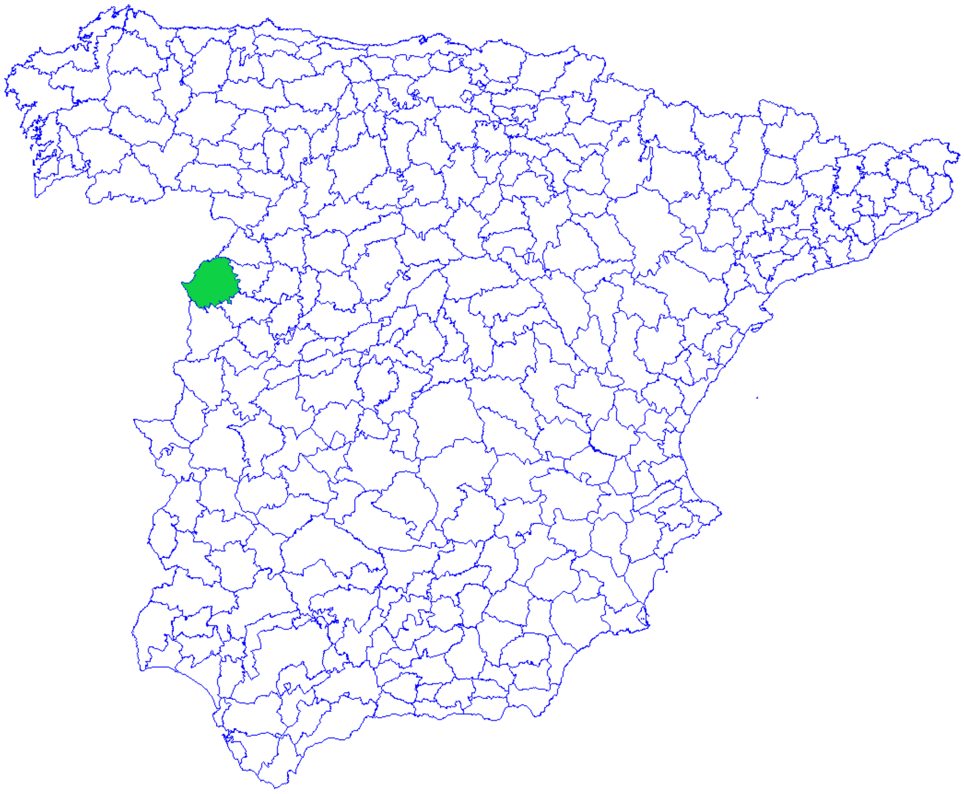

Fig 1. Location of the region of Vitigudino in peninsular Spain. Source: own elaboration

The municipalities of the Vitigudino region have lost 37.16% of their population since the beginning of the 21st century and 18.70% in the last ten years (INE, 2024b). However, the process of depopulation has been unfolding for a long time, intensifying during the 1950s, when rural exodus profoundly affected Spain's interior regions. Despite moderate migration growth in recent decades, the continuous decline in fertility rates and population aging have perpetuated demographic decline. Today, the Vitigudino region faces critical challenges to its economic and social sustainability (Álvarez, 2018).

Comprising 56 municipalities, this region represents a paradigmatic case of rural depopulation in Spain. Studying its current situation, as well as simulating its future evolution under different conditions, can provide valuable insights into the depopulation phenomenon in other European regions facing similar circumstances.

The SPANDAM (Spanish Demographic Dynamics Assessment Model) model was used to conduct the analysis and perform the simulations. SPANDAM is a system dynamics model designed to analyse the effects of different policy packages on the population trends of areas at risk of depopulation. The model calculates a general population attractiveness indicator based on a series of specific attractiveness indicators (demography, economy, education, health, transportation and communications, other services, environment). These indicators are calculated from variables computed by the model itself or based on exogenous projections and are affected by the simulated policies[2]. The general indicator affects emigration and immigration within the model, thereby modifying population projections.

[2] The idea of population attractiveness has been discussed previously in the literature (Elshof et al., 2017; Faugnerova & Hume, 2019; Fleming & Sinnot, 2018; Meijers & Van Der Wouw, 2019; Vidickienė, 2017), as has the fact that this attractiveness can be modified by policies (Auclair & Vanoni, 2017; Servillo et al., 2012).

SPANDAM is one of the latest developments in modelling aimed at studying depopulation and designing policies to combat it. Before it, there have been several previous approaches, though they differ significantly in terms of methodology, the aspects of depopulation they examine, and the geographic regions they focus on. For example, Refsgaard & Johnson (2010) and Navarro & Tapiador (2019) – like SPANDAM – use system dynamics, focusing on Norway and Spain, respectively. Other models employ different methodologies and concentrate on countries such as Italy (Reynaud et al., 2020; Reynaud & Miccoli, 2018), Japan (Hori et al., 2021), Ireland (Ballas et al., 2005), Poland (Sahebgharani et al., 2024), or Spain (Alamá-Sabater et al., 2021). Some purely theoretical models do not focus on any specific geographic area (Márton, 2022; Silveira et al., 2006).

The article is divided into the following sections: following the introduction, a methodological section explains the advantages of system dynamics (SD) for studying the phenomenon of depopulation and provides a brief description of the SPANDAM model. In the third section, based on the data collected and using the model's indicators, the current situation of Vitigudino is presented, along with its strengths and weaknesses in terms of attracting and retaining population. The fourth section specifies the scenarios that have been constructed, taking into account the region's initial situation and applying different policy packages. In the fifth section, the results obtained from different scenarios are presented. The sixth section is a discussion section, in which the results obtained will be related to the existing literature on the subject. Finally, the last section draws the conclusions from the research.

2. Methods

2.1 System dynamics and depopulation

The SPANDAM model is developed under a system dynamics methodology. SD is a methodological approach designed to understand the behaviour of complex systems over time, particularly systems characterized by feedback loops, delays, and nonlinear interactions. Originating from the work of Jay Forrester (1961), SD enables the analysis of how individual components within a system influence each other and the overall structure, producing emergent behaviours. This approach is particularly useful for studying dynamic, multifaceted problems that evolve across various scales (Sterman, 2000), such as migration patterns or demographic shifts. By modelling interactions between variables, SD allows researchers to observe how population trends unfold in the context of economic, social, and environmental factors.

When applied to the study of depopulation, system dynamics offers several advantages. First, it provides a holistic framework that integrates the multiple dimensions affecting demographic trends – such as economic conditions, political decisions, migration flows, and social factors (Court & McIsaac, 2020; Taylor & Masys, 2018). Unlike traditional demographic models, which may focus narrowly on population size and fertility rates, SD emphasizes interdependencies and feedback loops (Whitmore, 1991), such as how a declining population can lead to reduced social services, which in turn accelerate further population decline.

Additionally, SD models enable scenario analysis, allowing policymakers to simulate various interventions and assess their potential impact on population retention or recovery (Lauf et al., 2012). For example, researchers can test the effects of policy changes like economic incentives for rural repopulation, improvements in healthcare, or increased investments in infrastructure, assessing how these initiatives might alter migration patterns and population density over time (Navarro & Tapiador, 2019). This capacity for scenario modelling is especially critical for regions facing persistent depopulation, such as some rural areas in Europe (Jato-Espino & Mayor-Vitoria, 2023; Navarro & Tapiador, 2019; Refsgaard & Johnson, 2010).

Finally, a key benefit of SD is its ability to capture the nonlinearities inherent in depopulation phenomena, where small changes in one aspect of the system can trigger disproportionately large effects across other dimensions. For instance, depopulation often correlates with economic decline, but the relationship is not linear. As population declines, local economies suffer, leading to further outmigration, exacerbating the issue in a self-reinforcing feedback loop (Navarro & Tapiador, 2019). SD models allow for the inclusion of such non-linear feedback, providing more nuanced insights than traditional linear approaches.

2.2 Model description

The SPANDAM model is organized into eight distinct modules (Figure 2): demographic, economic, other services, health, education, transport and communications, environmental, and attractiveness. Each module (except the attractiveness module) produces a population attractiveness indicator specific to its dimension. These indicators are created from multiple dimensional variables, normalized within a range of 70 to 130. The indicators from each module are then combined to form an aggregate population attractiveness indicator, which influences both emigration and immigration within the model. The methodology for constructing the indicators is based on INE (2020), Mazziotta & Pareto (2016, 2018) and OECD (2008).

Most modules are influenced by various external inputs that the user can adjust to analyse their impact on different variables. These inputs, referred to as policies, aim to simulate various policy interventions – primarily implemented by public authorities but also potentially by private initiatives – to assess their effects on specific indicators and endogenous variables (Rana & Morita, 2000). The sources of the model data are given in the Supplementary Material[3].

The demographic module is central to the model, as it accounts for the population within the case study area, differentiated by age (from 0 to 100+ years) and sex. The total population is divided into 202 groups. The projection methodology of the population is based on Willekens & Drewe (1984). However, in this methodology, the emigration rate and immigration are given exogenously, whereas in our model, migrations are calculated endogenously. To calculate population evolution, we use exogenous projections of mortality rates by age and sex, as well as fertility rates among women of childbearing age. These projections were generated by the Centre d'Estudis Demogràfics (CED) based on projections from the Instituto Nacional de Estadística (INE). The emigration and immigration rates by age and sex are calculated endogenously based on observed patterns in historical data and changes in the overall attractiveness indicator.

The demographic dimension indicator, later used in conjunction with other specific indicators to calculate the overall attractiveness indicator, comprises seven variables: the average age of the population, the sex ratio, the population growth rate, the birth rate, the migration balance per thousand inhabitants, the population density of the territory, and the percentage of the population that has arrived in the region within the last five years. To aggregate these seven variables into a single indicator, they are normalized within a range of 70 to 130. Normalization takes into account the values for municipalities across Spain, excluding outliers, where a value of 70 represents minimum attractiveness, and 130 represents maximum attractiveness. Depending on whether each variable positively or negatively correlates with population attractiveness, its relationship with the normalized variable will be either direct or inverse (Mazziotta & Pareto, 2016). The adjusted Mazziotta-Pareto method (Mazziotta & Pareto, 2018) is used to aggregate the seven variables into the demographic dimension-specific indicator. The same normalization and aggregation method is applied to construct the remaining population attractiveness indicators.

Additionally, within the demographic module, municipalities in the region are grouped into ten clusters, ordered by population size per municipality. The average population per municipality in each group (which evolves as the region's total population evolves) is used in other modules to calculate the endogenous component of service availability in the region.

[3] The Supplementary Material is divided into four files. One of them corresponds to the Model Parameters, which include the parameters that remain constant regardless of the scenario design. The other three files (one for each simulated scenario) are the Scenario Parameters and contain the parameters used to design the scenarios.

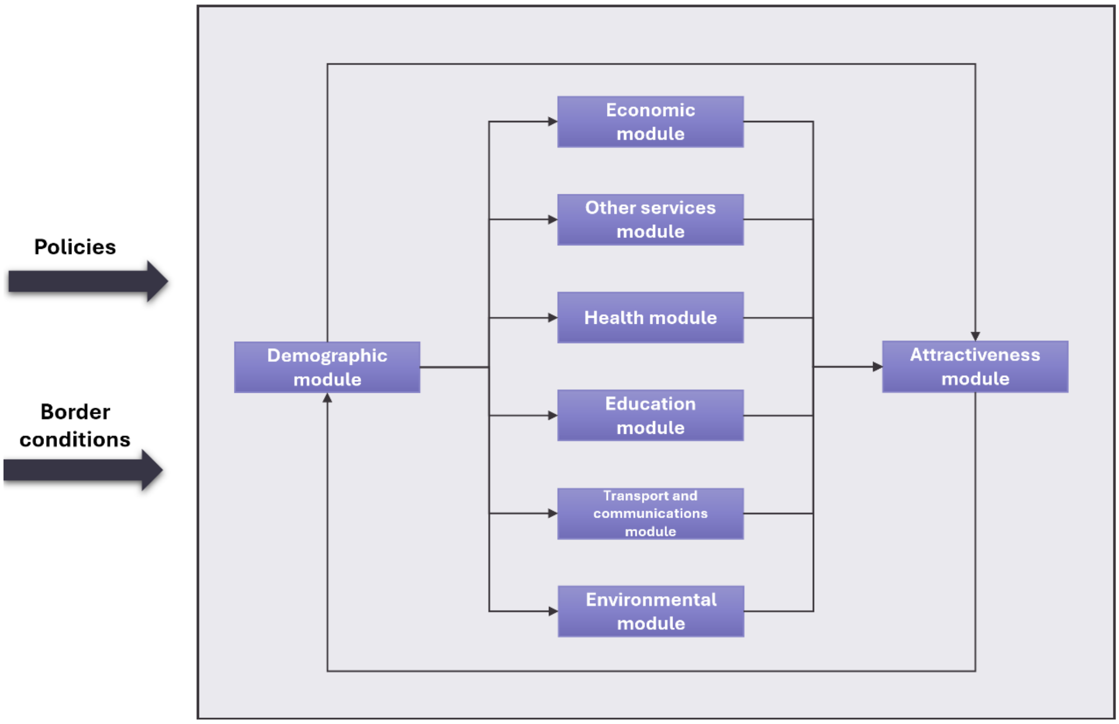

Fig 2. Model structure by modules. Source: own elaboration

In the economic module, variables relevant to understanding a region's attractiveness from an economic perspective are assessed. The positive correlation between a region's strong economic performance and its attractiveness to population has been extensively documented (Camarero, 2020; Camarero & Oliva, 2019; Jansen, 2020; Moreno et al., 2021). Variables forming part of the specific population attractiveness indicator for the economic dimension include the average number of enterprises per municipality (weighted by population), the diversification index[4], the unemployment rate, the temporary employment rate, and average net income per capita.

The regional unemployment rate is calculated as a function of the national unemployment rate, which is included as an exogenous input. The same approach is applied to net income per capita, which is calculated as a function of national GDP per capita. In both cases, improvements can be introduced exogenously as policies aimed at promoting employment or increasing residents' income. The diversification index and the temporary employment rate evolve exogenously, based on expectations or the effects of policies intended for the region. Finally, the average number of companies per municipality in the region is calculated from the average size of companies and employment. The average size of the companies may vary as part of the model scenarios.

The importance of accessibility to certain social services in attracting and retaining the population has been addressed by several authors (Camarero & Oliva, 2019; Merino et al., 2024; Merino & Prats, 2020; Pinilla & Sáez, 2021b; Sánchez-Zamora et al., 2014). Three of the modules of the model focus on this aspect and share a similar structure: education, health, and other services modules. Variables comprising their respective indicators include average travel time within the region to access certain services. In the case of health care, the variables included are: travel time to a health centre, a hospital, a pharmacy, and an emergency service. In the case of education, they are: travel time to a daycare centre, an institution offering cultural education services, a primary school, a secondary school, a high school or vocational training centre, a university, and an extracurricular training service. Finally, the 'other services' module includes the variables travel time to a police station, a library, a bank office, an entertainment company,

[4] This index reflects the level of economic diversification. It is calculated using the Shannon Index (Shannon & Weaver, 1949). The Shannon Index has been applied across various disciplines, including economics (Attaran & Zwick, 1987, 1989; Nissan & Carter, 2010).

a day centre, a post office, the proportion of the population living in municipalities with bars, and the rate of companies offering services to individuals per thousand inhabitants.

To calculate average travel time, the previously mentioned division of municipalities into ten groups is used. If there is availability of a service in a municipality, it is assigned a travel time of zero; if there is a lack of the service, travel time is calculated as a function of the number of such services in the region (the more services, the higher the likelihood of having one nearby). The number of services evolves with the population of each of the ten groups of municipalities, and additional services can be added as policy measures within the model.

In the other services module, two variables are not of the “time to x service” type and are part of the indicator. These variables are the rate of companies offering services to individuals per thousand inhabitants and the presence of a bar; while the former evolves exogenously, the second is endogenous, according to the changes in the population.

Additionally, the specific indicator for the communication and transport module includes the following variables: travel time to access a taxi service, a gas station, a highway, a train station, a provincial capital, a municipality with more than 2000 inhabitants, and the percentage of households with 100 Mbps internet coverage. The role of telecommunications, transport infrastructure and transport services is essential in ensuring good living conditions for the residents of a given area and, therefore, in improving the population attractiveness of that area. This issue has been extensively addressed in the literature (Garcilazo, 2013; Gutiérrez et al., 2020; Llorent-Bedmar et al., 2021; Marjavaara, 2007; Philip & Williams, 2019; Rosario et al., 2021).

The calculation for travel time to a taxi service, gas station, or municipality with over 2000 inhabitants, follows a similar procedure to those described in previous modules (for municipalities with more than 2000 inhabitants, no policies to add services apply). For train stations or highways, the change is exogenous, though it remains constant if no new railway lines or road networks are planned. The average time to reach the provincial capital also remains constant. The evolution of 100 Mbps internet coverage is exogenous, depending on technological progress or public policies to expand internet infrastructure.

Finally, the environmental module is the least complex in the model. Its indicator includes physical variables that are either fixed, like the average slope of the territory, or vary based on projections from the Agencia Estatal de Meteorología (AEMET), such as annual accumulated rainfall and average temperature.

The main equations of the model are shown in Appendix A.

3. Current situation of Vitigudino

The situation in Vitigudino is generally not positive in demographic terms. The region clearly shows a process of aging and depopulation, typical of many rural areas in Spain. With an average age of 56.7 years and a sex ratio of 107.7, the region has an older population structure and a higher male population than the national average. The low birth rate of 4.04‰ and a negative migration balance of - 4.78‰ indicate a loss of inhabitants, both due to the reduced number of births and migration to other regions. Although the population that has arrived in the municipality over the past five years constitutes 14% of the region's population, this immigration has not been sufficient to reverse the trend of population decline. All these factors result in a very low population density (15.9 people/km²), which is significantly below the national average and limits economic development and the provision of services.

Figure 3 shows the normalized variables that comprise the attractiveness indicator for the demographic dimension. All variables, except for the sex ratio, are below 100. For each variable, 100 represents the average of Spanish municipalities, excluding the extremes. The fact that the region is, in most cases, below the average highlights the critical situation it faces.

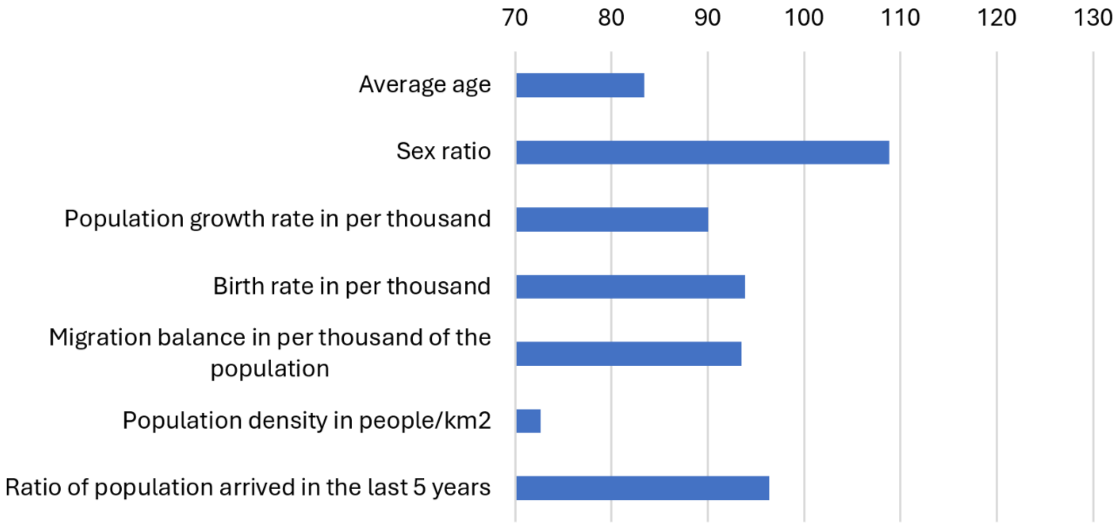

Fig 3. Normalized variables that compose the attractiveness indicator of the demographic dimension. Source: own elaboration

Regarding the situation in the other dimensions that make up the population attractiveness indicator, Figure 4 shows that Vitigudino does not reach a value of 100 in any of the dimensions, except for the environmental dimension, which slightly exceeds this value. A particularly poor result is obtained in the education dimension and the transportation and communications dimension, with values of 83.2 and 86.1, respectively.

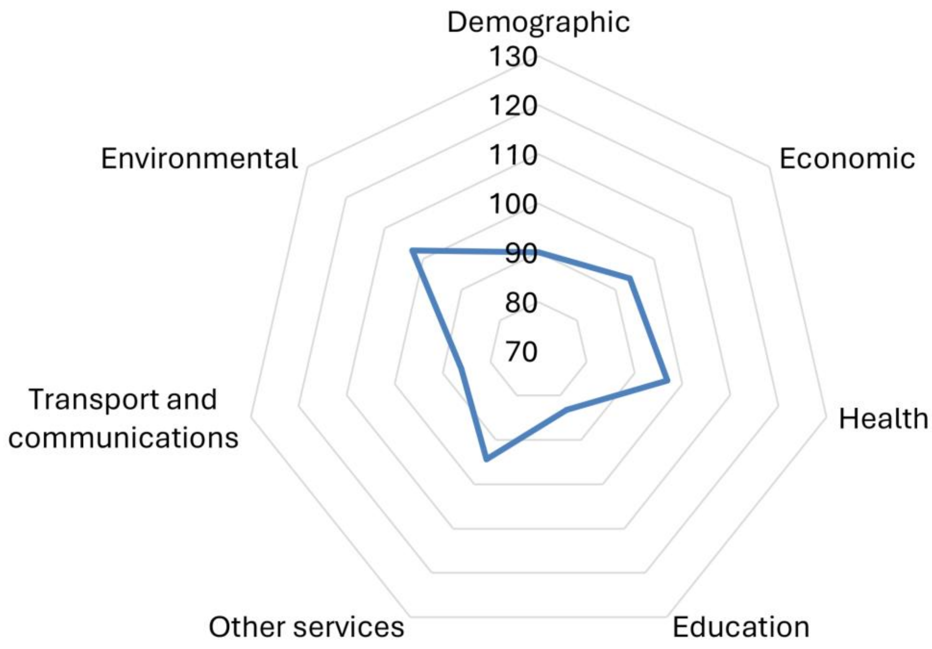

Fig 4. Value of the attractiveness indicators of the different dimensions at the start of the simulation. Source: own elaboration

As seen in section two, many of the variables that constitute the indicators are of the type "time to access x service." The time to access services primarily depends on two factors: the availability of services and the effectiveness of transportation infrastructures (which, in turn, depends on the quality of the infrastructures and the geography of the region). The availability of services in Vitigudino is significantly below the Spanish average in terms of the percentage of municipalities that have each service. Figure 5 compares the percentage of municipalities with a particular service in Spain as a whole and in Vitigudino. The provision of services is significantly lower for all types of services and that some important ones, such as childcare or day care, are completely lacking.

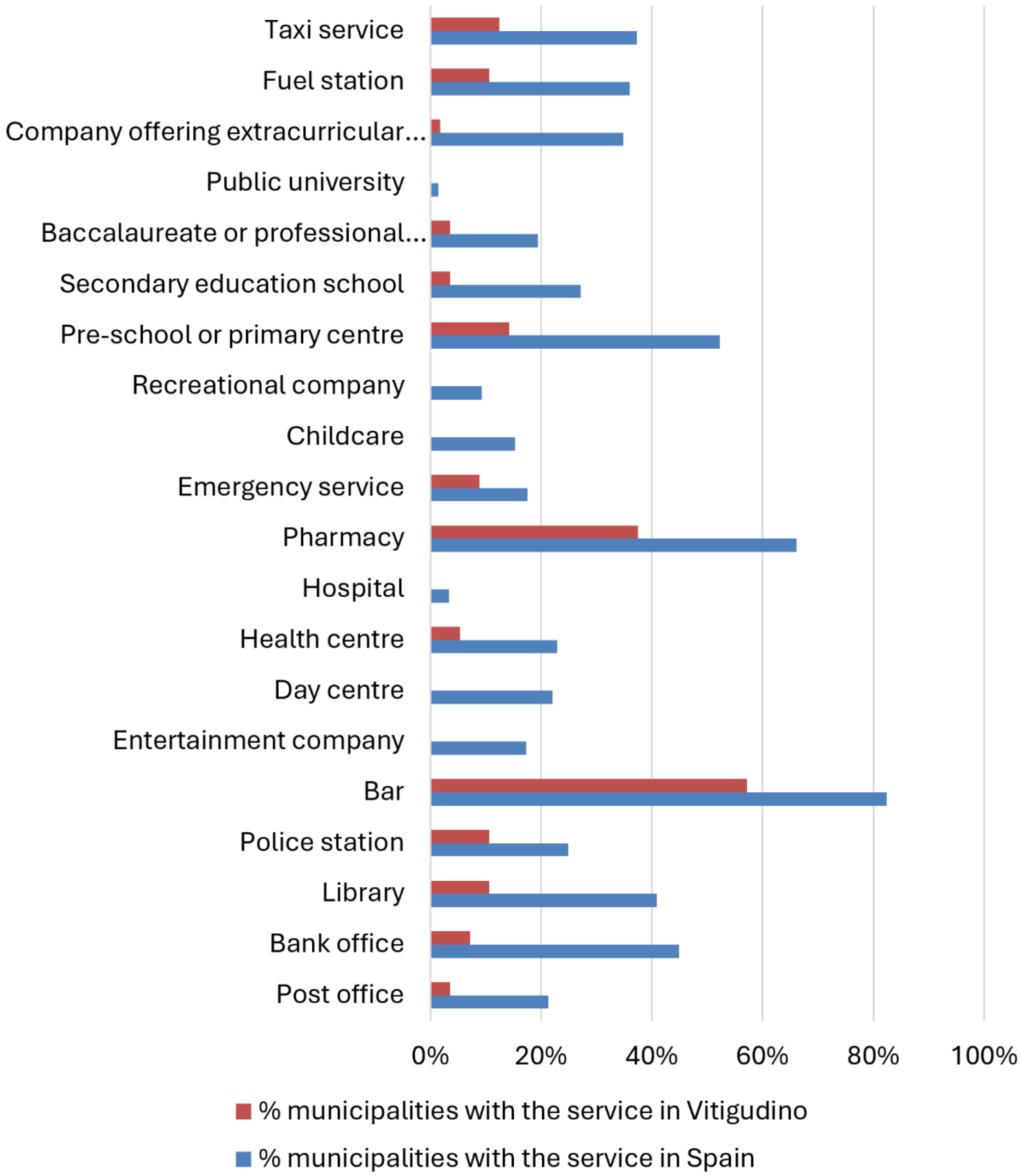

Fig 5. Comparison of the percentage of municipalities with a certain service in Vitigudino and in Spain. Source: own elaboration

On the other hand, to measure the effectiveness of transport infrastructures, the suitability of the geography and the efficiency of the distribution of services (whether or not they are highly concentrated in any part of the territory), the relation between the percentage of municipalities with a given service in the region and the average time of the municipalities that do not have the service can be used. Figure 6 compares this relationship in Vitigudino and in Spain as a whole. Interestingly, the curve corresponding to Vitigudino is below that of Spain, which means that with the same percentage of municipalities with a given service, the time to access that service in the municipalities that do not have it is less for Vitigudino than for the national average. This most probably has to do with the fact that the geographical concentration of services is greater in Spain than in Vitigudino and is not related to a lower quality of the infrastructures in the rest of Spain or with a less favourable geography. Thus, we can conclude that the poor provision of services constitutes the main problem in the region under study, rather than an inefficient transport infrastructure or a high concentration of services.

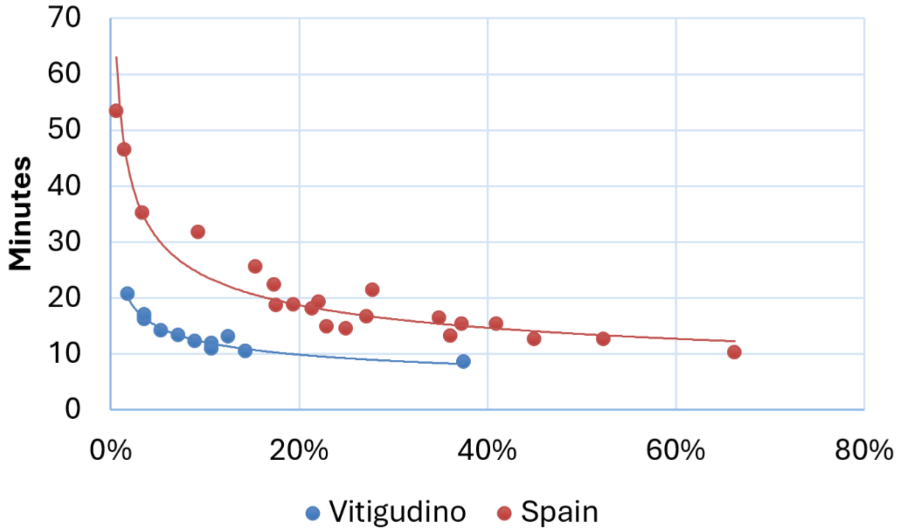

Fig 6. Average time to the closest service as a function of the percentage of municipalities in the region having the service for Vitigudino (blue curve) and Spain (red curve). Source: own elaboration

4. Scenario specifications

To assess the effects of policy implementation on the population in the Vitigudino region, three scenarios have been designed. A baseline scenario with no policies implemented simulates the continuation of current trends with no additional action from the government. A moderate policy scenario (Policy Scenario 1) seeks to improve the region's service provision and other key variables, starting from the current situation. Finally, an ambitious policy scenario (Policy Scenario 2) involves a more intensive intervention in the area.

In the scenarios design process, the aim has been to focus on the weakest dimensions with the greatest potential for improvement. First, since most policies involve adding additional services to the region – and, as observed in the previous section, Vitigudino is generally well below the average of Spanish municipalities – a policy has been established to bring the region up to a certain percentage of the Spanish average in terms of service provision.[5] In Policy Scenario 1, services reach 25% of the Spanish average, while in Policy Scenario 2, services reach 50% of the Spanish average. Secondly, efforts have been made to impact the variables that compose the attractiveness indicator in the economic dimension: the diversification index and temporary employment rate, which are already close to the Spanish average, are brought up to that level in both scenarios. The average company size is also reduced by 10% in Policy Scenario 1 and by 20% in Policy scenario 2. Additionally, a 1% increase in the employment rate and €500 in net disposable income have been added in policy scenario 1, and a 2% increase in the employment rate and €1000 in net disposable income in policy scenario 2. Both amounts are added to the unemployment rate and net income calculated endogenously in the model. Thirdly and lastly, the internet coverage ratio of 100Mbps has been increased to 100%, as the current Spanish government plan in this respect is to reach this target for all municipalities in Spain by 2025 (MINECO, 2022).

All policies are implemented gradually, with additional services being introduced following a linear function from the start of the simulation until 2050. The same applies to economic variables. The only exception is the internet coverage ratio of 100 Mbps, which has been achieved in 2025, as previously mentioned.

[5] As previously mentioned, the provision of services is endogenous in the model and, in addition to this endogenous provision, extra services can be added. Therefore, the policy is designed in such a way that, starting from the initial availability of services, x extra services are added, reaching, ceteris paribus, the desired percentage of municipalities with service. However, since the endogenous part does not remain constant, the result will not be the expected percentage, but will be above or below, depending on the behaviour of the model.

On the other hand, there are a series of boundary conditions common to all three scenarios: fertility and mortality rates, the evolution of Spain's GDP per capita, the behaviour of the national employment rate, and changes in temperature and precipitation throughout the simulation. The fertility and mortality rates were provided by the CED, based on INE projections. GDP per capita follows the growth trend of the past 20 years until 2071, the final year of the simulation. The national employment rate continues its current upward trend, reaching the historical peak of 2007 by 2035. From that point onward, it grows very slowly until the end of the simulation. Finally, temperature and precipitation follow AEMET projections (AEMET, 2024), aligned with the Representative Concentration Pathway (RCP) 4.5 of the Intergovernmental Panel on Climate Change (IPCC).

The values of the boundary conditions and policies are detailed in Appendix B. Additionally, the Excel files corresponding to the data introduced into the model for each scenario can be found in the Supplementary Material.

5. Results

The simulation results show a clear improvement in attractiveness indicators; however, this improvement is not sufficient to reverse the depopulation process, although it does manage to slow it down. Figure 7 presents three radial charts, each corresponding to one of the simulated scenarios.

In the Baseline scenario, the demographic and economic dimensions improve slightly compared to the beginning of the simulation. The demographic indicator increases from 90.1 at the start of the simulation to 92.5 by the end, while the economic indicator rises from 93.8 to 98.7. This improvement is attributed to positive national or regional trends, such as fertility and mortality rates, as well as GDP per capita and employment, which are sufficiently favourable to produce this slight improvement. In contrast, the indicators for healthcare, education, communications and transportation, and other services dimensions gradually deteriorate. This decline is due to the continuous population loss in Vitigudino, which results in a corresponding loss of services. Consequently, access times to these services in the area increase, leading to a decrease in the respective indicators. Meanwhile, the environmental indicator remains relatively stable. Since its variables are exogenous, this indicator evolves in the same way across all three simulations.

Policy Scenario 1 results in an improvement across several indicators that worsened in the Baseline scenario, as well as a more pronounced improvement in those that were already positive. From the start to the end of the simulation, the demographic indicator increases from 90.1 to 94.3, the economic indicator from 93.8 to 100.4, the educational indicator from 83.2 to 98.6, and the other services indicator from 94.3 to 102.5. However, the healthcare and transportation and communications indicators decline. The healthcare indicator decreases from 96.9 to 91.3, while the transportation and communications indicator drop from 86.1 to 82.3. The decline in the transportation and communications indicator occurs despite achieving 100% coverage of the 100 Mbps internet ratio. This is because, as the population continues to decline, the only municipality in the region with more than 2,000 inhabitants falls below that threshold, significantly increasing the average travel time to a municipality of this size. In addition, policies to improve access times to a fast-track or train station have not been included either, as they are considered national policies with a low likelihood of implementation. Moreover, no additional healthcare services were included in Policy Scenario 1, adhering to the rules outlined in the previous section and as detailed in Appendix B.

Finally, in Policy Scenario 2, all dimension indicators improve except for transportation and communications, which remain almost constant (declining slightly from 86.09 to 86.03). The demographic indicator increases from 90.1 to 95.9, the economic indicator from 93.8 to 101.6, the healthcare indicator from 96.9 to 109.6, the educational indicator from 83.2 to 108.7, and the other services indicator from 94.4 to 113.7. It is noteworthy that only by including sufficient services to reach 50% of the Spanish average in terms of the percentage of municipalities with a given service is it possible to achieve a significant improvement in the time-to-service variables. Figure 8 illustrates a comparison of the values of time-to-service-x at the initial moment and the final moment for each of the three simulations.

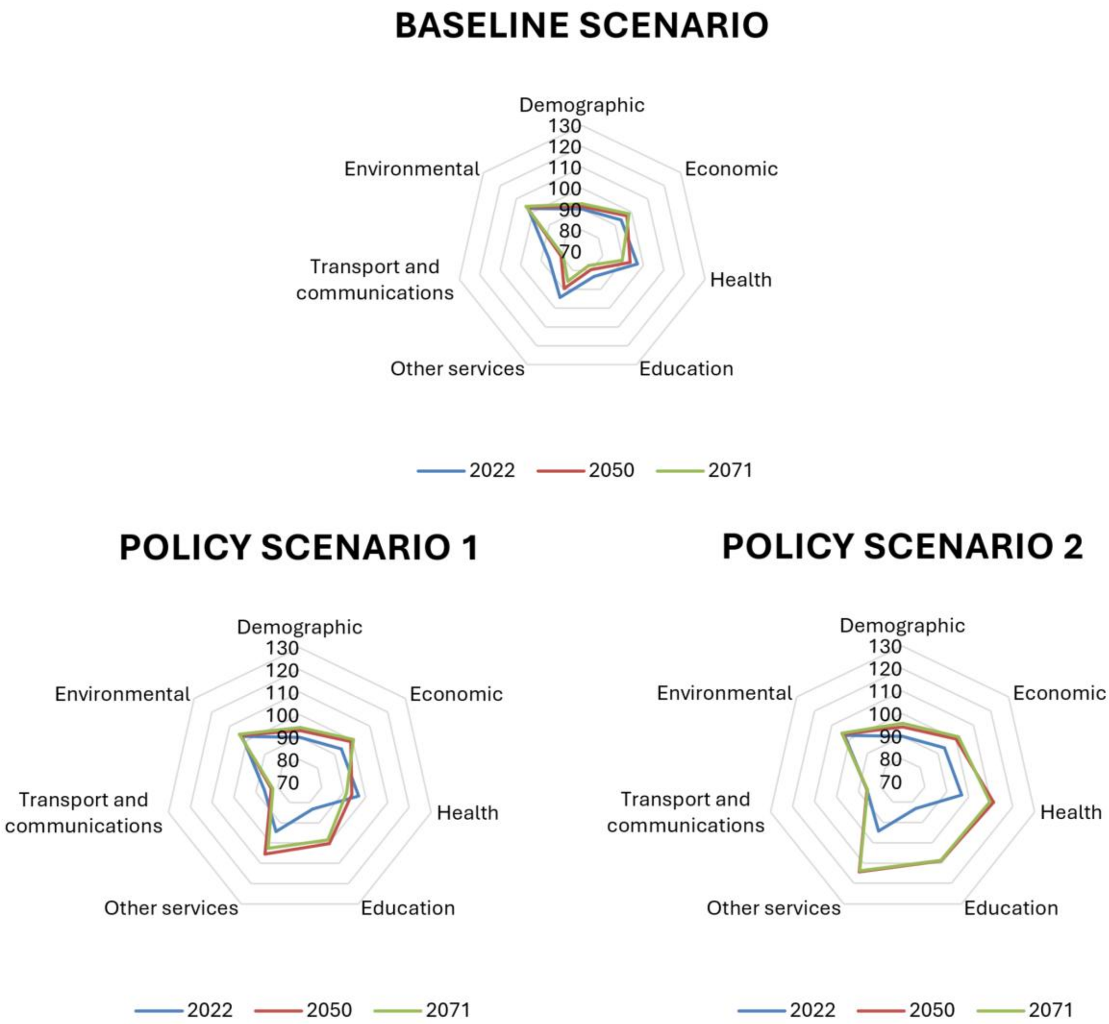

Fig 7. Value of the attractiveness indicators of the various dimensions in different scenarios. Source: own elaboration

This significant improvement in the indicators is partly related to the shape of the curve shown in Figure 6. When starting from a situation with few (or no) services of a certain type, the inclusion of new services of that type significantly reduces the average time to access them in the area. Conversely, for services that are already more abundant in the area, achieving substantial progress becomes much more difficult.

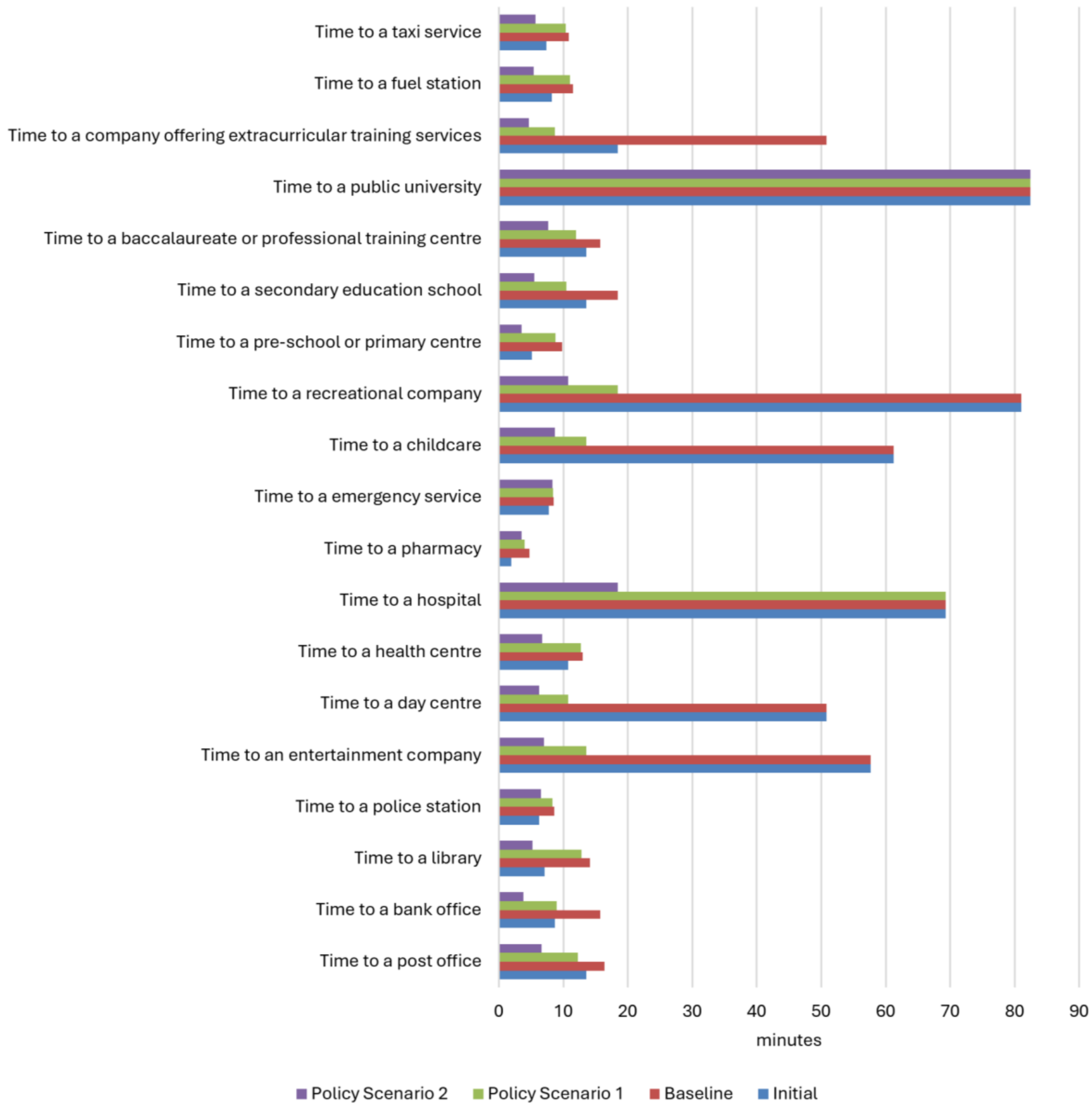

Fig 8. Comparison of time-to-service values at the initial and final time of simulation across the three simulations. Source: own elaboration

Regarding population, the trend is that it continues to decline across all three simulations. In 2022, the population stood at 14,804 people. However, in the Baseline scenario, by 2071, the population decreased by 64.7%, to just 5,223 individuals. On the other hand, in Policy Scenario 1, the population decreases by 57.8%, reaching 6,252, while in Policy Scenario 2, it declines by 50.2%, resulting in a population of 7,369.

The reason for this decline is the persistent negative natural population growth, which, unlike in other areas of Spain, is not offset by positive net migration. In all simulations, except for Policy Scenario 2, net migration remains negative. In Policy Scenario 2, the peak is reached in 2042 with a positive balance of 10 people, representing 0.9‰ of the region's population at that time. However, natural population growth, even in its best year (the final year of the simulation), stands at -8.6‰ of the population. The trends in population, population growth rate, natural growth, and net migration are illustrated in Figure 9.

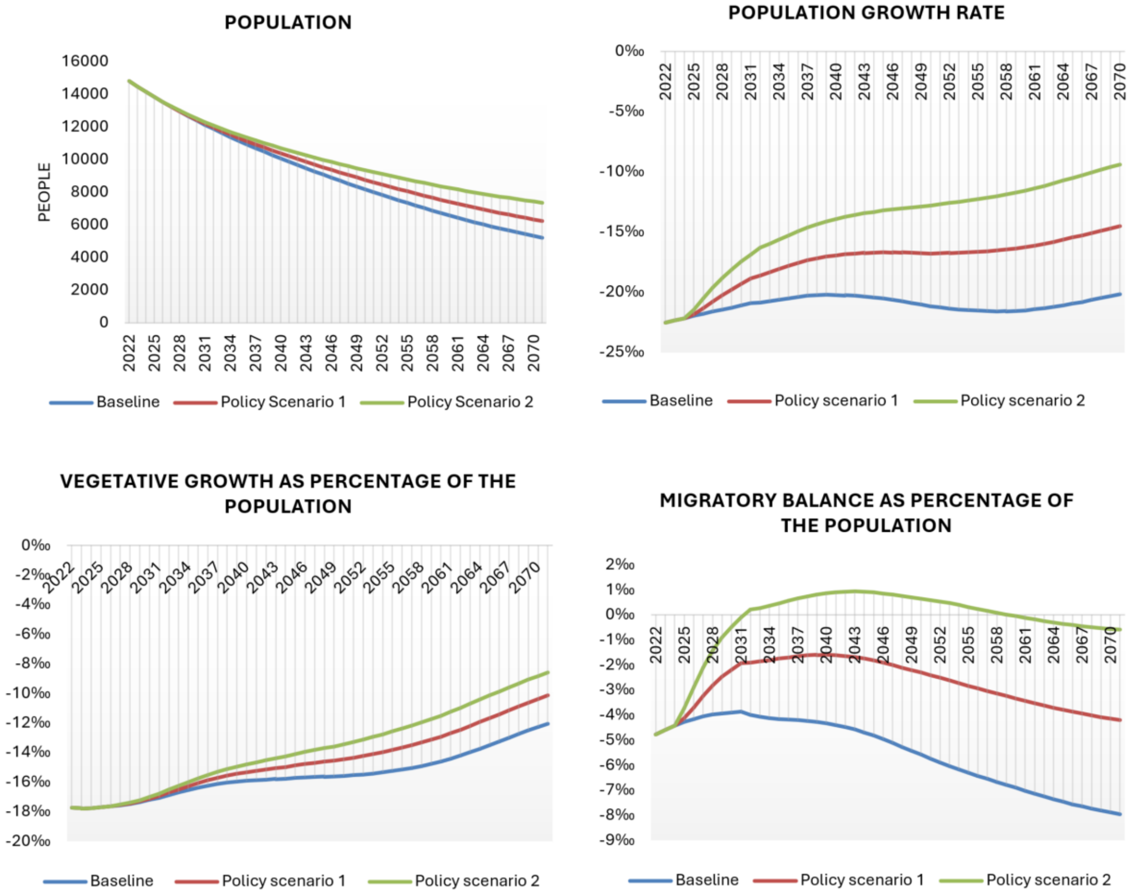

Fig 9. Trends in population, population growth rate, natural growth as a percentage of the population, and net migration as a percentage of the population. Source: own elaboration

Finally, the age and sex distribution of the population maintains a similar structure across all scenarios, as shown in the population pyramids in Figure 10. However, the varying net migration balances in the simulations introduce some differences. Figure 11 presents the region's average age and sex ratio. It can be observed that, although the average age decreases in all scenarios – primarily due to the deaths of a highly aged population – the scenarios with greater policy intervention result in a more rapid decline in the average age. This trend is driven by the increase in net migration, as migrants tend to have a lower average age compared to the overall population of the region. Also, in the pyramids, it can be observed that the central part, corresponding to adulthood, is wider in scenarios with greater political intervention. A similar pattern can be seen with the region's sex ratio. Since migrants typically exhibit a higher sex ratio, the increased net migration in Policy Scenario 1 and Policy Scenario 2 leads to a slightly higher sex ratio in these scenarios. This highlights how migration flows not only influence the population size but also subtly shape the demographic structure of the region.

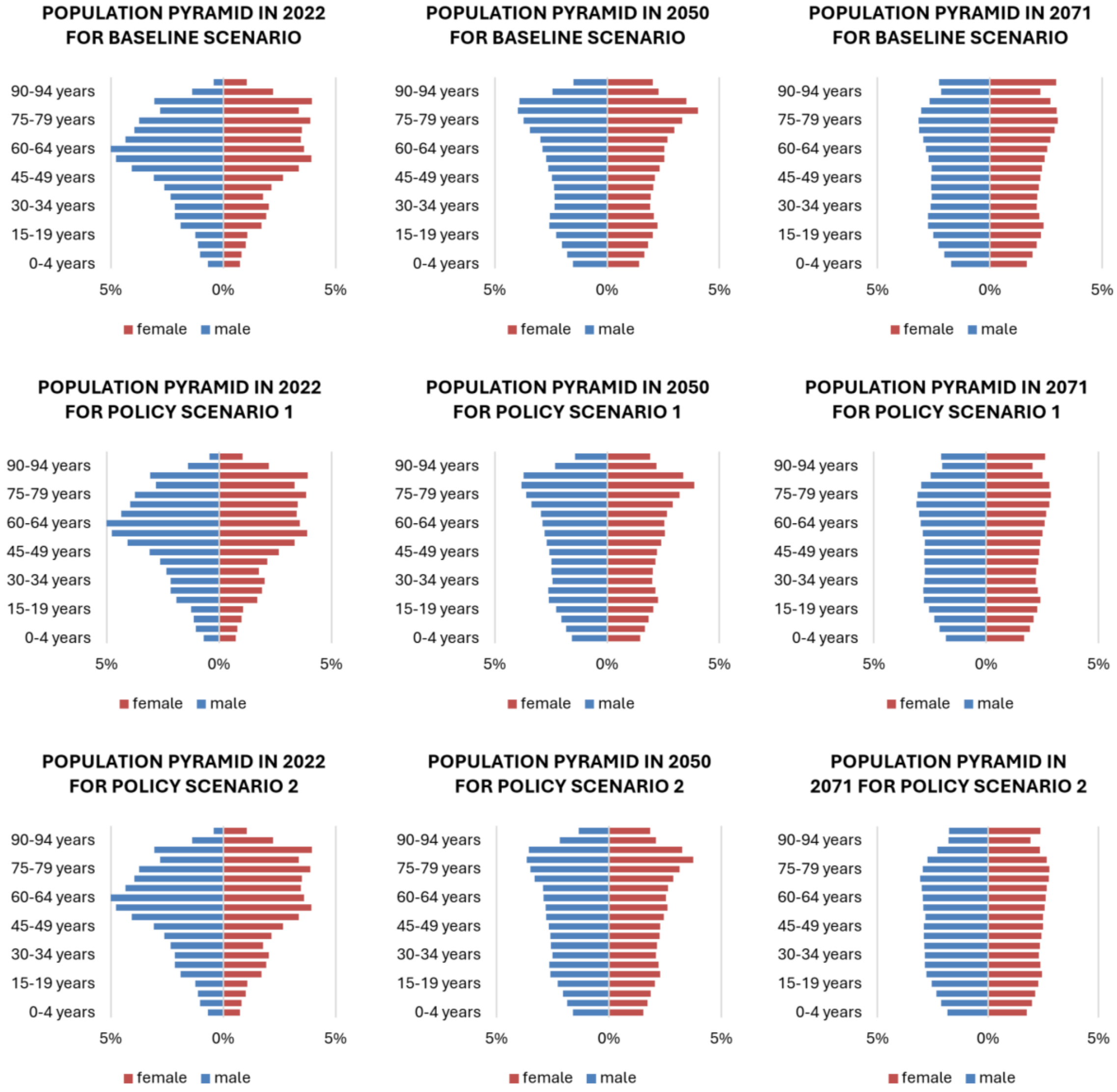

Fig 10. Population pyramids of the different scenarios. Source: own elaboration

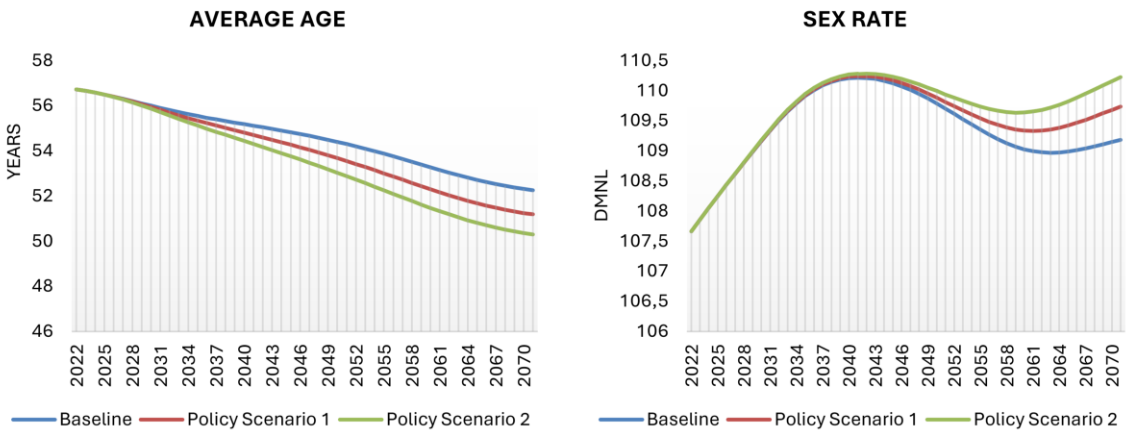

Fig 11. Average age and sex ratio. Source: own elaboration

6. Discussion

The policies implemented in the simulation have the potential to substantially enhance the region's attractiveness and the well-being of its inhabitants. However, this is not sufficient to reverse the depopulation trend. Other studies addressing this issue report similar findings (Martínez-Carrasco Pleite & Colino Sueiras, 2024; Williams et al., 2021). The model outputs from the baseline scenario highlight the severity of the region's demographic situation and the urgent need for political intervention. In Policy Scenario 1, which includes moderate improvements, depopulation continues to decrease, albeit at a slower pace. Conversely, the results from Policy Scenario 2, featuring more intensive political interventions, suggest that more aggressive policies could have a positive impact, though still insufficient to reverse the depopulation trend. This pattern reflects the persistent nature of depopulation (Bruno et al., 2021; Cawley, 1994; Makkonen & Inkinen, 2023; Mladenov & Ilieva, 2012; Otovescu & Otovescu, 2019; Paniagua, 2020), where factors such as low birth rates, aging populations, and emigration continue to influence demographic dynamics (Coghe, 2022; Slack & Jensen, 2020).

Nevertheless, it is important to recognize that Vitigudino's initial situation is particularly bad, which consequently affects the results. It is quite possible that in other regions where population aging is less severe and the initial provision of public services is not as low, implementing depopulation-combating policies with the same intensity as those applied to Vitigudino in our simulations could reverse the depopulation trend.

The success of anti-depopulation policies varies significantly (Pinilla & Sáez, 2021a). In the specific case of Spain, regions such as the Sierra de Guadarrama or the Pyrenees have implemented policies like tax incentives to attract new residents and infrastructure improvements (Maeztu Redín, 2020; Martínez-Carrasco Pleite & Colino Sueiras, 2024; Pinilla & Sáez, 2017; Rodríguez-Rodríguez & Larrubia Vargas, 2022). In some instances, such as in France or Germany, the combination of economic and social development policies has succeeded in stabilizing or even increasing the population. However, in Spain, interventions have proven insufficient (Stèbe et al., 2024). In the case of Vitigudino, the results of our model suggest that even with a relatively strong intervention, reversing the depopulation trend is not feasible.

The literature stresses that addressing the issue of depopulation requires a comprehensive approach that not only focuses on economic policies but also considers social and cultural factors (Koning et al., 2021; Larraz & García-Gómez, 2020; Rhodes, 2019; Rodríguez-Rodríguez & Larrubia Vargas, 2022). For instance, the study by Bruno et al. (2021) underscores the importance of fostering local identity and a sense of community to attract and retain the population. These issues, undoubtedly significant, are challenging to incorporate into a model and were not considered in our case. It would be an interesting avenue for future work to make an effort to integrate these factors into the model and analyse how they might influence the results obtained.

The results we have presented carry significant implications for policymakers. On the one hand, it is evident that policies need to reach a certain level of intensity to produce noticeable outcomes. On the other hand, they must address multiple aspects of life in municipalities. Simply improving services is not sufficient; a comprehensive approach is required, encompassing economic development, education, healthcare, and infrastructure (Coghe, 2022; Tancred et al., 2024). Relevant examples are the policies implemented in Estonia or Ireland, where coordinated approaches integrating multiple dimensions of rural development have yielded highly positive results (Stèbe et al., 2024). In Spain, the "Estrategia Nacional frente al Reto Demográfico" includes measures such as digital infrastructure expansion and fiscal incentives for rural entrepreneurs (Sáez, 2021). In Ireland, coordinated rural development programs have combined housing, transport, and education policies to stabilize population levels (Stèbe et al., 2024).

The literature also highlights the importance of involving the local community in the design and implementation of these policies (Sáez, 2021). Citizen participation can enhance the effectiveness of interventions, as residents possess in-depth knowledge of their needs and challenges (Hollander, 2013). In this context, the continuous evaluation of implemented policies is also essential (Stèbe et al., 2024), as it is the collaboration across different levels of government and sectors (Tancred et al., 2024). Once again, while these practices are highly important, they are challenging to incorporate into a model. One possible approach would be to adjust model parameters – or even the modelling of specific components – based on residents' insights gathered through surveys or interviews. A similar approach could be applied to the design of the policy packages implemented. However, the human and financial resources required to conduct this type of research are quite substantial.

From a theoretical perspective, this study contributes to the understanding of depopulation as a multidimensional and dynamic process, demonstrating the capacity of SD to capture feedback loops and non-linear processes, which makes it suitable for the study of the depopulation phenomenon. In addition to this, it is worth adding the advantages from a managerial point of view, as the findings highlight the importance of designing integrated policy packages that simultaneously address economic, infrastructural, and social dimensions. Local governments can use models like SPANDAM to prioritise interventions and anticipate long-term demographic impacts.

Lastly, it is essential to emphasize the limitations of SPANDAM and, more broadly, of models in general, in generating knowledge about the challenge of depopulation. Besides the points raised in the previous paragraphs, at least two additional considerations should be addressed. First, every model is a representation of reality based on a process of abstraction and formalization. This means that elements deemed incidental, which are not considered essential to the subject of study, are excluded from the dynamics being represented. In doing so, there is a risk of overlooking elements that may not be important in most cases but could be critical in specific contexts. In our case, we believe that this error has been avoided and that Vitigudino does not have unique characteristics significant enough to render SPANDAM inapplicable to its analysis. Second, it is important to highlight that, in the social sciences, the outcomes of models are dependent on the stability of the social structure they are built and seek to represent. If profound changes occur in this structure and alter the principles guiding human behaviour, a new model will be required to capture the resulting dynamics (Eidin et al., 2024; Meadows, 1999; Meadows et al., 2004; Sterman, 1991, 2000; Zhang et al., 2021).

7. Conclusions

In this article, the SPANDAM model was applied to analyse depopulation in Vitigudino and explore potential policy packages to address it. SPANDAM is a system dynamics model (Forrester, 1961; Sterman, 2000) designed to project population trends for a given region, considering the implementation of policies aimed at influencing emigration and immigration in the area. The model is divided into various modules that represent different aspects related to the population attractiveness of a territory (Elshof et al., 2017; Faugnerova & Hume, 2019; Fleming & Sinnot, 2018; Meijers & Van Der Wouw, 2019; Vidickienė, 2017), such as the economy, healthcare services, education services, transportation, and communications. Each module calculates a specific population attractiveness indicator corresponding to its dimension. Moreover, several of these modules allow for policy interventions that can alter the values of the respective indicators. All individual indicators are aggregated into a single general population attractiveness indicator. The value of this general indicator directly affects the number of emigrants and immigrants in the region.

To apply the model to the Vitigudino region, specific data of the area were collected, and policy packages were designed along with boundary conditions. These policy packages aimed to enhance the region's population attractiveness, focusing particularly on the aspects that are weaker compared to the general situation of municipalities across Spain. In addition to Policy Scenario 1 and Policy Scenario 2 (which primarily differ in the intensity of policy implementation), a Baseline Scenario was simulated. In the Baseline Scenario, no policies are applied, allowing the model to simulate the region's evolution following its current trajectory.

The results of the different scenarios show that while the indicators of population attractiveness improve and net migration increases, becoming positive in Policy Scenario 2, the population continues to decline, albeit at varying rates. The underlying reason is that none of the policy scenarios manages to offset the negative natural growth rate. Both the high degree of aging in the region and the low fertility rate among women – an issue affecting not only this region but much of the developed world – hinder the prospects of reversing the depopulation process.

Even so, the positive effects of these policies should not be overlooked, nor their particular role in improving the living conditions of the region's inhabitants. As Koning et al. (2021) and Stèbe et al. (2024) suggested, the phenomenon of depopulation should not be addressed solely from the perspective of reversing the process but should also aim to ensure a certain level of well-being for those living in depopulated areas.

It should be added that our study opens several promising avenues for future research. First, one possible way to improve the model would be to develop the environmental module, including changes in land use and improving the representation of the effects of climate change on demographics. Second, given that depopulation is a transnational issue, adapting these models to other European contexts could help identify broader patterns and potential solutions. Third, the current model treats fertility rates as exogenous; future refinements could incorporate policy impacts – whether existing or newly designed – to assess their influence on regional fertility (Deimantas et al., 2024). Finally, since SPANDAM is a quantitative model, enriching it with qualitative dimensions – such as cultural identity or social capital – could provide deeper insights into rural-urban migration dynamics.

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Appendix A. Main equations of the model

Demography

$$P_{0,s}^{t+1} = \frac{\left(1 - 0{,}5 \cdot \left(m_{0,s}^{t} + e_{0,s}^{t}\right)\right) \cdot B_{s}^{t} + I_{0,s}^{t}}{\left(1 + 0{,}5 \cdot \left(m_{0,s}^{t} + e_{0,s}^{t}\right)\right)} \quad (1)$$

$$P_{x,s}^{t+1} = \frac{\left(1 - 0{,}5 \cdot \left(m_{x,s}^{t} + e_{x,s}^{t}\right)\right) \cdot P_{x-1,s}^{t} + I_{x,s}^{t}}{\left(1 + 0{,}5 \cdot \left(m_{x,s}^{t} + e_{x,s}^{t}\right)\right)} \quad (2)$$

$$P_{100+,s}^{t+1} = \frac{\left(1 - 0{,}5 \cdot \left(m_{100+,s}^{t} + e_{100+,s}^{t}\right)\right) \cdot \left(P_{99,s}^{t} + P_{100+,s}^{t}\right) + I_{100,s}^{t}}{\left(1 + 0{,}5 \cdot \left(m_{100+,s}^{t} + e_{100+,s}^{t}\right)\right)} \quad (3)$$

P is the population, *B* are births, *I* are immigrations, *m* is the mortality rate, *e* is the emigration rate, and the indices *s*, *t* and *x* represent sex, time and age respectively.

$$SEI_{s}^{t} = SEI_{s}^{t_0} + \varphi \cdot \left(AI^{t} - AI^{t_0}\right) \quad (4)$$

SEI (sum of the emigration rates of all cohorts by sex) is the synthetic emigration index, SEI^{t0} is the synthetic emigration rate observed in the five historical years prior to the start of the simulation, *AI* is the Aggregate Indicator of population attractiveness and φ is the parameter that regulates how much the variation of the aggregate indicator affects the synthetic emigration index.

$$e_{x,s}^{t} = SEI_{s}^{t} \cdot ape_{x,s} \quad (5)$$

ape is the age pattern of emigrants, a constant.

$$TI^{t} = \left[i^{t_0} + \omega \cdot \left(AI^{t} - AI^{t_0}\right)\right] \cdot \sum_{x,s} P_{x,s}^{t} \quad (6)$$

TI is the total number of immigrants, i^{t0} is the rate of immigration that has been observed in the five historical years preceding the start of the simulation, $\sum_{x,s} P_{x,s}^{t}$ is the total population of the region and ω is the parameter that regulates how much the variation of the *AI* (aggregated indicator of population attractiveness) affects the immigration rate initially observed.

$$I_{x,s}^{t} = TI^{t} \cdot sr_{x} \cdot api_{x,s} \quad (7)$$

sr is the ratio of men and women over the total number of immigrants and *api* is the age pattern of emigrants.

The demographic module also takes into account the internal distribution of the total population across 10 groups of municipalities:

$$PG_{g}^{t} = p_{g} \sum_{x,s} P_{x,s}^{t} \quad (8)$$

PG is the population of each group of municipalities and *p* is the percentage of the population that corresponds to each group of municipalities. The index *g* represents the groups of municipalities and can take integer values from 1 to 10.

$$PM_{g}^{t} = \frac{PG_{g}^{t}}{M_{g}} \quad (9)$$

PM is the average population per municipality in each group of municipalities and *M* is the number of municipalities in each group.

Economy

$$YD_{pc}^{t} = \alpha \cdot GDPpc_{Spain}^{t} + YD_{pc\,extra}^{t} \tag{10}$$

YD_{pc} is the net income per person in the region, GDPpc is Spain's gross domestic product per capita, α is the parameter that enables the calculation of the region's net income per capita based on Spain's GDPpc per capita and $YD_{pc\ extra}$ is a policy that seeks to increase the net income of the territory's residents.

$$ER^{t} = \beta + ER_{Spain}^{t} + ER_{extra}^{t} \tag{11}$$

$$UR^{t} = 1 + ER^{t} \tag{12}$$

ER is the employment rate in the region, ER_{Spain} is the employment rate in Spain, β is the parameter that enables the calculation of the region's employment rate based on Spain's employment rate. ER_{extra} is a policy that increases the employment rate above the employment rate that is endogenously estimated in the model. UR is the unemployment rate.

$$LF^{t} = \gamma \cdot \sum_{s} \sum_{x=16}^{x=64} P_{x,s}^{t} \tag{13}$$

LF is the labour force and γ is the ratio of the labour force to the working-age population.

$$E^{t} = ER^{t} \cdot LF^{t} \tag{14}$$

$$E_{inside}^{t} = \varepsilon \cdot E^{t} \tag{15}$$

E is the number of people living in the region with employment, E_{inside} is the number of people working (geographically) inside the region and ε is the ratio of people working (geographically) in the region to people resident in the region who are employed.

$$C^{t} = \frac{E_{inside}^{t}}{CS} \tag{16}$$

$$WCM^{t} = \frac{C^{t}}{C^{t_0}} \cdot WCM^{t_0} \tag{17}$$

C is the number of companies, CS is the average company size and WCM is population-weighted average number of companies per municipality.

Calculation of time to services

In order to endogenously calculate the average time in the region to a certain service, first of all, the number of services of any type in each group of municipalities is calculated. For this purpose, a logistic function has been used that relates the percentage of municipalities with a certain service to the average population of the municipalities. In addition, the deviation of the territory from the function is also taken into account, as well as whether a policy is being applied that adds additional services.

$$SF_{g}^{t} = \left(1 - \epsilon + \frac{\epsilon}{1 + e^{-(\theta + \vartheta \cdot PM_{g}^{t})}}\right) \cdot M_{g} \tag{18}$$

$$DSF_{g} = S_{g}^{t_0} - SF_{g}^{t} \tag{19}$$

$$S_{g}^{t} = SF_{g}^{t} + DSF_{g} + ES_{g}^{t} \tag{20}$$

SF represents the outcome of the logistic function, and DSF is the constant added to this outcome, varying across different groups of municipalities. The variable S indicates the count of municipalities within each group that have the service, while ES denotes the number of additional municipalities with the service. The parameters ϵ, θ, ϑ are the estimated coefficients of the logistic function.

The average time to reach the service in each municipality group is then determined. First, parameters were estimated for a function that calculates the average access time to the service from municipalities lacking it within the region. The number of municipalities offering the service serves as the explanatory variable. Since the function has a vertical asymptote at zero, a cap on the time is applied by setting a maximum limit.

$$TNS^t = min\left[MTS, \chi \cdot \left(\sum_g S_g^t\right)^{\psi}\right] \qquad (21)$$

TNS represents the time to access the service if it is unavailable in a municipality, MTS is the maximum time to reach the service. χ and ψ are the parameters of the function.

To then calculate the average time to access the service across each group of municipalities, the time derived from the previous function is assigned to municipalities without the service, and a time of zero is assigned to municipalities that have it.

$$T_g^t = \frac{\left(M_g - S_g^t\right) \cdot TNS_g}{M_g} \qquad (22)$$

Finally, to determine the average time to the service across the region, a population-weighted average of all municipality groups is computed.

$$T^t = \frac{\sum_g T_g^t \cdot PG_g^t}{\sum_g PG_g^t} \qquad (23)$$

Normalization and attractiveness

Normalization, which enables the aggregation of variables that make up the attractiveness indicator for each dimension, is performed using the following formulas, depending on whether the relationship between the variable in question and population attractiveness is direct (first formula) or inverse (second formula):

$$NV = 70 + \frac{V - LLN}{ULN - LLN} \cdot 60 \qquad (24)$$

$$NV = 200 - \left(70 + \frac{V - LLN}{ULN - LLN} \cdot 60\right) \qquad (25)$$

NV represents the normalized variable, V is the original (non-normalized) variable, LLN stands for the lower limit of normalization, and ULN for the upper limit. These limits were chosen so that a normalized score of 100 indicates a reference value, which, in this case, corresponds to the municipal average.

The adjusted Mazziotta-Pareto method is then used to aggregate the normalised variables that make up the indicator:

$$Attractiveness\ indicator\ per\ dimension = \mu_{variables} - \frac{{\sigma_{variables}}^2}{\mu_{variables}} \qquad (26)$$

Where μ is the mean of the selected variables for each dimension to form its respective indicator and σ is the standard deviation of these variables.

The same method is used to aggregate the indicators of each dimension into a single overall indicator of population attractiveness.

$$Agg. Ind. of\ Population\ Attractiveness\ = \mu_{indicators} - \frac{{\sigma_{indicators}}^2}{\mu_{indicators}} \qquad (27)$$

Appendix B. Summary of policies and boundary conditions

Boundary conditions

Boundary Parameters	Value	Comments
Demographic scenario of the Autonomous Community	Medium	Projections generated by the CED, based on estimates from the INE.
Variation rate in national GDP per capita	24%	The value represents the rate of change from the start of the simulation to the end. The annual growth follows the historical trends of the last 20 years.
Variation in national employment rate	6%	The value represents the variation from the start of the simulation to the end. The employment rate follows its current increasing trend until it reaches the historical peak of 2007 in 2035, thereafter it increases very slowly.
Variation rate in annual cumulative precipitation per municipality	-7%	AEMET projections, consistent with IPCC RCP 4.5.
Variation rate in average annual temperature	9%	AEMET projections, consistent with IPCC RCP 4.5.

Baseline

In the baseline simulation, all the policies listed in the table below have a value of 0.

Policy scenario 1

Policy	Value	Comments
Company size variation rate	-10%	Own criteria.
Diversification index variation	0,110	The value of the Diversification index increases to reach the average of the municipalities in Spain.
Temporariness rate variation	-0,007	The value of the Temporariness rate decreases to reach the average of the municipalities in Spain.
Extra employment rate	1%	Own criteria.
Extra income per person	500 €	Own criteria.
Extra post offices	1	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra bank offices	2	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra libraries	0	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra police stations	0	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra bars	0	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra entertainment companies	2	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra day centres	3	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Businesses providing services per thousand inhabitants variation rate	0	Constant, since it starts from a value above the Spanish average.
Extra health centres	0	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra hospitals	0	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra pharmacies	0	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra emergency services	0	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.

Policy	Value	Comments
Extra childcares	2	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra recreational companies	1	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra Pre-school or primary centres	0	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra secondary education schools	2	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Baccalaureate or professional training centres	1	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra public university centres	0	Constant, as it depends on regional and national plans.
Extra companies offering extracurricular training services	4	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra fuel stations	0	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Extra taxi services	0	Services are added to reach, according to the initial endowment of the region, 25% of the Spanish average.
Variation rate in the time to a train station	0	Constant, as they are national infrastructure policies.
Variation rate in the time to a highway or freeway	0	Constant, as they are national infrastructure policies.
Variation in internet coverage ratio of 100Mbps	77%	100% reached by 2025 (MINECO, 2022).

Policy scenario 2

Policy	Value	Comments
Company size variation rate	-20%	Own criteria.
Diversification index variation	0,110	The value of the Diversification index increases to reach the average of the municipalities in Spain.
Temporariness rate variation	-0,007	The value of the Temporariness rate decreases to reach the average of the municipalities in Spain.
Extra employment rate	2%	Own criteria.
Extra income per person	1.000 €	Own criteria.
Extra post offices	4	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra bank offices	9	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra libraries	5	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra police stations	1	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra bars	0	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra entertainment companies	5	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra day centres	6	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Businesses providing services per thousand inhabitants variation rate	0	Constant, since it starts from a value above the Spanish average.
Extra health centres	3	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra hospitals	1	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.

Policy	Value	Comments
Extra pharmacies	0	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra emergency services	0	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra childcares	4	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra recreational companies	3	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra Pre-school or primary centres	7	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra secondary education schools	6	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Baccalaureate or professional training centres	3	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra public university centres	0	Constant, as it depends on regional and national plans.
Extra companies offering extracurricular training services	9	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra fuel stations	4	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Extra taxi services	3	Services are added to reach, according to the initial endowment of the region, 50% of the Spanish average.
Variation rate in the time to a train station	0	Constant, as they are national infrastructure policies.
Variation rate in the time to a highway or freeway	0	Constant, as they are national infrastructure policies.
Variation in internet coverage ratio of 100Mbps	77%	100% reached by 2025 (MINECO, 2022).