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ARTICLES

Ömer Tarık GENÇOSMANOĞLU [*], Kemal Buğra YAMANOĞLU [**]

TESTING THE SOLOW HYPOTHESIS FOR FISCAL CONVERGENCE: A DYNAMIC SPATIAL ANALYSIS

Abstract. The study of regional fiscal convergence is a recent extension of the neoclassical growth theory. Various studies have shown the existence of fiscal convergence across countries or states in federally governed countries. This paper tests the growth theory on income and fiscal variables differently in a centrally ruled country. Therefore, we estimate spatial and non-spatial panel models from 2004 to 2022 for Türkiye. A general-to-specific methodology is applied for selecting an appropriate model to determine spatial interactions of the variables by using the panel data at the level of 81 Turkish provinces. The Ordinary Least Squares (OLS) estimation results from the non-spatial model partially validate the growth theory as the study does not find evidence of absolute convergence for government expenditures. The results, however, confirm the conditional convergence for all variables. The Maximum Likelihood (ML) method is applied for the estimation of the dynamic and static spatial panel models to explain their spatial interactions. The ML findings are consistent with the OLS results. Moreover, unlike direct and total effects, it is not possible to define indirect effects explaining spatial spillover effects in the short and long terms.

Key words: spatial econometrics, dynamic spatial panel models, income convergence, fiscal convergence.

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1. INTRODUCTION

The convergence phenomenon predicted by the neoclassical (Solow) growth theory has, on the one hand, mostly been linked to income and numerous studies have been undertaken. On the other, there has been growing research into whether the convergence hypothesis holds for other macroeconomic variables such as public spending, taxes, imports, or exports. One of the primary reasons for this is that governments are increasingly pursuing fiscal policies that try to eliminate disparities in growth and development between countries or across regions.

A large portion of the relevant research conducted in this context has focused on the convergence of fiscal variables, particularly tax revenues and public spending. The Solow growth model implies that tax revenues are a constant proportion of total income and public expenditures should be equal to tax revenues under the balanced budget condition. As a consequence, we expect fiscal variables to grow at the same rate as total income. In other words, the convergence in fiscal variables should follow a parallel course to income. A mathematical derivation of this proposition was provided by Yamanoğlu (2022).

The existing literature, although empirically demonstrating convergence in fiscal variables, has nevertheless been limited to considering the incidence of convergence across countries or states in federally administered countries (Scully, 1991; Sanz and Velazquez, 2001; Annala, 2003; Gemmell and Kneller, 2003; Coughlin *et al*., 2007; Perovic *et al.*, 2016; Acemoğlu and Molina, 2021; Kremer *et al*., 2021). To put it another way, Solow's theory of fiscal variables has yet to be proven in centrally governed economies. Additionally, the related research, which commonly employs cross-sectional or panel methodologies, has barely included analyses of spatial interactions between states or nations (Annala, 2003; Perovic *et al*., 2016).

In reality, a country's political and administrative structures inevitably influence its public finances. For example, in countries with centralised administration, the main concerns of the governments are to eliminate income inequalities and gaps in economic development levels between regions, as well as to ensure a fair distribution of resources and public services throughout the country. Political considerations have also more or less influence on the budget and fiscal policies implemented to achieve their goals. Therefore, governments may implement policies that favour specific groups or regions when planning public expenditures. In summary, countries with central governments might differ from those governed by the federal system concerning public finance.

The purpose of this paper is to test Solow's theory on fiscal variables in a centrally ruled country, namely Türkiye. The insights from the Turkish example could allow us to assess the outcomes of other research investigating federal systems. This study, therefore, makes several important contributions to the existing literature. First, the fiscal convergence proposition based on the growth theory is tested for a country ruled by a central government for the first time through the example of Türkiye. The study explores the presence of fiscal convergence in relation to income levels and provides helpful understanding by demonstrating different convergence patterns. Second, this is one of the rare studies that uses the dynamic and static spatial models together in fiscal convergence analysis. Studies have also scarcely applied the dynamic spatial analysis for income convergence for Türkiye. Third, the spatial spillover effects of fiscal variables are assessed in comparison with income. The results show no evidence of absolute convergence for government expenditures, although all three variables converge conditionally and show spatial interactions. The findings underline significant implications for its claims as they do not fully confirm the Solow growth model. The key conclusion is that the political inclinations of governments or policymakers and the type of administrative structure − centralised or decentralized − that shapes a country's public finances determine whether the Solow hypothesis of convergence for fiscal variables is reliable.

The research is divided into the following sections. First, we discuss in detail the literature on income and fiscal convergence. Next, the dataset and research methodology are presented. The results and discussion are provided subsequently. The last part concludes the discussion.

2. LITERATURE REVIEW

An economy eventually reaches a steady state where it cannot expand or contract according to the convergence concept put forward by the growth theory. The further away capital and income per capita are from the stationary state, the faster the growth resulting in convergence through a dynamic process. There are two distinct meanings of the convergence notion (beta or β) in literature. For absolute convergence, if rich and poor economies have the same levels of technology, investment rates, and population growths, the poor ones will grow faster than the rich ones and attain a similar steady state (Barro and Sala-i-Martin, 2004). However, conditional convergence is supported by the reality that economies do not have all the same characteristics. In other words, unless rich and the poor economies share economically comparable conditions, the gap in development between them will not eventually diminish (Galor, 1996).

Contrary to expectations, early studies based on cross-sectional models estimated a convergence rate of approximately 2% (Baumol, 1986; Barro and Sala-i-Martin, 1990, 1992; Mankiw *et al.*, 1992; Sala-i-Martin, 1996). These studies could not account sufficiently for unobservable variations between economies, hence panel models with fixed effects were used in subsequent research (Islam, 1995; Canova and Marcet, 1995; Caselli *et al.*, 1996; De la Fuente, 1997, 2000;

Pesaran *et al*., 1997; Lee *et al*., 1998; Tondl, 1998; Rodriguez, 2008; Barro, 2012, 2016; Acemoğlu and Molina, 2021; Kremer *et al*., 2021). They have shown that economies with distinct initial conditions tend to approach their steady state more rapidly than a shared equilibrium.

Rey and Montouri (1999) also contributed substantially by being the first to incorporate geography into econometric analysis. Their study on the United States (US) has demonstrated that regional income distribution increases robustly and collectively in the long term. Subsequent regional studies have confirmed the significance of spatial analysis (Le Gallo and Dall'Erba, 2003, 2008; Arbia and Piras, 2005; Arbia *et al*., 2005; Ertur and Koch, 2007; Arbia *et al*., 2008; Maza and Villaverde, 2009; Elhorst *et al.*, 2010; Evans and Kim, 2014; Royuela and Garcia, 2015; Palomino and Rodriguez, 2019).

The last two decades have seen a variety of findings from studies on regional income convergence in Türkiye. Three studies, i.e., Canova and Marcet (1995), Filiztekin (1998), and Tansel and Güngör (1998), prove that Turkish regions exhibit both absolute and conditional convergence. Furthermore, Gezici and Hewings (2004, 2007) discovered a strong spatial correlation for income convergence. According to Çelebioğlu and Dall'erba (2010), geographic location affects education level, public investments, and income based on the data from 1995 to 2001. Gezici and Hewings (2007) and Çelebioğlu and Dall'erba (2010) discovered a geographical autocorrelation in income level, but not income growth. Yıldırım (2005) could not determine the spatial impact of regional policies on convergence over the 1990–2001 period. The findings of the subsequent studies based on spatial models indicated the existence of income convergence (Yıldırım and Öcal, 2006; Yıldırım *et al*., 2009; Akçagün, 2017; Yamanoğlu, 2022).

The premier studies that apply convergence analysis for fiscal variables were provided by Scully (1991) and Annala (2003). After that, Coughlin *et al.* (2007) employed spatial analysis to extend their research. They discovered that tax revenues and government spending likewise converged throughout the US, supporting their argument. Increased economic integration and fiscal adjustment policy were associated with research on the fiscal convergence of the European Union (EU). They have demonstrated convergence in tax revenues and government expenditures apart from income. Rivero (2006) has concluded that fiscal convergence is supported by harmonised fiscal policies for enhanced economic integration according to an analysis from 1965 to 2003 for the EU. Perovic *et al.* (2016) investigated conditional convergence in public spending subcategories for the EU15 from 1995 to 2010, observing notable regional effects in education, health, and defence. Cross-national studies also examine whether rising globalisation causes government expenditures to converge. For example, Sanz and Velazquez (2001) examined the OECD countries from 1970 to 1998 and found a convergence pattern for each subgroup of public spending. Gemmell and Kneller (2003) studied a similar influence of fiscal variables on income growth between 1970 and 1995 for the EU10 and OECD15 countries. Strong convergence in fiscal variables for the OECD countries for the period 1960–2000 was found by Skidmore *et al.* (2004). Studies like Acemoğlu and Molina (2021) and Kremer *et al.* (2021) that broadened nation groups have also supported the convergence of the fiscal variables.

The studies on Türkiye have focused solely on income convergence across provinces or the influence of government spending and investment on this pattern. Studies on fiscal convergence, however, are scarce. Sağbaş (2002), for example, was not able find any evidence regarding the effect of government expenditures on income convergence in the 1990–2005 period. Saruç *et al*. (2007) reported a convergence in public spending between 1990 and 2005, however, they could not provide any evidence concerning tax revenues. Alataş and Sarı (2021) applied the club convergence analysis for 81 provinces between 2004 and 2018 to examine any convergence in public expenditures with its nine subcategories. The results indicate that, except for spending on social and environmental protection, total public expenditure with its seven subcategories exhibits multiple steady states. Also, the steady states are significantly different between individual provinces, especially in eastern and western regions. Karaş and Karaş (2023) used the Evans–Karras and Panel Threshold Unit Root tests to determine the absolute fiscal convergence across the country from 2004 to 2020. After applying spatial panel data models to examine the 2006–2020 period, Yamanoğlu (2022) has concluded that public expenditures do not exhibit absolute convergence contrary to income and tax revenues. Furthermore, the analysis has not identified a provincial spatial interaction of tax revenues while demonstrating conditional convergence in all three variables.

3. METHODOLOGY

The study employs non-spatial and spatial (static and dynamic) panel models of beta convergence to explore the fiscal convergence patterns across Turkish provinces. Afterwards, the models are extended by the spatial models to examine spatial interactions of the provinces. The study also investigates spatial autocorrelation by calculating Moran's I values.

3.1. Beta convergence

We examine the course of beta convergence across Turkish provinces using panel data analysis following the literature by the model described in equation (1) that associates the average growth rate of real per capita income with the initial level of per capita income:

$$\ln\left(\frac{y_{it}}{y_{i(t-1)}}\right) = \partial - (1 - e^{-\lambda}) \ln y_{i(t-1)} + \upsilon_{it} \quad (1)$$

where y represents real per capita income, υ_{it} is the error term, and ∂ is the rate of technological growth which is supposed to be identical for all provinces. The coefficient of initial per capita income $(1 - e^{-\lambda})$ decreases for a certain λ since the growth rate declines as per capita income rises. The speed of convergence (λ) determines how quickly Turkish provinces converge towards the steady state. We can re-write the equation (1) by the substitution below[1]:

$$\beta = -(1 - e^{-\lambda}) \quad (2)$$

After the replacement (2) into the equation (1), we obtain:

$$\ln\left(\frac{y_{it}}{y_{i(t-1)}}\right) = \partial + \beta \ln y_{i(t-1)} + \upsilon_{it} \quad (3)$$

Then, the following models specify the absolute and conditional models in terms of income, respectively:

$$\ln\left(\frac{y_{it}}{y_{i(t-1)}}\right) = \partial + \beta \ln y_{i(t-1)} + \eta_t + \upsilon_{it} \quad (4)$$

$$\ln\left(\frac{y_{it}}{y_{i(t-1)}}\right) = \partial + \beta \ln y_{i(t-1)} + \mu_i + \eta_t + \upsilon_{it} \quad (5)$$

where μ_i and η_t stand for unit and time-fixed effects. In other words, the absolute convergence model is interpreted as models that only include time effects, but the conditional convergence model has both unit and time effects (Caselli, 1996; Canova and Marcet, 1995; Rodriguez, 2008). The equation allows us to consider unobservable and unmeasurable components of regional disparities, such as technology. It is not possible to confirm absolute or conditional convergence unless a negative and statistically significant β coefficient is estimated. The existence of convergence implies that poor provinces are likely to grow faster than

[1] When the log-linearisation method around the steady state is applied to the dynamic capital accumulation equation ($\dot{k}/k = s.f(k)/k - (x + n + \delta)$) in the neoclassical model, the β coefficient is obtained as follows: $\beta = -(1 - e^{-\lambda})$. The parameters in the equation represented by the capital share k, rate of technological progress x, the population growth rate n, and the depreciation rate δ.

the rich by converging to a common level of real per capita income. We adapt equations (4) and (5) for public expenditures and tax revenues, respectively, after replacing the dependent variable y with g and t. Fiscal variables should have the same spatial effects on income convergence that are often discovered in earlier research.

As explained before, the parameter λ defined in equations (1) and (2) is the speed or annual rate of convergence. An alternative measure of the convergence process, namely the half-life period (τ), can also be used. It measures the time required for economies to close half of the gap between their steady states (Arbia *et al*., 2005). The speed of convergence λ is derived from equation (5) as follows which β is estimated from equation (3):

$$\lambda = -\ln(1 + \beta) \tag{6}$$

Accordingly, the speed of convergence can be considered as follows for the length of the interval is T:

$$\lambda = -\frac{\ln(1 + T\beta)}{T} \tag{7}$$

The measure of the half-life (τ) can be calculated by using the formula below:

$$\tau = \frac{\ln(2)}{\lambda} \tag{8}$$

3.2. Spatial models

Anselin (2001) has suggested that it is possible to add the spatial dependence to the basic equations (4) and (5) as an additional regressor, either as a spatially lagged dependent variable or as an error term. Accordingly, it is possible to formulate the main models with the following parameters for explanatory variables and different types of spatial interaction: β (exogenous explanatory variables), ρ (endogenous interaction effect or spatial autoregressive), θ (exogenous interaction effects), and λ (spatial correlation effect of errors or spatial autocorrelation).

The spatial lag models include a spatial lag operator entailing a weighted average of the growth rates in adjacent provinces. It is the product of a spatial weights matrix (W) with the vector of observations of dependent variable y and defined as (Anselin, 2001):

$$W \times y_i = \sum_{j=1}^{N} w_{ij} \times y_j \tag{9}$$

where $w_{i,j}$ is an element of a fixed and positive $N \times N$ spatial weights matrix W. The matrix gives weights that degree the strength of the relationship among pair of spatial units and it is one of the major parts for modelling spatial interdependence between provinces (Le Gallo *et al*., 2003). The extensive literature on the specification of weights matrices mentions several approaches. It is delicate issue since spatial effects are more robust to the selection of weights matrix than spatial parameters. There are various discussions, however, showing the difficulty of matrix selection, which is subject to technical arguments (Stakhovych and Bijmolt, 2009). Accordingly, the extensive literature on the specification of weights matrices mentions three basic approaches: (i) taking them as completely exogenous structures, (ii) allowing the data to define them, and (iii) estimating them. We follow the first approach which includes examples of spatial contiguity, inverse distance, common border, or centroids. More precisely, we establish a row-standardised simple binary contiguity matrix based on the shared boundary principle. It contains non-zero elements ($w_{ij} = 1$) if provinces have a common border or zero elements ($w_{ij} = 0$) otherwise. The economic reason for this preference is the nature of public expenditures in Türkiye. The expenditures presumably have positive or negative diffusion effects that spread beyond a province's borders by influencing the well-being of those living in neighbouring provinces. If expenditures have a complementary (for instance, infrastructure and road construction) or substitution (building dams establishing universities, etc.) nature, contiguity becomes more important than distance-based neighbourhood.

Having incorporated spatial weights matrix as a spatial lag operator and spatial correlation terms into the basic model (5), we can define the general static spatial model as follows:

$$\ln\left(\frac{y_{it}}{y_{i(t-1)}}\right) = \partial + \beta \ln y_{i(t-1)} + \rho \sum_{j=1}^{N} \omega_{ij} \ln\left(\frac{y_{it}}{y_{i(t-1)}}\right) + \theta \sum_{j=1}^{N} \omega_{ij} \ln(y_{i(t-1)}) + \mu_i + \eta_t + \upsilon_{it} \tag{10}$$

where $\upsilon_{it} = \lambda \sum_{j=1}^{N} w_{ij} \upsilon_{it} + \varepsilon_{it}$.

Based on the constraints of spatial interaction ($\theta = 0$, $\lambda = 0$ or $\rho = 0$), we can derive three forms of spatial lag models. If we assume that endogenous interaction doesn't exist and spatial externalities matter ($\rho = 0$), the model becomes the Spatial Durbin Error Model (SDEM). The model is referred to as the Spatial Autocorrelation Model (SAC), if we assume that the parameter for exogenous interaction effects is zero ($\theta = 0$). The parameter θ refers to the spatial lag coefficient of the initial level of income. In this form of the model, however, the β estimators are biased and do not converge when the model includes exogenous interactions of the weights matrix, which signifies the omitted variable bias (Lesage *et al.*, 2009). Moreover, using the same spatial weights matrix for the model might cause weak identification concerns as suggested by Le Gallo (2002). The last form of the model is the Spatial Durbin Model (SDM) when we assume $\lambda = 0$. Despite the presence of spatially auto-correlated errors, we have unbiased estimators and valid test statistics in this scenario. Therefore, the model will be more robust against a poor model selection. There are also different sub-models of the SAC and SDM. If we add, for instance, the assumption of $\lambda = 0$ to the SAC model, we obtain the Spatial Lag Model (SAR). We can also derive the Spatial Error Model (SEM) by establishing the common factor hypothesis ($\theta = -\rho\beta$) in the SDM model.

We also employ spatial dynamic models in our analysis of convergence, which include the lag-dependent variable as an explanatory variable in the equation (10). Therefore, the dynamic model in general form is written by extending the model (10) with the lag-dependent variable as follows:

$$\ln\left(\frac{y_{it}}{y_{i(t-1)}}\right) = \partial + \beta \ln y_{i(t-1)} + \psi \ln\left(\frac{y_{it}}{y_{i(t-1)}}\right)_{t-1} + \rho\sum_{j=1}^{N}\omega_{ij}\ln\left(\frac{y_{it}}{y_{i(t-1)}}\right) + \theta\sum_{j=1}^{N}\omega_{ij}\ln(y_{i(t-1)}) + \mu_i + \eta_t + \upsilon_{it} \tag{11}$$

where $\upsilon_{it} = \lambda\sum_{j=1}^{N} w_{ij}\upsilon_{it} + \varepsilon_{it}$.

Please note that the model (11) becomes a general spatial static model again when the coefficient of the lag-dependent variable is zero ($\psi = 0$). Given the dynamic nature of the model, it reveals both short- and long-term effects. Therefore, the estimation results will be reported by their direct (own-province) and indirect (other-province or spill-over) effects. We can attain the Dynamic Spatial Autoregressive Model (DSAR) and the Dynamic Spatial Durbin Model (DSDM), respectively, after imposing the constraints in the cases of the SDM and SAR models to Model (11).

We initially estimate the absolute and conditional convergence models by using the ordinary least squares (OLS) method. The OLS estimation of spatial lag models, however, produces inconsistencies in regression parameter estimates due to the spatially lagged dependent variable, which is always associated with the error term. Therefore, we ought to use the maximum likelihood (ML) method for estimating the spatial lag model (Le Gallo *et al.*, 2003; LeSage and Pace, 2009). Depending on the constraints applied to the equations (11), we use in our analysis both static (the SAR, SEM, and SDM models) and dynamic models (the DSAR and DSDM models). For the most appropriate model selection, we follow the general-to-specific methodology suggested by LeSage and Pace (2009) and Elhorst (2010) and start with the DSDM model as the general specification before applying multiple tests (Lagrange multiplier-LM and likelihood ratio-LR). According to the methodology, we commence using the LM tests. The robust LM_ρ test from the residuals of the OLS model is used to conclude if there is an autoregressive term (i.e., $\rho \neq 0$ and $\lambda = 0$). The robust LM_λ test is also applied to detect residual autocorrelation (i.e., $\rho = 0$ and $\lambda \neq 0$). If the LM test results reveal that the use of spatial models is necessary, then we consider the LR test for the most appropriate spatial model selection. Reference can also be made to other tests during model selection. For instance, we test the dynamic spatial model checking whether the coefficient (ψ) of the lag-dependent variable is zero. In addition, information criteria such as the Akaike (AIC) or the Bayesian (BIC) allow us to compare the models that show the most proper fit to the sample data.

3.3. Spatial autocorrelation

The most distinct characteristic of spatial data from others is that they are usually spatially autocorrelated. Spatial autocorrelation is the association between a variable of interest and itself when measured at various places. In this context, Moran's *I* is one of the most often used tests for detecting spatial autocorrelation (Moran, 1950). Moran's *I* statistic is computed using the formula below and tested against the null hypothesis of no-spatial autocorrelation (i.e., *Moran I* = 0):

$$I = \frac{N}{S_0} \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} w_{ij} (y_i - \bar{y})(y_j - \bar{y})}{\sum_{i=1}^{N} (y_i - \bar{y})^2} \tag{12}$$

where *I* is the Moran *I* statistic, y_i and y_j represents variable measure at locations *i* and *j*, $\bar{y}$ is the mean of the variable, S_0 indicates the variance ($\sum_{i=1}^{N} \sum_{j=1}^{N} w_{ij}$) and w_{ij} is the spatial weights matrix indexing location of *i* and *j*. Please note that $N = S_0$ for a row-standardised weights matrix, as in our study. Moran's *I* is a correlation coefficient that indicates the level of spatial autocorrelation in specific data properties. The test is based on geographical covariance, which is then standardized by data variance. It is calculated using a neighbourhood list obtained from a spatial weights matrix. Moran's *I* values vary from -1 to 1, where -1 and 1 represent perfect negative or positive spatial autocorrelation, respectively, while 0 shows a random pattern.

4. DATA

The sample comprises 81 provinces in Türkiye from 2004 to 2022. The study uses provincial data in real terms for income, tax revenues, and public expenditures. Turkish Statistical Institute (TurkStat) provides the per capita income statistics from the "National Accounts" database in dollars and the province population data from the "Address Based Population Registration System (ADNKS)". The Ministry of Treasury and Finance releases data on tax revenues and government expenditures in Turkish lira. After converting all nominal values from local currency to dollars, we use the US consumer price index (2010=100) from the World Bank database to convert all nominal values to real terms. Real values are divided by each province's population to get the real per capita figures.

The national fiscal policy is characterised by the patterns in tax revenues and government expenditures during the sample period (Fig. 1). First, compared to government expenditures, tax revenues have a steadier income percentage. As an illustration, on the one hand, the tax revenues show an income rate variation of 2.6 percentage points, from 15.4% to 17.9%. Government spending, on the other, varies over time by a larger range (i.e., 6.9 percentage points) between 19.5% and 26.5% of income. Second, the proportions of revenues from taxes and public spending depended on income levels influenced by global macroeconomic trends in the relevant period. For example, from 2008 to 2011, tax revenues fell due to the rapid reduction in income after the global financial crisis. Even though, the percentage of tax revenues to income remained nearly constant. In contrast, the fact that the level of government spending did not decrease compared to previous years caused the share of these expenditures in income to increase. We see a similar progress in the 2019–2021 period.

The third important facet of fiscal policy is shown in Fig. 2. It shows that as average real per capita income falls by province, tax revenues decrease and public spending rises. This means that a smaller portion of public spending is covered by tax revenues; as a result, the government uses more budgetary resources, as well as taxes received from high-income provinces, to support government expenditures in low-income provinces. The government is possibly trying to bridge the development gap across the provinces by putting this policy into effect (Sağbaş, 2002). In conclusion, public spending can be planned centrally and independently of income, in contrast to tax revenues, given Türkiye's administrative structure and the political preferences of the government.

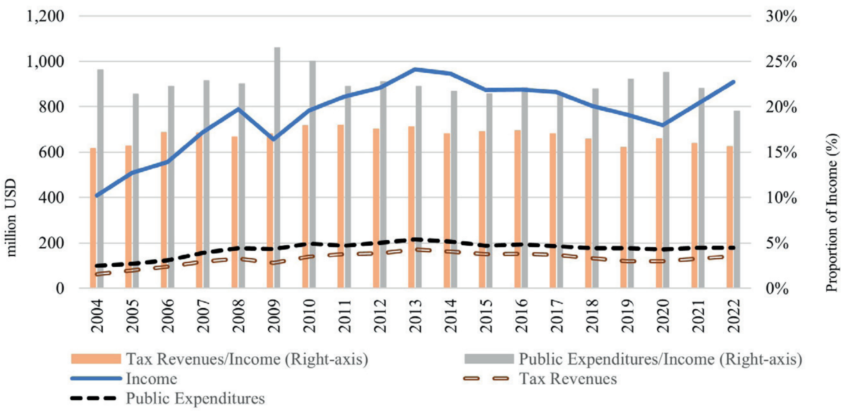

Fig. 1. Income percentage shares of tax revenues and public expenditures, for the period 2004–2022
Source: own work based on the data from Turkish Ministry of Treasury and Finance.

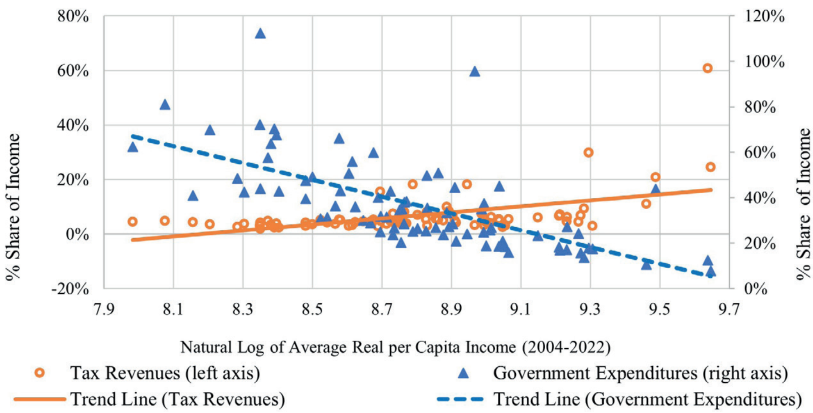

Fig. 2. Relationship between fiscal variables and provincial income for the period 2004–2022
Source: own work based on the data from Turkish Ministry of Treasury and Finance and TurkStat.

Fiscal policies entailing equal distribution of public expenditures and tax burden across a country are important for long-term development. For the tax burden to be shared between regions, public spending should be financed rationally across a country. According to the Statistical Regional Units Classification (NUTS) used for Türkiye, IIBS-1 and IBBS-2 are divided into 12 and 26 subregions, respectively, whereas IBBS-3 (an administrative classification) contains 81 provinces. The 81 provinces chosen for this study allow for a more precise determination of geographic connection among the smaller divisions. As a result, the sample of 81 provinces will be better suited for spatial models, while also providing the ability to work with extensive data compared to other classifications.

We create a balanced and short (time series) panel data set by calculating the natural logarithms of all pertinent values. Reasonably, each lag value used in the models results in the loss of one observation in the sample. As a result, 1,458 observations across 81 provinces for 18 years are there in the statistical analysis. The summary statistics are presented in Table 1. The coefficient of variation expressing the dispersion as a percentage of the mean briefly demonstrates that, out of all the variables, tax revenues in terms of levels and income in terms of growth values have the biggest variation.

The initial assessment of the validity of our hypotheses is provided by the levels of the variables at the beginning of the year (i.e., 2004) and their yearly average growth rates during the sampling period. Three different kinds of illustrations are prepared for this purpose. The first is placed on the left side of Figures 3, 4, and 5, display the fiscal variables and income distribution for the beginning year. The provincial distribution of their average growth rates throughout the same period is shown in the second illustration, displayed on the right side of Figures 3, 4, and 5. The relationship between annual average growth rates and the natural logarithm of beginning year values is depicted in the third illustration, the dispersion diagram (Fig. 6). In the first two illustrations, the variables get higher values as the shade of red gets darker.

Table 1. Descriptive statistics

Variables	Observation	Mean	Std. Error	Min	Max	Coefficient of Variation
$\ln(y_{i,t}/y_{i,t-1})$	1,458	0.010	0.108	-0.398	0.398	14.387
$\ln(g_{i,t}/g_{i,t-1})$	1,458	0.001	0.109	-0.583	0.739	108.700
$\ln(t_{i,t}/t_{i,t-1})$	1,458	0.008	0.194	-1.657	1.535	23.386
$\ln y_{i(t-1)}$	1,458	8.808	0.389	7.719	9.881	0.044
$\ln g_{i(t-1)}$	1,458	7.683	0.378	6.805	9.352	0.049
$\ln t_{i(t-1)}$	1,458	5.855	0.886	2.325	9.498	0.151

Source: own work from Stata.

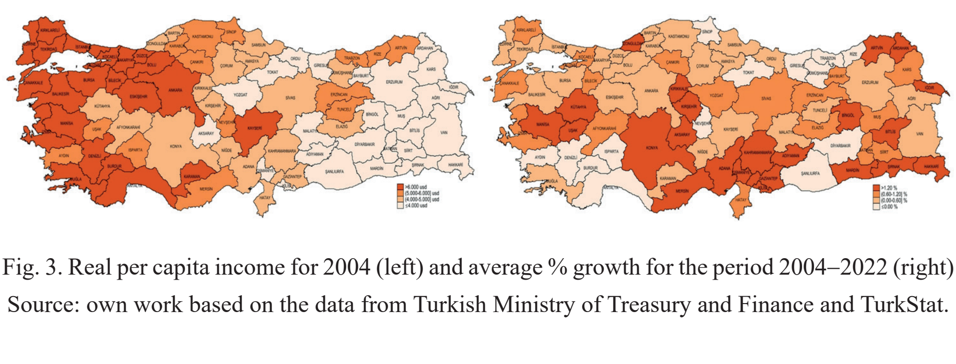

Fig. 3. Real per capita income for 2004 (left) and average % growth for the period 2004–2022 (right)

Source: own work based on the data from Turkish Ministry of Treasury and Finance and TurkStat.

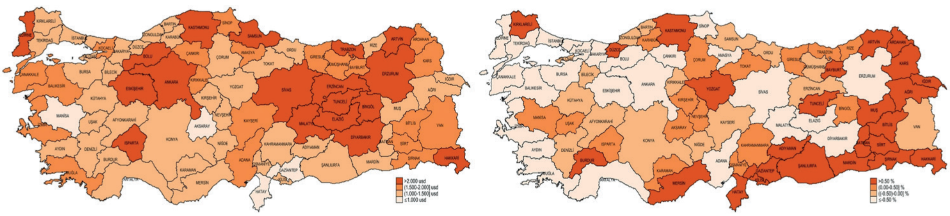

Fig. 4. Real per capita expenditures for 2004 (left) and average % growth for the period 2004–2022 (right)

Source: own work based on the data from Turkish Ministry of Treasury and Finance and TurkStat.

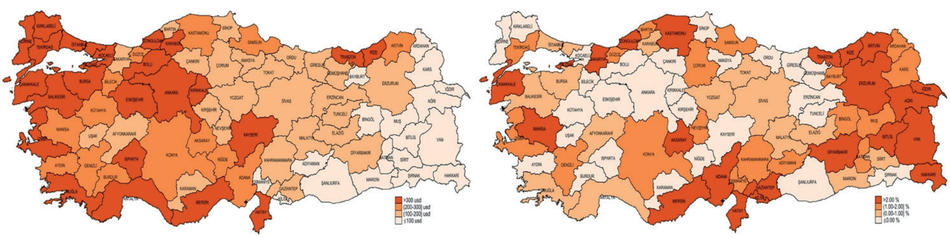

Fig. 5. Real per capita tax revenues for 2004 (left) and average % growth for the period 2004–2022 (right)

Source: own work based on the data from Turkish Ministry of Treasury and Finance and TurkStat.

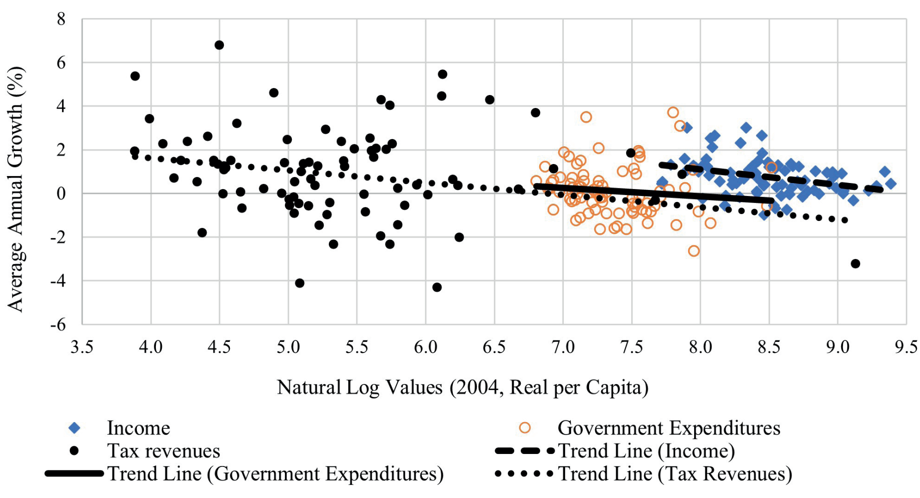

Fig. 6. Dispersion diagrams

Source: own work based on the data received from the Ministry of Treasury and Finance and TurkStat.

The intense regions in the figures depicting the distribution of income and fiscal variables indicate spatial heterogeneity. The western provinces have higher per capita incomes while the eastern regions have lower ones. Neighbouring provinces have similar income levels, indicating a spatial autocorrelation. These spatial characteristics resemble those of tax revenues. The concentration of public expenditures is shifting towards the eastern provinces. In contrast, the maps showing the average growth rates of the variables reveal that there is weaker spatial interaction between provinces. However, the variables have no polarization across the country.

The real per capita income and tax revenues increased by 0.7% and 0.8% annually on average throughout the sampling period, while the real per capita public expenditures decreased by 0.4%. Figures 3, 4, and 5 show that most provinces with low initial values for all three variables are associated with higher average growth rates. The dispersion diagram (Fig. 6) supports this conclusion. It shows that the starting year values for each of the three variables and the annual average growth rates have a negative connection. Contrary to government expenditures, there is a greater negative correlation between tax revenues and real per capita income.

To assess the spatial correlation of the variables, we additionally compute the Global Moran's *I* values (Table 2). At the 1% level, all level variable values are positive and statistically significant. In contrast to fiscal variables, per capita income has a larger value of spatial correlation coefficient. Throughout the relevant period, the coefficient values for per capita public expenditures increased while those for per capita income and tax revenues decreased. However, as the Moran *I* values are not statistically significant each year, there is no spatial autocorrelation in the growth values of the dependent variables. These outcomes align with the research conducted by Çelebioğlu and Dall'erba (2010) and Gezici and Hewings (2007). Unlike the level values, the growth rates exhibit a relatively weak spatial dependence. The Moran test results are consistent with Figures 3, 4, and 5. As already explained above, a spatial interaction is visible in the maps on the left of the figures showing the levels of the variables on a provincial basis. In contrast, there is no clear evidence of spatial interaction in the maps on the right, which corresponds to the growth rates of the variables.

Table 2. Global Moran's *I* values

Year	$\ln y_{i(t-1)}$	$\ln g_{i(t-1)}$	$\ln t_{i(t-1)}$	$\ln(y_{i,t}/y_{i,t-1})$	$\ln(g_{i,t}/g_{i,t-1})$	$\ln(t_{i,t}/t_{i,t-1})$
2004	0.718*	0.289*	0.503*			
2005	0.734*	0.308*	0.502*	-0.006	-0.093	0.224*
2006	0.724*	0.292*	0.497*	0.128**	0.172*	-0.024
2007	0.729*	0.320*	0.477*	0.220*	0.068	0.053
2008	0.736*	0.355*	0.477*	0.213*	0.233*	-0.034

Table 2 (cont.)

Year	ln $y_{i(t-1)}$	ln $g_{i(t-1)}$	ln $t_{i(t-1)}$	ln($y_{i,t}$/ $y_{i,t-1}$)	ln($g_{i,t}$/ $g_{i,t-1}$)	ln($t_{i,t}$/ $t_{i,t-1}$)
2009	0.736*	0.362*	0.449*	0.283*	0.008	0.016
2010	0.736*	0.388*	0.444*	0.267*	0.218*	0.010
2011	0.724*	0.381*	0.441*	-0.040	-0.029	0.112**
2012	0.705*	0.388*	0.396*	0.040	0.168**	-0.013
2013	0.688*	0.383*	0.399*	0.155**	-0.116	0.060***
2014	0.725*	0.360*	0.429*	0.180*	-0.094	-0.025
2015	0.751*	0.350*	0.443*	0.219*	-0.005	-0.119***
2016	0.753*	0.345*	0.429*	0.148**	0.225*	-0.015
2017	0.722*	0.356*	0.368*	0.134**	0.191*	0.085
2018	0.714*	0.339*	0.309*	0.080	0.235*	0.080
2019	0.691*	0.381*	0.295*	0.253*	0.167*	0.019
2020	0.672*	0.376*	0.379*	0.114***	0.103	0.108***
2021	0.675*	0.355*	0.402*	0.397*	0.015	0.110***
2022	0.692*	0.333*	0.392*	0.291*	0.065	0.083

Note: It is statistically significant at the $^{*}p < 0.01$, $^{**}p < 0.05$ and $^{***}p < 0.10$

Source: own work from Stata.

5. RESULTS

The descriptive statistics, on the one hand, confirm that spatial effects might influence income and fiscal variables. On the other, we start by estimating non-spatial models (4) and (5) with the OLS method to understand whether an econometric model that considers spatial effects is required.

5.1. Fixed effects models

We use the models (4) and (5) with time and unit fixed effects (FE) following Barro (2012), Acemoğlu and Molina (2021), and Kremer *et al.* (2021) in estimating absolute and conditional-beta convergence. The two-way FE model enables to control of unobserved heterogeneity across regions while addressing potential omitted variable bias. The model is especially effective when controlling two types of unobserved heterogeneity (i) that varies across units but is constant over time and (ii) that varies over time but is constant across units. As a result, this approach helps estimate more consistent and unbiased coefficients.

Table 3 displays the OLS estimation results with the Moran and multiple tests (Lagrange multiplier-LM, likelihood ratio-LR). They show that the models are statistically significant based on *F* values at the 1% level. The values remain significant at the corresponding level once the unit effects are incorporated into the model. According to *t* and R^2 values, almost all fixed effects are statistically significant and adequately explain the models. In our two-way panel fixed effect model, the high R^2 value is due to the model's ability to explain a large portion of the variation in the dependent variable by accounting for both individual and time-fixed effects. These fixed effects control for unobserved heterogeneity across individuals and over time, significantly reducing the residual variance. Also, the p-values less than 0.05 of Moran tests show that the null hypothesis of no spatial autocorrelation is rejected.

Table 3. OLS estimation results for fixed-effects models

Coefficient of variables	**Income**		**Public expenditures**		**Tax revenues**	
	Absolute	**Conditional**	**Absolute**	**Conditional**	**Absolute**	**Conditional**
Constant	0.278^* (0.030)	2.350^* (0.163)	0.117^* (0.032)	1.775^* (0.122)	0.312^* (0.030)	1.704^* (0.118)
β, $\ln y_{i(t-1)}$	-0.012^* (0.004)	-0.256^* (0.019)				
β, $\ln g_{i(t-1)}$			-0.007 (0.004)	-0.240^* (0.017)		
β, $\ln t_{i(t-1)}$					-0.015^* (0.005)	-0.255^* (0.020)
Convergence	1.3%	29.6%	No convergence	27.4%	1.5%	29.4%
Half-life Period	55.26	2.34		2.53	45.25	2.36
R^2	0.81	0.84	0.75	0.79	0.41	0.48
$\bar{R}^2$	0.81	0.83	0.74	0.77	0.40	0.45
Log-likelihood	2,395	2,501	2,165	2,297	707	803
AIC	-4,752	-4,805	-4,292	-4,396	-1,376	-1,408
BIC	-4,651	-4,282	-4,191	-3,873	-1,275	-885
Time-FE	Yes	Yes	Yes	Yes	Yes	Yes
Unit-FE	No	Yes	No	Yes	No	Yes
F-test, $\sum\eta_t = 0$	347.74 (0.000)	329.53 (0.000)	242.03 (0.000)	255.45 (0.000)	56.48 (0.000)	51.16 (0.000)
F-test, $\sum\mu_t = 0$		2.67 (0.000)		3.38 (0.000)		2.39 (0.000)
Moran *I*	0.000	0.000	0.000	0.000	0.041	0.017

Table 3 (cont.)

Coefficient of variables	Income		Public expenditures		Tax revenues	
	Absolute	Conditional	Absolute	Conditional	Absolute	Conditional
LM_ρ	0.000	0.000	0.000	0.000	0.050	0.030
LM_ρ (robust)	0.000	0.000	0.000	0.001	0.000	0.083
LM_λ	0.000	0.000	0.000	0.002	0.061	0.083
LM_λ (robust)	0.000	0.319	0.000	0.034	0.000	0.248
$LM_{\rho\lambda}$	0.000	0.000	0.000	0.000	0.000	0.049

Note: Values in parentheses below coefficient estimates represent robust standard errors or probabilities in F-test. For spatial autocorrelation tests, the p-value is indicated. It is statistically significant at the $^{*}p < 0.01$, $^{**}p < 0.05$ and $^{***}p < 0.10$

Source: own work from Stata.

The findings reveal an absolute convergence of 1.3% and 1.5% annual rates across provinces for per capita income and tax revenues. Based on these estimated rates, the provinces would need approximately 110.5 and 90.5 years to reach the same per capita income and tax revenue, respectively. However, there is no indication of absolute convergence in per capita government spending. The results align with a recent study conducted by Yamanoğlu (2022). He estimated a 2% convergence rate for income and taxes between 2006 and 2020 but found no comparable evidence in government expenditures.

The literature supports that panel data estimates produce results more consistent with conditional-beta convergence, as they consider the individual characteristics of the provinces in the fixed effects component. As a result, we estimate the beta-convergence coefficients for all variables with both unit and time-fixed effects and report the statistically significant results in Table 3. The findings demonstrate that the dependent variables represent conditional convergence on a provincial level and have comparable rates throughout the sample period. As projected, the convergence rates rise to 29.6% for per capita income, 27.4% for per capita public expenditures, and 29.4% for per capita tax revenues. Moreover, provinces would achieve their potential income and tax revenue levels in 4.7 years. For government expenditures, this period is 5.1 years.

Other research using panel data estimations calculates similarly high convergence values. For instance, Yamanoğlu (2022) measured the rate of per capita income at 30%, whereas Filiztekin (1998) and Canova and Marcet (1995) calculated it at 33%. Canova and Marcet (1995) further showed that the convergence coefficient rose to 23% as each region approached its steady state. Similar to this, Tondl (1998) obtained high rates of convergence for the European countries from 1975 to 1996, ranging from 21% to 82%. Elhorst (2010) computed convergence rates of 0.9% and 7.8% for 193 EU regions during the period 1977–2002 by utilising pooled regression and two-way fixed effects models. According to Yamanoğlu (2022), public expenditures and tax revenues have a conditional convergence of 33% and 36% from 2006 to 2020, respectively.

5.2. Spatial models

Following the OLS and ML estimations, we can discuss the result of spatial econometric analysis of beta-convergence for income and fiscal variables separately across Turkish provinces from 2004 to 2022.

We perform the LM tests explained in the methodology section to realize whether there is any spatial error or lag in the models before estimating the spatial models. The robust LM test (LM_ρ) from the residuals of the OLS model shows an autoregressive term (i.e., $\rho \neq 0$) for all models in Table 3. Furthermore, the robust LM test (LM_λ) concludes residual autocorrelation (i.e., $\lambda \neq 0$) for the absolute-beta convergence models. We can continue estimating spatial models through the ML methodology since there is either lag or spatial error in all models according to the LM tests. This conclusion is also verified by the ($LM_{\rho\lambda}$) tests.

Table 4 shows the ML results of the five spatial panel models, both dynamic and static, to explain the spatial effects on the convergence of income, government expenditures, and tax revenues. Since a two-way fixed effects model is the appropriate specification, we only focus on their estimation results. The findings from the OLS and ML estimations are consistent. Based on the approach suggested by LeSage and Pace (2009) and Elhorst (2010), the LR tests in Table 5 conclude that the static SEM provides the most appropriate model for all the variables of income, government expenditures, and tax revenues. They have the lowest AIC and BIC scores while the highest log-likelihood values. The absence of divergence in findings between the non-spatial model (OLS) and the SEM suggests that the SEM model specification is precise and does not suffer from an omitted variable problem.

The ML estimation of spatial models suggests that the per capita income growth rate spills over from neighbouring provinces. Therefore, the models measure the total effects that can be divided into two distinct parts: (i) direct effect sourcing from own-province and (ii) indirect effect due to the other provinces or spatial spillover. Nevertheless, these effects are not linked directly with the estimated parameters of spatial models, and hence, they cannot be interpreted as direct or indirect effects. Additional calculations are necessary for gauging these effects. Furthermore, dynamic spatial models permit us to examine both short- and long-run effects (Rios *et al.*, 2017). If only the SEM model is used, however, the usual interpretation of the OLS results is still applicable. Because the SEM model accounts for a general dispersal effect deriving from spatially autocorrelated errors.

Table 4. Estimation results of spatial models for income, government expenditures and tax revenues, based on a binary contiguity matrix

Coefficient of variables	Income					Government expenditures					Tax revenues				
	SEM	**SAR**	**SDM**	**DSAR**	**DSDM**	**SEM**	**SAR**	**SDM**	**DSAR**	**DSDM**	**SEM**	**SAR**	**SDM**	**DSAR**	**DSDM**
ψ				0.078* (0.028)	0.0762* (0.027)				0.023 (0.027)	0.033 (0.027)				0.045 (0.029)	0.051*** (0.029)
β	-0.264* (0.018)	-0.240* (0.018)	-0.268* (0.019)	-0.273* (0.020)	-0.302* (0.021)	-0.249* (.017)	-0.238* (0.016)	-0.260* (0.017)	-0.250* (0.019)	-0.272* (0.020)	-0.258* (0.019)	-0.254* (0.019)	-0.262* (0.019)	-0.277* (0.022)	-0.288* (0.022)
ρ		0.358* (0.031)	0.390* (0.031)	0.359* (0.032)	0.393* (0.032)		0.126* (0.037)	0.157* (0.037)	0.133* (0.038)	0.159* (0.038)		0.076*** (0.039)	0.096* (0.040)	0.070 (0.038)*	0.093** (0.041)
λ	0.390* (0.033)					0.163* (0.037)					0.096* (0.040)				
θ			0.141* (0.033)		0.148* (0.035)			0.110* (0.031)		0.098* (0.034)			0.081* (0.040)		0.094** (0.044)
Convergence	30.7%	27.4%	31.1%	31.8%	36.0%	28.6%	27.1%	30.1%	28.7%	31.7%	29.8%	29.3%	30.5%	32.45%	33.93%
Half-life period	2.3	2.6	2.2	2.2	1.9	2.4	2.6	2.3	2.4	2.2	2.3	2.4	2.3	2.1	2.0
Log-likelihood	2,568	2560	2,569	2,407	2,416	2,306	2,303	2,309	2,166	2,169	806	805	807	735	737
AIC	-5,131	-5,115	-5,130	-4,809	-4,822	-4,607	-4,596	-4,610	-4,323	-4,329	-1,606	-1,606	-1,606	-1,461	-1,463
BIC	-5,115	-5,099	-5,109	-4,786	-4,796	-4,591	-4,584	-4,589	-4,303	-4,302	-1,590	-1,588	-1,585	-1,441	-1,437
Short-run effects															
Direct				-0.283*	-0.300*				-0.252*	-0.271*				-0.279*	-0.287*
Indirect				-0.147*	0.051				-0.039*	0.068***				-0.022***	0.079***
Total				-0.430*	-0.249*				-0.291*	-0.203*				-0.301*	-0.209*
Long-run effects															
Direct	-0.264*	-0.247*	-0.263*	-0.309*	-0.326*	-0.249*	-0.238*	-0.257*	-0.258*	-0.280*	-0.258*	-0.254*	-0.261*	-0.292*	-0.303*
Indirect		-0.126*	0.053	-0.181*	0.041		-0.033*	0.077**	-0.041*	0.068***		-0.020***	0.058	-0.025***	0.082***
Total		-0.372*	-0.211*	-0.490*	-0.284*		-0.271*	-0.180*	-0.299*	-0.212*		-0.274*	-0.203*	-0.316*	-0.221*

Note: It is statistically significant at the $^{*}p < 0.01$, $^{**}p < 0.05$ and $^{***}p < 0.10$. Values in parentheses below coefficient estimates represent robust standard errors or probabilities in F-test and spatial autocorrelation tests

Source: own work from Stata.

Table 5. Model selection for income, government expenditures and tax revenues

Variables	Test statistics			Decision	Selected model
	χ^2	p-value	Null-hypothesis (H_0)		
Income					
SAR vs DSAR	7,91	0.005	$\psi = 0$	Reject	DSAR
SDM vs DSDM	7,71	0.006	$\psi = 0$	Reject	DSDM
DSAR vs DSDM	17,76	0.000	$\theta = 0$	Reject	DSDM
SEM vs DSDM	9,10	0.011	$\theta = -\beta\lambda$ ($\theta = -\beta\rho$), $\psi = 0$	Accept	SEM
Government expenditures					
SAR vs DSAR	0,73	0.394	$\psi = 0$	Accept	SAR
SDM vs DSDM	1,45	0.228	$\psi = 0$	Accept	SDM
SAR vs SDM	12,49	0.000	$\theta = 0$	Reject	SDM
SEM vs SDM	5,46	0.020	$\theta = -\beta\lambda$ ($\theta = -\beta\rho$), $\psi = 0$	Accept	SEM
Tax revenues					
SAR vs DSAR	2,43	0.119	$\psi = 0$	Accept	SAR
SDM vs DSDM	3,16	0.075	$\psi = 0$	Accept	SDM
SAR vs SDM	4,09	0.043	$\theta = 0$	Reject	SDM
SEM vs SDM	2,12	0.146	$\theta = -\beta\lambda$ ($\theta = -\beta\rho$), $\psi = 0$	Reject	SEM

Note: When performing hypothesis tests, the significance level is set at 0.01. The AIC, BIC and log-likelihood values obtained from the models are also considered to establish the significance level

Source: own work from Stata.

The interpretation of the SEM model is similar to the OLS model but does not provide an estimate of direct effects. Therefore, we might consider an alternative spatial model that can calculate direct and indirect effects. For this reason, we need to evaluate the other spatial models to comprehend the two effects since we consider the SEM model the most appropriate for all variables.

The SEM model infers that the estimated coefficient of the initial per capita income (0.264) from Table 4 is negative and significant, which approves the presence of beta-convergence. This result is consistent with the OLS estimation (0.256) which has already been presented. We utilise the estimated beta coefficient and the direct effect (0.264) to scale the speed of convergence and the half-life for the sampling period. The SEM model provides 30.7% convergence rate and a 2.3 half-life period for per capita income, which are comparable with the OLS results from the non-spatial model (29.6% and 2.3, respectively). This conclusion also proposes that the original model of conditional beta-convergence estimated through the OLS method is not affected by misspecification arising from omitted spatial dependence. According to the positive and significant spatial autocorrelation coefficient (λ = 0.390) from the SEM model, the growth in per capita income in a given province is positively correlated with a shock that occurs in neighboring provinces. Explicitly, there will be a 3.9% change in a given province's per capita income growth due to a 10% parallel shock in the neighbours.

The estimated β coefficients for the other static and dynamic spatial models in Table 4 are not only negative and statistically significant but also comparable with the SEM model. The lowest (0.240) and highest (0.302) values are obtained from the SAR and DSDM models, respectively. Like the beta-coefficient, the estimated values of spatial externalities (ρ) in Table 4 are significant and positive. The values from different models are consistent, ranging from 0.358 in the SAR model to 0.393 in the DSDM model. The results imply that a 10% change in the rise of per capita income in neighbouring provinces corresponds to an income growth between 3.6% and 3.9% in the relevant province.

The significant and positive θ coefficients for the initial level of income from the SDM (0.141) and DSDM (0.148) models are also very analogous. This interaction appears when a specific province's effect will depend on the observable peculiarities of its neighbours. The negative and significant direct effects ranging between 0.247 (the SAR model) and 0.326 (the DSDM model) imply the presence of beta-convergence as estimated from the non-spatial model. The direct effect is 0.263 for the SDM and 0.309 for the DSAR models.

The positive and insignificant indirect effects for the SDM (0.053) and the DSDM (0.041) indicate no confirmation of spillover effects. Consequently, the spatial diffusions are presumed to be trivial which suggests that the growth rate of per capita income in a given province is not significantly affected by its neighbours. This conclusion is consistent with the Moran tests found in the descriptive statistics section for the growth rate of per capita income across Türkiye. That said, the SAR and the DSAR models conclude negative and significant indirect effects, which signifies the evidence of dispersion effects. We are cautious about concluding spatial spillover effects due to the mixed results for testing indirect effects. Notwithstanding, the estimated values of total effects for all models are negative and significant. The highest and lowest total effects are estimated for the DSAR and the SDM models (0.490 and 0.211), respectively.

We should also underline that the estimated coefficients of the lag-dependent variable (ψ) for the DSAR and DSDM models are positive and significant. That means the dynamic spatial models might be valid specifications for our analysis. These two models enable us to measure the direct and indirect effects in the short run. The results, however, do not provide any evidence of significant differences between the short-run and long-run.

In conclusion, Table 4 provides comparable results of the estimated spatial coefficients for all models. They are also consistent with the non-spatial model. Therefore, it would be the most effective way to apply information criteria when selecting an alternative spatial model to define the direct and indirect effects. The

AIC and the BIC criteria conclude that the SDM model can be considered. The SDM model has not only the lowest AIC (5,130) and the BIC (5,109) scores but also the highest log-likelihood value.

The spatial estimation results from public expenditures and tax revenues agree with the findings obtained from income with a few exceptions. Mind you, the SEM model is chosen as the most appropriate model for all variables according to the LR tests in Table 5. The SEM models confirm beta-convergence for both public expenditures and tax revenues, as is the case of income. Furthermore, these results are consistent with the OLS estimates. The convergence rates and half-life periods are around the values calculated for income. Accordingly, the convergence rates are 28.6% and 29.8% for public expenditures and tax revenues while their half-life scores are 2.4 and 2.3, respectively. The results going along with the OLS verify the absence of an omitted variable bias problem. The positive and significant spatial autocorrelation coefficients (λ) reveal the existence of a positive correlation of the growth in fiscal variables between a given province and its neighbours. However, the strength of this correlation is considerably lower than that of income (3.9%). Indeed, a 10% shock in the neighbouring provinces causes a change of 1.6% in public expenditures and 1.0% in tax revenues in the relevant province.

The negative and statistically significant β and ρ coefficients for the alternative models are not estimated differently from the SEM model. The estimated values of spatial externalities (ρ), however, indicate that a 10% change in the public expenditures of neighbouring provinces leads to an expenditure growth between 1.3% and 1.6% in the relevant province. This impact would be between 0.8%–1.0% for tax revenues.

The θ coefficients for the initial level of income from the SDM and DSDM models are significant and positive. Their values are very similar for the two fiscal variables. The negative and significant direct effects reveal that the presence of conditional beta-convergence is consistent with the non-spatial model. The value of direct effect ranges between 0.238 and 0.280 for public expenditures and -0.254 and -0.303 for tax revenues.

The most important difference in spatial estimates of public expenditures and tax revenues compared to income is to reveal the presence of indirect effects. Therefore, the fact that the growth rates in fiscal variables are affected by neighbouring provinces approves the presence of a spillover effect. However, the estimated values of indirect effects are positive and significant for the SDM and DSDM models while negative and significant for the SAR and DSAR models. In other words, according to the SDM and DSDM models, the impact of neighbouring provinces on the growth of fiscal variables is negative while the SAR and DSAR models indicate that these effects are positive. Accordingly, total effects are reduced by indirect effects in the SDM and DSDM models while being expanded in the SAR and DSAR models. For direct and indirect effects, there are no big differences between the values calculated for the short and long terms.

The difference in spatial estimates for public expenditures and tax revenues stems from dynamic models. The estimated values of the lagged variable in the DSAR and DSDM models for public expenditures are insignificant, unlike income and tax revenues. Therefore, the validity of dynamic spatial models for public expenditures is controversial. Lastly, the AIC and the BIC scores as well as the log-likelihood values indicate that the SDM model can be considered for the interpretation of direct and indirect effects.

We also provide a robustness check to our results through an alternative distance-based neighbourhood matrix. The distance in the matrix is computed between centroids of Turkish provinces. The neighbourhood structures are defined by considering different distances of 250 km, 300 km, 350 km, and 400 km. If the distance is less than 250 km, for instance, it is considered that there is a contiguity relationship between the provinces, and the value is given as 1, otherwise 0. Also, its standardized (normalised) version is used in the analysis. The robust estimation results for the SEM and the SDM models are presented in Table 6.

According to the estimation results obtained from the SEM and the SDM models through the distance-based matrix, the estimated beta coefficients are negative and significant while not varying depending on the distance. Likewise, we find statistically significant results for the spatial coefficients in all models. Moreover, the distance influences the spatial coefficients to a certain extent for all variables. As the number of provinces in the neighbourhood increases, the distance affects the coefficients more. The estimates using the alternative matrix, however, make only the spillover effect (indirect effect) significant differently for public expenditures and tax revenues. The log-likelihood, AIC, and BIC values obtained for the SEM and SDM models are also comparable with the previous estimations.

Table 6. Estimation results of the SEM and SDM models for income, government expenditures and tax revenues, established on a distance-based matrix

Coefficient of variables	**SDM**				**SEM**			
	Distance				**Distance**			
	250 km	**300 km**	**350 km**	**400 km**	**250 km**	**300 km**	**350 km**	**400 km**
Income								
β	-0.266*	-0.264*	-0.263*	-0.265*	-0.264*	-0.262*	-0.261*	-0.263*
	(0.019)	(0.018)	(0.018)	(0.019)	(0.018)	(0.018)	(0.018)	(0.018)
ρ	0.422*	0.452*	0.519*	0.557*				
	(0.034)	(0.038)	(0.041)	(0.043)				
θ	0.149*	0.155*	0.168*	0.184*				
	(0.037)	(0.041)	(0.045)	(0.048)				
λ					0.423*	0.452*	0.519*	0.558*
					(0.034)	(0.038)	(0.041)	(0.043)

Coefficient of variables	SDM				SEM			
	Distance				Distance			
	250 km	300 km	350 km	400 km	250 km	300 km	350 km	400 km
Long-run effects								
Direct	-0.263*	-0.261*	-0.260*	-0.263*				
Indirect	0.057	0.058	0.058	0.074				
Total	-0.205*	-0.202*	-0.202**	-0.189***				
Log-likelihood	2,567	2,562	2,567	2566	2,566	2,562	2,567	2,566
AIC	-5,125	-5,116	-5,126	-5,124	-5,126	-5,117	-5,127	-5,126
BIC	-5,104	-5,095	-5,104	-5,103	-5,110	-5,102	-5,111	-5,110
Government expenditures								
β	-0.264*	-0.271*	-0.284*	-0.284*	-0.250*	-0.256*	-0.260*	-0.258*
	(0.017)	(0.017)	(0.018)	(0.018)	(0.017)	(0.017)	(0.017)	(0.017)
ρ	0.157*	0.240*	0.226*	0.198*				
	(0.042)	(0.048)	(0.054)	(0.061)				
θ	0.137*	0.183*	0.237*	0.251*				
	(0.033)	(0.036)	(0.038)	(0.041)				
λ					0.169*	0.260*	0.270*	0.257*
					(0.042)	(0.048)	(0.054)	(0.060)
Long-run effects								
Direct	-0.261*	-0.267*	-0.280*	-0.280*				
Indirect	0.109	0.149*	0.2163*	0.238*				
Total	-0.152*	-0.118*	-0.0631	-0.042				
Log-likelihood	2,309	2,317	2,320	2318	2,305	2,311	2,309	2,305
AIC	-4,610	-4,625	-4,632	-4,627	-4,603	-4,616	-4,611	-4,605
BIC	-4,589	-4,604	-4,610	-4,606	-4,587	-4,600	-4,596	-4,589
Tax revenues								
β	-0.260*	-0.264*	-0.268*	-0.268*	-0.257*	-0.257*	-0.257*	-0.257*
	(0.019)	(0.019)	(0.019)	(0.020)	(0.019)	(0.019)	(0.019)	(0.019)
ρ	0.115*	0.129*	0.162*	0.180*				
	(0.045)	(0.052)	(0.058)	(0.065)				
θ	0.074*	0.128*	0.160*	0.157*				
	(0.042)	(0.047)	(0.049)	(0.052)				
λ					0.117*	0.117*	0.117*	0.117*
					(0.045)	(0.045)	(0.045)	(0.045)

Table 6 (cont.)

Coefficient of variables	SDM				SEM			
	Distance				Distance			
	250 km	300 km	350 km	400 km	250 km	300 km	350 km	400 km
Long-run effects								
Direct	-0.258*	-0.262*	-0.266*	-0.266*				
Indirect	0.046	0.103**	0.055**	0.128**				
Total	-0.212*	-0.159*	-0.055**	-0.138**				
Log-likelihood	807	808	810	810	806	806	806	806
AIC	-1,606	-1,609	-1,613	-1,611	-1,607	-1,607	-1,607	-1,607
BIC	-1,585	-1,588	-1,591	-1,590	-1,591	-1,591	-1,591	-1,591

Note: It is statistically significant at the $^{*}p < 0.01$, $^{**}p < 0.05$ and $^{***}p < 0.10$. Values in parentheses below coefficient estimates represent robust standard errors

Source: own work from Stata.

6. CONCLUSIONS

The study of fiscal convergence on a regional basis is a new topic that extends neoclassical growth models. According to the model, under the balanced budget assumption, government expenditures are funded only by tax revenues, which are a constant fraction of income. As a result, the growth in tax revenues and public expenditures should coincide with income. Although this claim has been validated by several studies, very few studies have employed spatial econometric analysis. Moreover, Solow's proposition on fiscal policy has been mostly tested across countries or states in federally governed countries. In other words, findings regarding fiscal convergence have been limited to domestic regions or countries where fiscal autonomy is more prevalent.

The use of dynamic panel models is one of the most noteworthy characteristics that distinguishes this study from prior research. Another notable aspect is that the study is carried out for Türkiye, a country with a central government. For this purpose, we use both spatial (static and dynamic) and non-spatial models to investigate the convergence and spatial interactions in income and fiscal variables across Turkish provinces.

The estimation results obtained from the non-spatial fixed effects model partially justify Solow's proposition. Because absolute convergence could not be determined for per capita public expenditures, unlike per capita income and tax revenues. Earlier studies have yielded mixed results. Our findings are, on the one hand, consistent with, for example, Yamanoğlu (2022). On the other, Saruç *et al*. (2007) has found strong absolute convergence for public expenditures in their study for the 1990–2005 period but could detect it for tax revenues. Karaş and Karaş (2023) showed an absolute convergence for the fiscal policy by using the variable of tax revenues as a percentage of public expenditures from 2004 to 2020. The convergence rates for per capita income and tax revenues (1.3% and 1.5%, respectively) are calculated in line with previous studies. Yamanoğlu (2022) gaged these rates as 2.0% and 2.1%.

The reason why there is no convergence in public expenditures is presumably that public expenditures do not move together with income. Because the preferences or political inclinations of decision-making institutions or governments, whether centralized or not, can affect national fiscal policies. This outcome differs from the findings obtained from convergence studies conducted across countries or states. Using cross-sectional regression analysis, Scully (1991), Annala (2003), and Coughlin *et al*. (2007) showed the presence of absolute convergence for income and fiscal variables across states. In contrast, only Couglin *et al.* (2007) additionally consider spatial dependence in their study. Overall, research on fiscal convergence across states supports the Solow model. Similar results have been identified in studies examining convergence across the EU or OECD countries (Sanz and Velazquez, 2001; Gemmell and Kneller, 2003; Skidmore *et al.*, 2004; Rivero, 2006; Perovic *et al.*, 2016). Among the studies, only Perovic *et al*. (2016) considered spatial effects and emphasised their importance on fiscal convergence. In studies addressing a larger group of countries, Acemoğlu and Moline (2021) and Kremer *et al*. (2021) reached results that supported fiscal convergence using non-spatial models.

In the case of Türkiye, tax revenues are expressed as a more fixed or steady fraction of income than government expenditures. The main reason is the fiscal policy instrument of public spending, which the central government has employed to close development gaps among provinces by spending more than the revenues collected. Put another way, taxes collected from high-income regions are transferred to low-income regions. Additionally, budgetary resources other than tax revenues finance government spending. However, there is no fiscal policy that would prohibit tax revenues from remaining a consistent and stable proportion of income. As a result, the absolute convergence estimates for tax revenues in Türkiye yield findings consistent with the Solow model. In contrast, the fact that government expenditures represent changing proportions of income over time violates the Solow model's assumption, and hence, absolute convergence is not discovered in public spending.

The OLS estimation results of the non-spatial models with time and unit fixed effects validate the conditional convergence. They show that the provinces are approaching their equilibrium rather than a common steady state. The non-spatial model results show that the convergence rates for per capita income, public expenditures, and tax revenues across provinces are 29.6%, 27.4%, and 29.4%, respectively. These rates broadly agree with the findings of the other research that are particular to Türkiye. After following a similar methodology, Yamanoğlu (2022) calculated the convergence rates for the 2006–2020 period as 31.5%, 32.5%, and 36.0%, respectively. The relatively lower calculation of convergence rates in this study is probably due to the longer period examined.

The study addresses whether income, tax revenues, and government spending interact spatially. We use the ML estimation results of the dynamic and static spatial panel models to explain their spatial interactions. The findings from ML estimations are consistent with the OLS results. The comparable results indicate that the models do not suffer from misspecification caused by omitted variable problems. We refer to the SEM and SDM models for the interpretation of the estimation results. According to the most appropriate SEM specification, the convergence rates are computed as 30.7%, 28.6%, and 29.8% for per capita income, public expenditures, and tax revenues, respectively. The negative and significant direct effects expose the existence of conditional beta-convergence which corresponds to the non-spatial model. Because of the inconsistent results for investigating indirect effects, we are hesitant to conclude that spatial spillover effects exist in the short and long terms. However, the total effects for all models are negative and significant. The robustness checks to these results using an alternative distance-based neighbourhood matrix is also provided. The only study suitable for comparison in this field is conducted by Yamanoğlu (2022). He could not find any spatial dependence in per capita tax revenues, unlike per capita income and public expenditures. This result is also probably due to the length of our study period.

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EXPLORING THE ROLE OF REGIONAL RESEARCH AND DEVELOPMENT SUPPORT IN ENHANCING FOREIGN INVESTMENT IN POLAND: A SPATIAL ANALYSIS PERSPECTIVES

Abstract. This study aims to investigate the nature and drivers of foreign investment in 16 regions of Poland. Using a spatial analysis approach, the study examines the spatial characteristics of the factors that influence foreign investment, namely labour and research and development (R&D) support. The results of the first analysis indicate strong spatial characteristics and interregional correlations in the observed variables, although they are not characterised by spatial dependence. The regression analysis results show that R&D expenditure significantly supports the enhancement of foreign investment alongside the labour factor, which has a more substantial impact.

Key words: foreign investment, labour, research and development (R&D), spatial analysis, Poland.

1. INTRODUCTION

Foreign investment has become a key driver of economic growth in the European Union region, contributing to economic integration and modernisation of the industrial sector in various Member States (Berkowitz *et al.*, 2020; Drahokoupil, 2008; Radosevic and Ciampi Stancova, 2018). Since the transition in the 1990s, the Central and Eastern European (CEE) region, including Poland, has attracted

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foreign investors by dint of market openness and trade factors, especially after Poland's accession to the European Union in 2004. Foreign investment in Poland has not only increased competition and market efficiency but has also facilitated the transfer of knowledge and technology. As a resource-rich country in the CEE region, Poland has experienced significant foreign investment, leading to an increase in foreign capital, labour dynamics, infrastructure development, and a diffusion of innovation and technology (Aghion *et al.*, 2011; Gorynia *et al.*, 2009; Krpec and Wise, 2022). With its strategic location in the heart of Europe and the advantageous connections via the Baltic Sea and the Eurasian region, Poland has gained recognition among global investors and ranks among the top ten European countries for foreign investment (Grgić, 2023; Kavalski, 2018; Krpec and Wise, 2022). As an EU Member State, Poland is using EU funds to improve its competitiveness by investing in innovation and infrastructure. Foreign investment in Poland is also increasingly targeting the services and technology sectors, helping to diversify the economy (Churski, 2008; Goujard and Guérin, 2018; Murzyn, 2020). As one of the key players in attracting foreign investment in the European region and beyond, Poland strategically benefits from several location factors, including an ample labour supply, a relatively stable economic environment, and government financial support to strengthen local infrastructure. The Polish government has also implemented various policy initiatives to attract foreign investment by encouraging innovation and strengthening domestic technology by supporting research and innovation activities. The presence of foreign investors has contributed to the growth of the local economy and industry (Brandt, 2018; Kapil *et al.*, 2013; Tuznik and Jasinski, 2022).

Various studies have shown the significant economic impact of foreign investment, including its impact on labour absorption. Conversely, labour, as a critical factor of production, is also an essential consideration in influencing foreign investment decisions (Ambroziak and Hartwell, 2018; Bermejo Carbonell and Werner, 2018; Kurtishi-Kastrati, 2013; Su and Liu, 2016). In addition to the labour supply factor, the role of research and development (R&D) in encouraging foreign investment is also critical. Research conducted by Götz (2020) shows that support for R&D in a region can attract foreign investment because it can increase local innovation and productivity. When combined with the labour supply factor, R&D support directed not only at infrastructure investment but also at improving the quality of R&D personnel is an important input for innovation that will ultimately increase local innovation capacity and thus attract foreign investment (Tóth *et al.*, 2020; Yaghi and Tomaszewski, 2024). Tuznik and Jasinski (2022) and Chybowska *et al.* (2018) reported that the Polish government has demonstrated the importance of R&D in driving innovation and economic growth by introducing various funding schemes and incentives to encourage domestic and foreign investment. This relationship highlights the need for a deeper understanding of how R&D support directly and indirectly affects foreign investment. However, the importance of regional R&D support in the context of foreign investment is less explored in literature. Previous studies on these factors have tended to consider them separately. There is a limited number of studies which link it to foreign investment, although some studies specifically examine R&D support in the context of foreign investment to support innovation (Castellani *et al.*, 2022; Newman *et al.*, 2015; Sharma, 2019). Conversely, studies of foreign investment are more likely to be associated with key factors of production, such as the quality and quantity of labour, and their impact on the economy (Asongu *et al.*, 2018; Iamsiraroj, 2016; Newman *et al.*, 2015). Therefore, the literature on foreign investment needs more attention, especially on how labour-intensive and knowledge-intensive foreign investment can complement each other. In such cases, a spatial analysis approach becomes important, especially to identify which regions have better availability of production factors, innovation, and productivity to attract foreign investment.

A study by Wibisono (2023) identified a spatial dependence between knowledge inputs and innovation in the Visegrad regions (Poland, Hungary, Czech Republic, and Slovakia). The study found that personnel with specialised skills in R&D significantly impact innovation, while public expenditure on R&D, although significant, negatively impacted innovation in the Visegrad region. A study by Hintošová *et al.* (2020) in the same region, where the analysis used a fixed effects model, found that R&D spending had a negative effect on FDI inflows in the Visegrad region over the period 1989–2016. Busom *et al.* (2014) have argued that continuous government funding of R&D can create dependency and reduce the competitiveness of firms, leading to a less competitive and less attractive environment for investment. Zúñiga-Vicente *et al.* (2014) and Pellens *et al.* (2018) have argued that the negative effects of R&D may be due to inefficient resource allocation, with R&D support being directed to less productive and less competitive sectors. Thus, a region may have high R&D support but low foreign investment intensity, or *vice versa*.

These descriptions reveal some inconsistencies regarding the impact of R&D on foreign investment. Some studies show that R&D support has a positive impact on foreign investment through increased productivity and local innovation. Meanwhile, other studies in regional contexts, such as CEE or Visegrad, show a negative impact of R&D support on innovation and foreign investment inflows. The author argues that each country has specific regional characteristics, so the results may differ in the context of other countries or regions. These phenomena then raise the question of the extent to which R&D support, in addition to human capital support, affects foreign investment in the context of a specific region in a country such as Poland. Specifically, this study questions what the spatial characteristics of foreign investment, labour, and R&D support in Poland are, and to what extent labour and R&D support can influence foreign investment in its spatial context. Using a spatial analysis approach, this study investigates these questions by examining 16 voivodeship regions in Poland. The results of the first analysis indicate that there are strong spatial characteristics and interregional correlations in the observed variables, although they are not characterised by spatial dependence. Most regions in Poland are classified in the high and medium categories for the intensity of each observed variable, yet at least one third of the regions in Poland still need to improve in terms of foreign investment and its enabling factors. Furthermore, the estimation results of this study show that R&D support has a positive and significant influence on foreign investment, alongside the labour factor, whose influence is more substantial. The results of this study provide an essential contribution to the literature specifically examining R&D support or policies related to foreign investment, as well as have implications for broader regional policies of Poland and contribute to academics and practitioners in the field of international studies and regional studies.

The paper is organised as follows. The second section of the paper outlines background literature on foreign investment and its supporting factors, particularly in the context of regional and spatial analysis. The third section outlines the methodological approach used and the steps of the analysis. The fourth section presents the results and a discussion. The fifth section presents conclusions, implications, limitations, and opportunities for future research.

2. LITERATURE REVIEW

The economic characteristics of a region or country often play an essential role in MNEs' investment decisions. Factors such as the host country's labour force and the level of knowledge and technology are critical determinants (Castellani *et al.*, 2006; Dunning and Lundan, 2008). These decisions reveal strategic differences in how foreign firms manage costs and acquire critical resources such as labour and knowledge. Recent literature provides valuable insights into foreign direct investment (FDI) preferences, whether for labour-intensive or knowledge-intensive firms or industries (Amoroso and Moncada-Paternò-Castello, 2018; Nielsen *et al.*, 2018). However, there is an urgent need for a deeper understanding of the reasons behind these choices, especially in developing and transition economies such as Poland. Historically, Poland has been an attractive destination for foreign investment in labour-intensive sectors due to its low labour costs and growing infrastructure (Jantoń-Drozdowska and Majewska, 2016). However, as the economy has progressed and its innovation capacity has grown, there has been a noticeable shift towards knowledge-based sectors (Klagge and Klein-Hitpaß, 2010; Salamaga, 2023). This transition requires a comprehensive understanding of how research and development (R&D) policies or technological advances can influence foreign investment decisions. Poland faces particular challenges in transitioning from a labour-intensive to a knowledge-based economy. While the country has made significant investments in high technology and research, it needs to focus on attracting high-quality FDI and ensuring that the positive effects of these investments are spread evenly throughout the economy.

Labour-intensive industries depend highly on labour and often attract foreign direct investment (FDI) because of lower production costs. According to the Heckscher-Ohlin model and the classical theory of comparative advantage, countries with abundant labour at lower wages tend to attract foreign investment in sectors such as light manufacturing, textiles, and agribusiness (Rahman *et al.*, 2019; Siddiqui, 2018). MNCs can reduce costs by taking advantage of cheap labour in these sectors. Some studies suggest that while labour-intensive sectors create jobs and income in the short term, they may be less stable in the long term because firms can quickly shift production to low-cost countries (Omoruyi, 2021). Excessive reliance on labour-intensive foreign investment may hinder economic diversification and long-term innovation, especially in developing countries seeking to transition to a knowledge-based economy. Conversely, knowledge-based firms depend on knowledge, technology, and innovation. Countries that invest in R&D or technological infrastructure often attract foreign investment in high-tech sectors. According to Porter's (1990) theory of competitive advantage, countries with strengths in innovation and R&D are more likely to attract investment in knowledge-based industries (Ge and Liu, 2022). Studies show that MNEs are attracted to countries with thriving innovation ecosystems that offer advanced technologies, a skilled workforce, and growing markets (Suseno and Standing, 2018). While some studies show that countries with established innovation ecosystems tend to attract knowledge-based foreign investment, the literature needs a comprehensive analysis of the role of factors such as R&D policies in attracting FDI. For economies in transition, such as those in Central and Eastern Europe (CEE), deciding whether to attract foreign investment in labour-intensive or knowledge-intensive activities is challenging. Countries such as Poland have successfully attracted foreign investment in both sectors but with different policy strategies. Initially, foreign investment growth in the early stages of the transition was driven by labour-intensive manufacturing. However, investments in education, research, development, and technology have increased foreign investment inflows into more knowledge-intensive sectors (Bryl, 2018; Wyszkowska-Kuna, 2014).

Research and development funding is increasingly important in attracting foreign direct investment (FDI). By supporting innovation capacity, competitiveness, and technological progress, R&D funding can increase the attractiveness of a country or region to foreign investors (Guimón, 2009; Guimón *et al.*, 2018; Hu and Mathews, 2005). In practice, R&D funding can stimulate foreign investment inflows in several ways. First, investment in R&D promotes the creation and diffusion of innovations, leading to productivity and efficiency gains for local firms (Erdal and Göçer, 2015; Liang, 2017). A strong track record of innovation makes domestic firms more attractive to foreign investors seeking partnerships or a strong base for market entry at the local or regional level. Second, extensive R&D initiatives can foster a highly skilled and educated workforce, an essential factor that multinationals carefully consider when making investment decisions (Hegde and Hicks, 2008; Di Minin *et al.*, 2012; Piva and Vivarelli, 2009). R&D funding is often linked to higher education and technical training programs that can upgrade the local workforce's skills, attracting multinationals requiring specialised expertise. Third, R&D funding can strengthen a country's global innovation and technology centre position. A positive reputation can significantly influence foreign investors' perceptions of a country's economic potential, encouraging more investment (Dunning and Lundan, 2009; Fu, 2008). Countries known for their vital R&D infrastructure and continued government support for innovation often attract high-tech foreign investment.

Several empirical studies have demonstrated the positive relationship between R&D investment and foreign investment inflows. De Beule and Somers (2017) and Du *et al.* (2022) have found that increased R&D intensity in a country significantly affects the location preferences of multinational firms, with increased R&D spending increasing the attractiveness of foreign investment. Ben Hassine *et al.* (2017) and Ghosh *et al.* (2018) have also concluded that R&D increases the attractiveness of locations for foreign investment and increases the potential for technological spillovers that benefit the domestic economy. The importance of R&D investment in promoting foreign investment is increasingly relevant in economic policy discussions in Central and Eastern Europe, including Poland, Hungary, the Czech Republic, and Slovakia. A recent study by Medve-Bálint and Éltető (2024) shows a positive correlation between increased public R&D funding in CEE including Poland and an increase in foreign investment inflows, especially in the high-tech sector. This suggests that R&D investment is an important policy tool for attracting foreign investment. However, it is important to keep in mind that the effectiveness of R&D investment in attracting foreign investment may depend on various region-specific contextual factors, including the advantage of the region's location within a country (e.g., capital vs. peripheral), institutional stability, consistent economic policies, and supportive infrastructure (Jindra and Rojec, 2018; Zoltán and Gábor, 2022). Overall, the literature suggests that R&D investment is critical for attracting foreign investment by strengthening innovation capabilities, improving workforce skills, and building an international reputation as a centre of technological excellence.

Regional connectivity is essential in foreign investment location decisions. This can be explained by a spatial economic analysis. According to the agglomeration economic theory, firms tend to cluster together to benefit from lower transportation costs, improved market access, and technology spillovers (Lee and Hwang, 2014; Mariotti *et al.*, 2010). In the context of foreign investment, a high concentration of foreign investment in a region can create an attractive environment for other investors due to improved infrastructure, availability of skilled labour, and strong industrial networks (Götz, 2020; Mariotti *et al.*, 2010; Popescu, 2014). The density of foreign investment in a region can influence the attractiveness of foreign investment in neighbouring regions through the spillover effect mechanism. The spatial economic analysis suggests that investment decisions are influenced not only by a region's characteristics but also by surrounding regions, especially those that are adjacent or related to it in terms of resource-related factors (Jaworek *et al.*, 2019). For example, if a region has a high concentration of foreign investment in the technology sector, nearby regions may become more attractive for foreign investment due to the proximity of firms, which allows for the sharing of resources and knowledge. In addition, the level of foreign investment density in a region can influence investment decisions in neighbouring regions. Regions with high foreign investment density often become agglomeration centres, attracting other firms in the same industry and promoting economic diversification through multiplier effects. Successful industrial clusters in a region can indicate the quality of local institutions, supportive policies, and economic stability, all of which are attractive to foreign investors (Bailey, 2018; Feldman *et al.*, 2005). These benefits not only attract direct foreign investment to the region but also enhance the reputation and trust of surrounding regions, which ultimately increases their attractiveness to foreign investment as well. The concept of spatial spillovers suggests that the positive effects of foreign investment density can extend beyond regional boundaries and enhance the broader economic potential of the region (Lin and Kwan, 2016; Serwicka *et al.*, 2024). Therefore, government policies aimed at attracting foreign investment may be more effective if designed with these spatial effects in mind. A comprehensive understanding of the spatial interactions between regions and their impact on foreign investment is essential for policymakers to develop strategies that enhance the overall attractiveness of a region.

3. METHODOLOGY

This study is based on secondary data on foreign investment in domestic foreign-affiliated companies in the 16 voivodeships of Poland. The dataset contains information on the presence and activities of these firms in different regions. The study focuses on analysing the spatial distribution patterns of foreign investment and the factors influencing foreign investment decisions in Poland. The analysis is based on the most recent data available on the website of the Polish Statistical Office (https://stat.gov.pl). In the first stage, the spatial distribution of the observed variables is examined. In particular, a spatial analysis is used in this stage to examine the spatial relationship or spatial dependency of foreign investment and its determinants, such as labour force and R&D expenditures. The second step is to estimate the impact of labour force and R&D expenditures on foreign investment. The regression model assesses the impact of labour force (measured by total number of employees) and intramural R&D expenditure by cost type and province/region (RDP_EXP) on foreign investment (measured by total foreign capital, FORG_EQTY). Following the spatial regression estimation procedure outlined by Wibisono (2023), the estimation starts with an ordinary least squares (OLS) regression analysis, followed by an identification of spatial dependence and a subsequent spatial regression analysis. The operationalisation of these variables is documented in Table 1.

Table 1. The operationalisation of variables

Variables	Information
FORG_EQTY	Total foreign capital in firms with more than 10 employees (in million PLN)
TOT_EMPL	Total number of employees
RDP_EXP	Intramural expenditure on R&D by type of costs and voivodeships in 2020 (in thousands PLN)

Source: https://stat.gov.pl/en/topics/economic-activities-finances [accessed on: 28.02.2023].

A logical explanation for the existence of spatial dependence effects of observed variables is that geographical distance may change the way knowledge and technology are transmitted from foreign firms to host firms in a given region (Makieła *et al.*, 2021; Thompson and Zang, 2023; Tian and Zhang, 2019). Spatial analysis enables us to interpret the interactions arising from a variable observed at one location in a region as a result of the activity of the same variable in other regions around it (Capik and Drahokoupil, 2011; Orlic *et al.*, 2018). Different sources and spillover mechanisms of foreign investment in one region may have the same or different effects on neighbouring regions. Large geographical distances should technically decelerate technology spillovers. However, with the advancement of the ICT industry today, geographical distance may have a reciprocal relationship with its negative effects (Leamer and Storper, 2017). Long distance or negative geographical proximity can still increase the knowledge spillover effect (Cieślik, 2020; Tchorek, 2016). In addition, geographic distance is expected to affect the spillover effects of foreign investment in terms of agglomeration or labour mobility. Foreign investment firms with greater financial capacity may ignore distance when hiring more skilled workers, leading to high labour intensity in certain regions and beyond (Chellaraj and Mattoo, 2019; Loncan, 2021; Wang *et al.*, 2021).

This study applies the spatial regression analysis procedure by Wibisono (2023, pp. 114−116). Firstly, the spatial distribution analysis is observed to see the spatial distribution and intensity of the observed variables. Secondly, OLS regression and spatial regression analysis of the observed variables are performed. Before estimating spatial regression, it is important to determine the weighting matrix and identify spatial autocorrelation from the results of Moran's I global univariate statistical analysis. The decision of modelling estimation is based on the best regression estimate among ordinary least squares (OLS), spatial lag model (SLM), and spatial error model (SEM). While the best estimate between SLM and SEM is based on the significance value of one of them or the most significant Lagrange Multiplier (LM) value if both are significant (Anselin, 2005; Lu and Zhang, 2010; Sisman and Aydinoglu, 2022).

The basic OLS equation of the proposed regression estimation models is as follows:

$$FORG\_EQTYi = \alpha + \beta 1\ TOT\_EMPLi + \beta 2\ RD\_EXPi + \varepsilon \tag{1}$$

Spatial regression estimation that meets the requirements of the Spatial Lag Model (SLM) implies the existence of spatial dependence effects resulting from the spillover of lag variables from neighbouring regions. This effect is denoted by the spatial autoregressive coefficient (ρ) and must be evaluated to prove the existence of spatial autocorrelation of the observed lag variables ($\rho \neq 0$). The Y variable in one region and the lag variable from another adjacent region are associated with a spatial weighting matrix (***W***) so that a new variable ($\rho \boldsymbol{W}$) appears in the SLM regression model. This is what distinguishes the SLM spatial regression model from the OLS estimation model. The base equation for SLM is as follows:

$$Y = \alpha + \rho \boldsymbol{W} Y + \beta X + \varepsilon \tag{2}$$

The spatial regression estimation that meets the requirements of the Spatial Error Model (SEM) indicates the presence of spatial autocorrelation in the error term (ε). In SEM, the composition of ε consists of multiplying ε by the spatial weighting matrix (***W***). The parameter coefficient of ε is denoted by λ, whose existence must also be evaluated ($\lambda \neq 0$). The basic equation of SEM is as follows:

$$Y = \alpha + \beta X + \varepsilon; \quad \textbf{\textit{where}}\ \varepsilon = \lambda \boldsymbol{W} \varepsilon + \xi \tag{3}$$

4. RESULTS AND DISCUSSION

Figure 1 shows the spatial distribution of foreign capital investment in Poland's 16 provinces (voivodeships). The distribution of foreign investment is shown in three quantile maps. The high quantile group, with foreign investment values ranging from

11,173 million to 63,682 million Polish zlotys (PLN), is represented by dark brown areas. This group includes five regions: Mazowieckie, Małopolskie, Śląskie, Dolnośląskie and Wielkopolskie, all of which are classified as regions with high foreign investment intensity. Mazowieckie, the country's capital region, is the centre of government institutions and the headquarters of multinational companies. The region is an important economic centre characterised by rapid development, advanced infrastructure and wide market access. Śląskie is known for its strong industrial presence, with various manufacturing and high-tech companies attracted to the area due to its strong innovation and technology ecosystem. Similarly, Dolnośląskie, Wielkopolskie, and Małopolskie have advanced commercial and industrial centres, and strong international connections. Wroclaw, the capital of Dolnośląskie, thrives in manufacturing and electronics, while Poznań, the capital of Wielkopolskie, serves as one of Poland's largest trade and logistics centres with easy access to Western European markets. Krakow, one of Poland's most important historic cities, is home to leading universities and research centres that foster an environment conducive to technological innovation and development, making it an attractive destination for foreign investment focused on advanced technology domains.

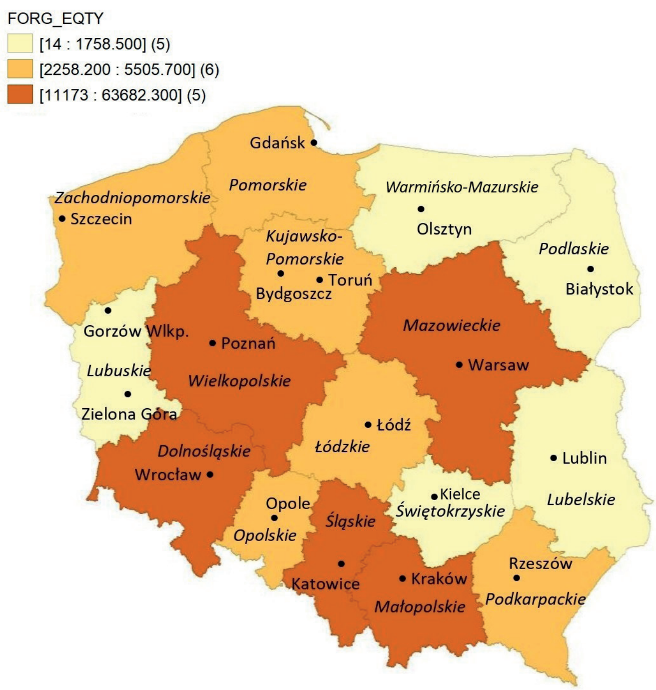

Fig. 1. Spatial distribution of total foreign capital

Source: own work.

In the middle quantile, regions in Poland have attracted foreign investments for PLN 2,258 to 5,505 million. The six regions included in this category are Podkarpackie, Łódzkie, Opolskie, Kujawsko-Pomorskie, Pomorskie, and Zachodniopomorskie. Although not in the highest investment category, these regions offer unique investment potential. Podkarpackie, with Rzeszów as its capital, has a rich history in the aviation industry. The region benefits from a strong engineering and technological infrastructure, with an international airport in Rzeszów facilitating access to global markets and promoting various international partnerships. Łódzkie, located in the central part of Poland with the capital city of Łódź, has a long history of textile and manufacturing industries. Opolskie and Kujawsko-Pomorskie focus their investments on agribusiness, logistics, and light industry. Pomorskie and Zachodniopomorskie, both on the Baltic Sea, are critical players in the maritime economy and host Poland's strategically important trade, logistics, and transport services industries. The remaining five regions are classified in the lower quantile, with an average foreign investment value of less than PLN 1,758 million. These regions are Warmińsko-Mazurskie, Lubuskie, Lubelskie, Podlaskie, and Świętokrzyskie. These regions are generally characterised by agriculture and light industry, which tend to develop (e.g., Lubelskie, and Lubuskie). Some are advanced in the tourism industry due to their magnificent landscapes (e.g., Warmińsko-Mazurskie, and Podlaskie). Świętokrzyskie has a history of industry, especially mining and minerals, but tends to lag despite being flanked by more developed regions.

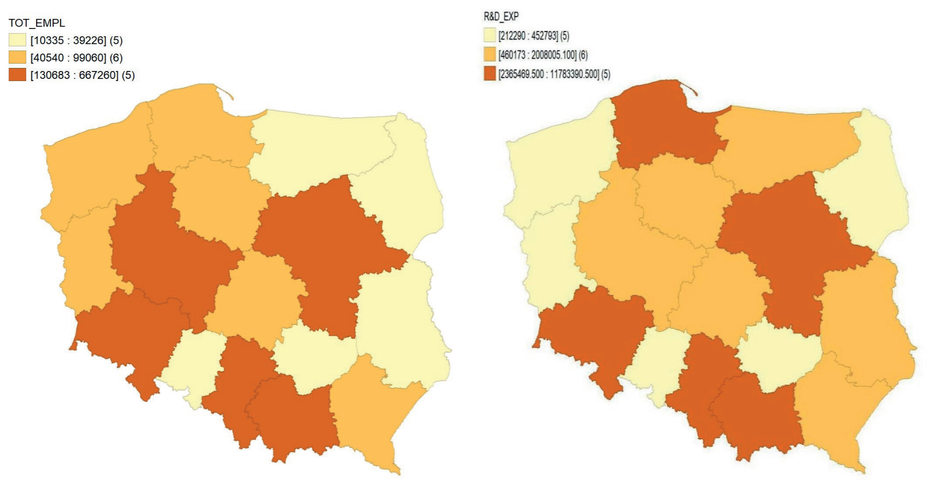

Fig. 2. Spatial distribution of total number of employees (left) and intramural R&D expenditure (right)

Source: own work.

Foreign investment has been a critical driver of labour-intensive industrial development in Poland, where foreign firms often invest in labour-intensive manufacturing sectors such as textiles, electronics, and automotive (Dziemianowicz *et al.*, 2018). In some cases, foreign investment is even directed to regions with abundant labour availability and relatively low labour costs (Drahokoupil *et al.*, 2015; Jantoń-Drozdowska and Majewska, 2016). Figure 2 (left) shows that almost all regional distributions based on labour are similar to the distribution of foreign investment, except for Lubuskie, which has medium labour density but belongs to a region with low foreign investment density. Despite its moderate labour density, the relatively low density of foreign investment in Lubuskie may be due to a lack of specific skills or the level of education required by companies. Moreover, attracting foreign investment often depends on the availability and quality of R&D facilities. According to Crescenzi *et al.* (2016), regions can attract foreign investment by having a robust R&D infrastructure, mastering essential technologies that are in demand by many firms, or fostering strong innovation networks.

Using a three-quantile classification, the pattern of labour distribution can be categorised into high labour density areas (around 130,000 to 667,000 employees), medium labour density areas (around 40,000 to 100,000 employees), and low labour density areas (less than 40,000 employees). Several factors contribute to this similar spatial distribution pattern. According to Kottaridi *et al.* (2019), regions that can attract foreign investment usually have skilled labour available to meet the needs of the industry. Consistent with Götz (2020) findings, foreign firms are likely to invest in Polish firms in regions with access to an educated and trained workforce. Götz *et al.* (2023) and Tarlea (2017) have found that regions with leading universities and colleges in Poland often attract more foreign investment due to the availability of highly skilled graduates. In addition, high-quality infrastructure also facilitates efficient labour allocation, which allows for easy worker mobility. As a result, regions with high-quality infrastructure tend to have higher levels of labour allocation (Horobet *et al.*, 2021; Salike, 2016). Ślusarczyk (2018) found that Polish local governments also offered incentives such as tax breaks or support for skills development to attract foreign investment. These policies not only attract foreign investment but also create jobs at the same time. As foreign investment inflows increase, so does the demand for labour. foreign investment is often industry-specific. Ablov (2015) showed that in Poland, regions with a concentration of specific industries were more likely to attract investment in these sectors and thus created more jobs in these industries. Several previous findings have shown that these points contribute to the pattern of labour distribution, which is reflected in the pattern of foreign investment concentration in Polish regions.

In the map of the spatial distribution of R&D expenditure (Fig. 2, right), the pattern of R&D expenditure is divided into three quantiles. The high quantile includes regions with total R&D expenditure ranging from about PLN 2,400 million to PLN 11,800 million. In particular, Mazowieckie, Małopolskie, Śląskie, Dolnośląskie, and Pomorskie are highlighted in this quantile due to their intensive R&D expenditure, which is represented by dark brown areas. The distribution of R&D in these top regions closely mirrors the distribution of foreign investment. However, while Pomorskie is in the middle quantile for the foreign investment distribution, it is in the top quantile for the R&D expenditure distribution. Moving to the middle quantile, the R&D expenditure of the regions ranges from around PLN 460 million to PLN 2,008 million. Interestingly, Wielkopolska, which is in the high quantile for foreign capital distribution, is classified in the middle quantile for R&D expenditure. Conversely, Lubelskie and Warmińsko-Mazurskie, which are in the lower quantile for foreign capital distribution, are in the middle quantile for R&D expenditure. Finally, the lower quantile includes regions with total R&D expenditure ranging from around PLN 212 million to PLN 452 million. Notably, Zachodniopomorskie has a low R&D density while having a medium foreign investment density, whereas the remaining regions have low densities for both R&D and foreign investment.

From R&D expenditure distribution some questions may arise, such as why there are regions that have low R&D density but can have higher foreign investment density, for example, in Zachodniopomorskie or such as in Pomorskie, which belongs to the high R&D quantile but belongs to the medium foreign investment quantile. In this case, there are several possible reasons behind it. Pomorskie, despite belonging to the high R&D quantile, has a foreign investment density that is only at a medium level due to the role of infrastructure and accessibility that influence investment decisions. According to Bocheński *et al.* (2021), Pomorskie, which has the leading port in Gdańsk and is one of the main ports on the Baltic Sea, provides direct access to international markets, playing an important role in sea trade and transportation. This sector makes Pomorskie attractive to foreign investors seeking a location with high connectivity and direct access to global markets, regardless of whether the region has a density of R&D activity. Similarly, according to Saidi *et al.* (2020), a region can attract foreign investment in sectors that are less dependent on R&D, such as traditional manufacturing, transportation, and logistics, where the presence of R&D facilities is not a key determinant, but instead tends to be a facilitator or catalyst. Moreover, regions with lower R&D density may attract foreign investment in sectors that do not require large investments in technological innovation or scientific research but may focus more on strategic location or cost advantages. For instance, this is the case in Zachodniopomorskie, which is classified in the low R&D quantile but belongs to the medium foreign investment quantile. The availability of low operating costs and a competitive labour force could be a significant factor for foreign investment decisions in the region (Götz, 2020). Regions with lower R&D but skilled labour and low cost of living can attract investors, especially in labour-intensive industries that do not require high R&D activities. This allows the region to remain competitive in attracting foreign investment despite its lack of significant research and development activity.

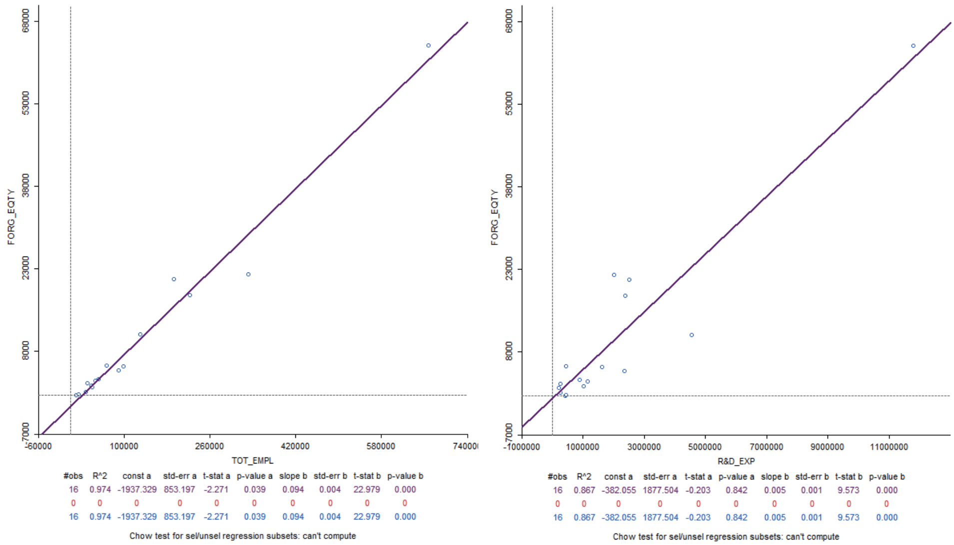

Fig. 3. Scatter plot of the observed variables

Source: own work.

Figure 3 shows a strong positive correlation between the number of employees (by 97.4%) and R&D expenditure (by 86.7%) and foreign investment in the Polish regions. The scatter plot on the left shows a statistically strong positive relationship between total labour and foreign investment in Polish regions. The high level of total labour in Poland acts as a driver of foreign investment growth in these regions. The spatial distribution in Fig. 1 and Fig. 2 shows examples of how much labour is closely related to foreign investment. For example, Mazowieckie, where Poland's capital is, has the highest quantile distribution for foreign investment and total labour. This is due to the fact that a large city like Warsaw provides access to a well-educated and skilled workforce, thus attracting foreign companies interested in investing or establishing a presence in cities in this region. Several other regions in the spatial distribution map also show that high total labour is likely associated with high foreign investment density. Meanwhile, the scatter plot on the right shows a statistically strong positive relationship between R&D spending and foreign investment. This implies that a larger budget allocated to R&D activities can potentially increase foreign capital inflows into the region. Referring to the spatial distribution maps in Fig. 1 and Fig. 2, for example, the Dolnośląskie (Wrocław) and Pomorskie (Gdańsk) regions are known to have vital innovation ecosystems and provide significant support for R&D activities and foreign investment (Baumane-Vītoliņa and Dudek, 2020). In line with this, some literature also shows that foreign firms often choose locations with high R&D activities with the potential to increase global competitiveness or access to new technologies (Belderbos *et al.*, 2020; Di Minin *et al.*, 2012; Rugman *et al.*, 2012).

In Figure 4, we can see the spatial weight matrix representing the 16 voivodeship regions in Poland, along with a histogram graph showing their adjacency distribution. The adjacency approach is based on the Queen's contiguity method, where regions are considered adjacent if they share a common corner or edge. The histogram shows that, on average, voivodeship regions in Poland have 3–5 neighbours, which is particularly noticeable at the edges of the country. Meanwhile, regions in the country's middle tend to have more neighbours. For example, Łódzkie, Świętokrzyskie, and Mazowieckie have six neighbours, while Wielkopolskie has seven. Next, we examine whether this neighbourliness indicates a spatial autocorrelation between the regions. The chart in Fig. 5 displays the global autocorrelation distribution and Moran's I values for the three observed variables. Moran's I statistic is a widely used global spatial autocorrelation measure describing the correlation between the original variable (*x-axis*) and the spatially lagged variable (*y-axis*). The slope of the scatterplot corresponds to Moran's I value (Anselin, 1995, 2005; Anselin and Florax, 2012). This scatterplot indicates negative slopes for the three observed variables, with Moran's I values of -0.27 for foreign investment, -0.28 for labour, and -0.22 for R&D expenditures. Through a randomisation test with 999 permutations, these three variables were statistically significant with a *p*-value of less than 0.05. In this context, the negative and significant spatial autocorrelation suggests that high foreign investment, labour, and R&D expenditure values in a region are surrounded by regions with lower values, or *vice versa*. Szaruga *et al.* (2022), in their study on spatial autocorrelation in renewable electricity development in Poland, refer to this negative autocorrelation as spatial rivalry, indicating the potential for interregional competition and a tendency for a variable to have spatial distribution characteristics that spread rather than concentrate.

Property	Value
type	queen
symmetry	symmetric
file	WEIGHT_1.gal
id variable	POLY_ID
order	1
# observations	16
min neighbors	3
max neighbors	7
mean neighbors	4.25
median neighbors	4.00
% non-zero	26.56%

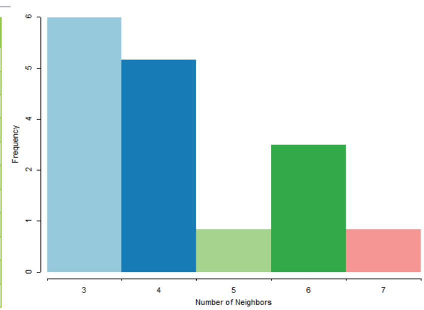

Fig. 4. Weights tables and neighbour histogram

Source: own work.

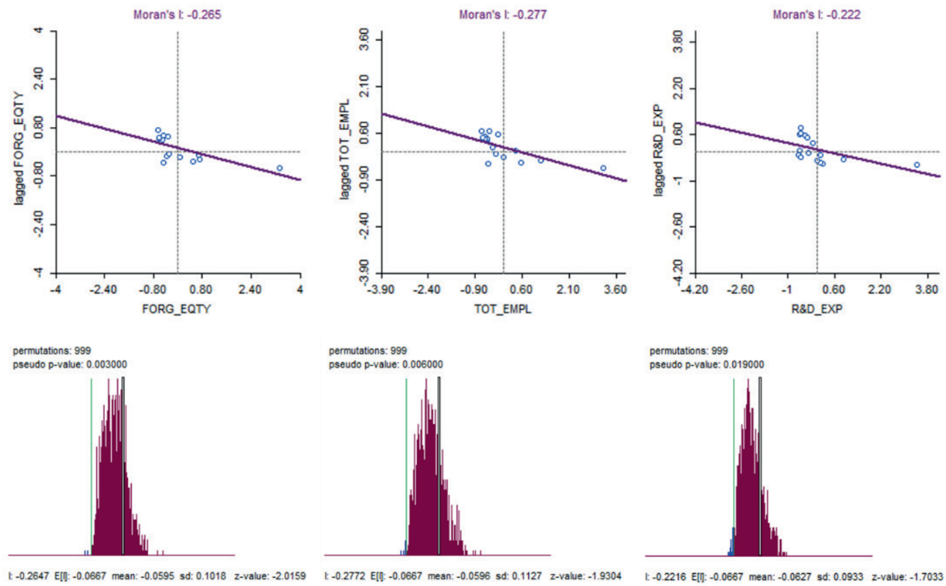

Fig. 5. Univariate Moran's I scatter plot

Source: own work.

Spatial autocorrelation links global autocorrelation, which concerns the broader regional context, with local autocorrelation, which addresses the characteristics of individual regions. However, it does not indicate the significance of a specific variable within a region (Anselin, 1995; Getis, 2008; Kurek *et al.*, 2021). LISA (Local Indicators of Spatial Association) is used in spatial analysis to identify non-random spatial patterns. The LISA cluster map in Fig. 6 shows groups of regions based on the three observed variables. The left side of the figure shows that there is only one region in Poland (Mazowieckie) that has a statistically significant level of foreign investment of the high-low type, meaning that this region has high foreign investment intensity, but its six neighbouring regions have lower foreign investment intensity. This condition is similar to the labour variable (middle figure), where Mazowieckie also has a significantly high level of labour density, while its six neighbouring regions have a lower level of labour density. This tendency can also be clearly observed in the LISA significance maps shown in Fig. 7 (left and middle), where the distribution of foreign investment and labour in the Mazowieckie region appears to be dispersed rather than spatially clustered.

The significance and cluster map in terms of R&D expenditure in Polish regions is somewhat different. There is a significant difference in the level of R&D expenditure in the Świętokrzyskie region (Fig. 6, right), where this region has a low level of R&D expenditure, while its six neighbouring regions have medium and high levels of R&D expenditure, which is also reflected in Fig. 2. The same pattern can also be seen in the LISA significance map in Fig. 7 (right), where R&D expenditure around the Świętokrzyskie region shows distinct characteristics. Capello and Lenzi (2018) and Crescenzi and Gagliardi (2018) have mentioned that less-developed regions can improve their competitiveness through industrial cluster policies or new technologies. Meanwhile, Götz and Jankowska (2017) have stated that forming industrial clusters in less-developed regions urgently requires adequate R&D policies. Świętokrzyskie is characterised as an underdeveloped region where the economic and industrial base is limited to traditional sectors with low R&D intensity. This impacts its economic diversification, which tends to be weak compared to neighbouring regions. The significant difference in R&D expenditure and labour supply in Świętokrzyskie seems closely related to the fact that foreign capital investment in the region is relatively low.

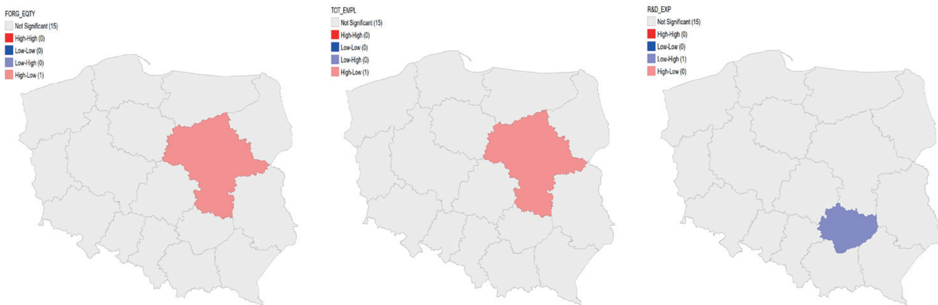

Fig. 6. LISA Cluster map of the observed variables

Source: own work.

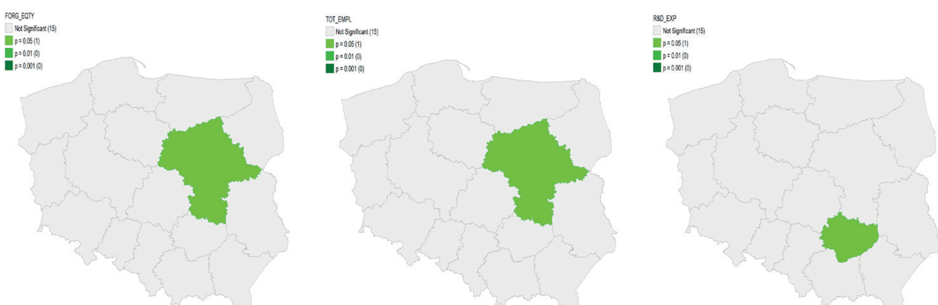

Fig. 7. LISA Significance map of the observed variables

Source: own work.

After analysing the spatial characteristics of the three observed variables, the next step is to estimate the impact of labour and R&D expenditures on foreign investment in Polish regions using a spatial regression approach. As described in the methodology section, the first step is to perform an OLS regression of the independent variables on the dependent variable, incorporating the weights obtained from the spatial distribution analysis. Based on the regression results presented in Table 2, the OLS regression results show that labour (TOT_EMPLY) and R&D expenditures (R&D_EXP) have a significant impact on foreign investment (FORG_EQTY), both individually and jointly. The adjusted R-squared value of 0.978 indicates that the two independent variables in the model explain 97.8% of the dependent variable, while other variables outside the model explain the remaining 2.2%. The probability values of the Breusch-Pagan and Jarque-Bera tests that exceed 0.05 indicate the robustness of the model to classical assumption problems such as heteroscedasticity and normality. The next step is to continue the estimation process using spatial regression. To estimate or run a spatial regression, we must first identify the presence of spatial dependence by performing a Lagrange Multiplier (LM) significance test based on the previous OLS model. As shown in Table 3, the OLS model shows insignificant LM values, as all spatial dependence test results yield probability values greater than 0.1. Therefore, the OLS model is the most appropriate model for this estimation process. The mathematical representation of this regression model is expressed in equation 4.

Table 2. Summary of OLS estimation results

Ordinary Least Squares Estimation			
Dependent Variable: FORG_EQTY			
Variables	**Coefficient**	**Std-error**	**Probability**
CONSTANT	-1982.83	744.859	0.01956
TOT_EMPL	0.0764292	0.00847613	0.00000
R&D_EXP	0.00115951	0.000499834	0.03726
Adjusted R-squared	0.978923		
F-statistic	349.332		
Prob(F-statistic)	5.02162e-12		
Regression Diagnostics			
Multicollinearity	6.438583		
Test On Normality of Errors: *Jarque-Bera*	**DF** *2*	**Value** *0.8388*	**Probability** *0.6574*
Diagnostics for Heteroskedasticity: *Breusch-Pagan Test*	**DF** *2*	**Value** *2.6690*	**Probability** *0.25936*

Source: own work.

Table 3. Diagnostics test results for spatial dependence

Test	MI/DF	Value	Probability
Moran's I (error)	-0.1244	-0.4583	0.64671
LM (lag)	1	0.0775	0.78066
Robust LM (lag)	1	0.2835	0.59442
Robust LM (error)	1	0.7090	0.39976
LM (SARMA)	2	0.7866	0.67483

Source: own work.

$$FORG\_EQTYi = -1982.83 + 0.0764\ TOT\_EMPLi + 0.0011\ RD\_EXPi + \varepsilon \quad (4)$$

The results of this regression analysis show that the labour variable significantly affects foreign investment in the Polish voivodeship. This result is consistent with our previous observations during the descriptive analysis and the assessment of the spatial distribution. It is also consistent with the previous studies which show that regions with sufficient labour or relatively low labour costs tend to attract foreign investment (Götz, 2020; Siddiqui, 2018; Su *et al.*, 2018). The spatial concentration of labour in some regions of Poland is very similar to the distribution of foreign investment, as shown in Fig. 1 and Fig. 2 (left). This supports the conclusion of Jantoń-Drozdowska and Majewska (2016) that the availability of labour strongly influences the location of foreign investment in transition economies in Europe and that this factor often attracts foreign investment to regions, especially when supported by relatively low labour costs. However, it is important to consider the long-term implications, as regions with high labour availability may become overly dependent on foreign investment, which may hinder innovation and economic diversification. According to Bermejo Carbonell and Werner (2018), a high labour supply may attract foreign investment in the short term but may lead to long-term dependency. Balancing labour-intensive foreign investment with investments in R&D capacity building and innovation is essential to promote sustainable economic growth and regional competitiveness (Cieślik *et al.*, 2021; Paliokaitė, 2019; Yaghi and Tomaszewski, 2024).

The regression analysis results also show that investment in R&D significantly impacts foreign investment in Poland. Similarly, Roszko-Wójtowicz and Grzelak (2021) have found that R&D support for projects in special economic zones and smart specialisation strategies are essential for attracting foreign capital to different regions in Poland. The results also revealed a significant correlation between R&D expenditures and increased foreign investment in regions with high R&D intensity, such as Mazowieckie and Pomorskie. Ge and Liu (2022) have also confirmed that countries with solid R&D support or focusing on knowledge-based industries are more likely to attract foreign investment. Guimón *et al.* (2018) has argued that substantial R&D funding creates an attractive environment for innovation in developing countries that rely on advanced technologies. Carboni and Medda (2021) have also indicated that innovations resulting from R&D efforts can increase productivity and efficiency, making investments more profitable. Crescenzi and Gagliardi (2018) have argued that strong R&D policies and a supportive institutional environment are crucial for attracting foreign investment by reducing production costs through innovation and creating a more stable ecosystem. These concurrent findings may indicate that Polish regions with strong R&D support tend to have better access to innovation and the latest technologies, so similar support could be extended to weaker Polish regions if they want their regions to be more attractive to multinational companies, especially those that prioritise innovation.

5. CONCLUSIONS

This study aimed to analyse the spatial distribution and influence of labour and R&D expenditures on foreign investment in Polish domestic firms linked to foreign firms through capital investment. The literature has extensively studied the factors influencing foreign investment in Poland, especially in the context of foreign direct investment. However, there is limited literature that examines the impact of R&D expenditures, in addition to labour factors, on foreign investment in a more specific context. This study aimed to fill one of the gaps in the research on foreign investment and, in particular, to show how this R&D expenditure and the labour factor can influence foreign investment in Polish firms in the context of spatial regions. This study used a spatial analysis approach to further investigate the spatial characteristics and distribution and impact of labour factors and R&D expenditures on foreign investment. The results of this study have shown how the three variables are spatially distributed and how their spatial characteristics indicate strong spatial relationships between regions. Although preliminary analysis revealed the presence of significant spatial autocorrelation, this has not led to the identification of spatial dependence in the factors affecting foreign investment in Poland. However, the estimation results indicate that regional R&D support has a significant impact on foreign investment, in addition to labour supply support, which has a much more substantial impact.

The results of this analysis have several implications. First, the spatial distribution analysis shows that sixteen regions in Poland and three observed variables can be simultaneously classified into three parts: five regions with high intensity, six with medium intensity, and five with low intensity. Regions with high foreign investment intensity are supported by preliminary evidence from the spatial distribution analysis that labour supply in the same region tends to have similar foreign investment densities. However, there is little difference in the contribution of R&D to foreign investment, suggesting that the nature of R&D support in specific contexts and interests may be less necessary in some regions (such as regions with high investment due to trade and maritime transport services) but highly essential in others (such as the capital region or regions with specialised industrial clusters). However, lower R&D support does not necessarily lead to a weak effect on foreign investment flows. Second, the interaction between the two factors on foreign investment is further explored through regression analysis. These estimates show that R&D expenditure has a positive and significant effect on foreign capital investment in Polish regions. Looking closely at the mathematical model of the regression estimation results, the strength of the R&D expenditure parameter is not as strong as the labour factor, which in much of the literature has been shown to have a strong influence on the attractiveness of foreign investment. Nevertheless, this condition indicates that R&D support in Polish regions needs serious attention in order to have a greater impact on increasing foreign investment. Third, there are strong indications that foreign investment in Poland tends to be concentrated in labour-intensive industries, which may be profitable in the short term, but may create dependency and potentially reduce economic diversification or technological improvement in the long term. Economists generally argue that economic diversification or technological improvement has a more sustainable long-term impact on the economy. The literature on innovation also shows how a region can increase its productivity in the long run through innovation, which is strongly driven by support for R&D. Therefore, practitioners and policymakers in Poland need to consider that R&D support is essential not only for increasing technological capacity and promoting innovation, but also for making the region an attractive investment destination for foreign investors, especially those concerned with knowledge-intensive industries or those that require continuous innovation. The existence of research and innovation policies can effectively promote this objective.

Finally, the author acknowledges the significant limitations of this study. First, concerning the number of data observations and, in particular, the selection of voivodeship regions. The spatial analysis approach, which started with the analysis of the spatial distribution and its specific characteristics, did not lead to a spatial regression estimation as intended in the analysis or modelling strategy. Although there was some indication of spatial dependence, it did not drive the results of further analysis to find spatial dependence or spatial regression models. The author argues that one of the reasons for this is the insufficient size of the data observations. Therefore, future studies are strongly recommended to further analyse the impact of the variables observed in this study by using more extensive data, such as data at a lower regional level (NUTS-3) or microdata at the firm level. The data observations can also be extended by extending the coverage area to three other regions, such as Hungary, the Czech Republic, and Slovakia, which together with Poland are part of the Visegrad group. Second, in the results and discussion section, the author briefly touches on the unique characteristics of R&D in two adjacent regions directly on the Baltic Sea, namely Zachodniopomorskie and Pomorskie. It is strongly suspected that these two regions have strong maritime characteristics, so that they have the same levels of foreign investment intensity, although these two regions provide different R&D support. It will be interesting for future studies to explore this issue further.

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DEPOPULATION AND POPULATION AGEING IN EUROPE IN THE 2010S: A REGIONAL APPROACH

Abstract. The paper analyses European countries and NUTS-3 units to determine which of them experienced depopulation in the 2010s, as well as the causes of this process. The progression of demographic ageing, particularly in countries and NTS3 units with annual population declines, is also examined. European countries and NTS3 units in selected years and periods between 2011 and 2020 are studied based on Eurostat vital statistics, data on migratory movements and population age structures using descriptive statistics, time-series methods, Webb's method, and cluster analysis. The data and research results are illustrated with tables, graphs, and choropleth maps.

In the 2010s, depopulation processes mainly occurred in Eastern and Southern Europe. The study found that between 2011 and 2020, eight countries (Bulgaria, Croatia, Greece, Hungary, Latvia, Romania, Serbia, and Ukraine) suffered population decreases annually, three countries (Albania, Lithuania, and Portugal) had only one or two years without a population loss, and four countries (Bulgaria, Croatia, Latvia, and Romania) were demographically the most disadvantaged as their populations decreased due to natural causes and migration in almost all years in the 2010s.

Most of the annually depopulating countries were relatively similar in terms of the population age structure. NTS3 units with annual population declines and a similar population age structures were found within the same country or in neighbouring areas in adjacent countries.

Key words: depopulation, population ageing, typology of population change, European countries, NTS3 units.

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1. INTRODUCTION

Europe has the oldest population of all continents and is the only one projected to decline in the coming decades. It is estimated that it will decrease by 0.8% from 2020 to 2030, 2.7% from 2020 to 2040, and 5% from 2020 to 2050 (UN data). At the same time, the proportion of people aged 65 or older is expected to rise from 19% in 2020 to 23% in 2030, 26% in 2040, and 28% in 2050 (in 2000 and 2010 the age group accounted for 15% and 16%, respectively). While in 2020, there were 120 elderly people per 100 children aged 0–14 years (105 in 2010), in 2030, 2040, and 2050 there will be 150, 180, and 190, respectively.

The term 'depopulation' has more than one interpretation. Some authors understand it as a decrease in population size in a period, others view it as a persistent and long-term decline in population, while others still ascertain the existence of depopulation based on the amount of population loss over a period (see, for example, Johnson and Lichten, 2019; Merino and Prats, 2020; Reynaud and Miccoli, 2018; Truskolaski and Bugowski, 2022).

Depopulation may result from a natural decrease (more deaths in the population than births), migration (more people leaving than arriving), or both these factors simultaneously (Majdzińska, 2021; see also Goldstein, 2009; Kiniorska *et al.*, 2023; Merino and Prats, 2020; Reynaud and Miccoli, 2018; Willekens, 2015). Population change is also related to its current structure and a phenomenon known as "an age wave" (Bloom and Canning 2008, p. 21), understood as alternating baby booms and baby busts (cf. Frątczak, 2002).

The main causes of depopulation in most European countries are falling fertility rates (much below the generation replacement level of 2.1 children per woman)[1], with relatively unchanging or declining mortality rates extending life expectancy in the long term[2], and migrations. In areas with little to offer to residents, depopulation is usually caused by both these factors. In residentially attractive areas, a natural decrease (if there is one) is counterbalanced by in-migration.

[1] In the early 2010s, the countries with the highest TFRs (1.9–2.0 children per woman) were France, Iceland, Ireland, Norway, Sweden, United Kingdom, Finland, and Belgium; at the end of that decade, the highest TFR (1.7–1.8) occurred in Bulgaria, Czechia, France, Iceland, Ireland, Montenegro, Romania, Sweden, and Denmark. In all (or most) years of the 2010s, the lowest TFRs (below 1.4) were noted in Cyprus, Greece, Italy, Malta, Poland, Portugal, Spain, and Ukraine (Eurostat data).

[2] European countries have different mortality rates. The lowest mortality occurs in the south and north of Europe (particularly in Switzerland, Spain, Italy, Iceland, Sweden, Norway, France, and Liechtenstein) where at the end of the 2010s (excluding 2020) the average life expectancy of a new-born (male or female) was 83–84 years; the highest mortality characterises the post-communist countries (particularly Ukraine, Bulgaria, Romania, Latvia, Lithuania, and Serbia), with an average life expectancy of 73–76 years (Eurostat data). In 2020 and 2021, mortality rates in most European countries were higher than in 2019 due to the COVID-19 pandemic (hence life expectancy was lower than before).

Changes in the family formation patterns and related low total fertility rates (TFR) that have been observed in Europe in the last several decades are mainly explained in terms of the Second Demographic Transition[3] theory (Lesthaeghe, 2010, 2020; van de Kaa, 1987, 1997, 2003). In post-communist countries, the changes frequently had a rapid course and occurred later than in the rest of Europe. In most cases, economic and political restructuring that the countries undertook after the collapse of the USSR coincided with the end of the first demographic transition[4] and the emergence of the second demographic transition (see, for instance, Lesthaeghe, 2010, 2020; Nikitović *et al*., 2019; Philipov, 2003; Philipov and Kohler, 2001; van de Kaa, 1997). As European countries are at different points of the second demographic transition, they naturally differ in the family formation patterns (see, for instance, Lesthaeghe, 2020; Majdzińska, 2021, 2022; Oláh, 2015).

Depopulation (especially persistent depopulation driven by natural and migratory changes) creates many negative demographic, social and economic problems, including changes in the age and sex structure of the population, accelerated population ageing, a decrease in the working-age population, etc., (see, e.g., Jarzebski *et al*., 2021; Kiniorska *et al*., 2023; Reynaud and Miccoli, 2018; Truskolaski and Bugowski, 2022), but it also has some advantages for the natural environment perspective for the (see, e.g., ESPON, 2017; Götmark, 2018; Jarzebski *et al*., 2021).

European regions represent a variety of demographic structures, demographic processes, and stages of socio-economic development (Eurostat, 2020, p. 22). Depopulation processes are particularly noticeable in Eastern and Southern Europe. In many European regions they have been present for decades, but their pace clearly accelerated in most of Europe in the 2010s. In most post-communist countries, negative population growth and faster population ageing have been observed since they embarked on the political and economic transition. In eleven post-communist European Union (EU) Member States depopulation gained momentum with their accession to the EU (see Fihel and Okólski, 2019, p. 2).

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[3] The changes include older average age at marriage, older age of mothers at first birth, fewer marriages, an increasing number of informal relationships, more people choosing not to have children, an increasing percentage of extramarital births, and a falling percentage of multi-child families. The changes are mainly driven by the evolving societal background, including a "rise of «higher order» needs: individual autonomy, self-actualisation, expressive work and socialisation values" […], "rising symmetry in gender roles, female economic autonomy" (Lesthaeghe, 2010, pp. 5–6; see also van de Kaa, 1997; van de Kaa, 2003). "The growing proportion of women giving birth later in life […] may be linked, among other factors, to: higher female participation rates in further education and/or more women choosing to establish a career before starting a family; lower levels of job security (for example, in precarious employment), the increasing cost of raising children and of housing" (European Commission, 2023, p. 28).

[4] The Demographic Transition Theory describes changes in societies that "experience modernization progress from a premodern regime of high fertility and high mortality to a post-modern one, in which both are low" (Kirk, 1996, p. 361).

Rural demographic growth in European countries is generally lower than urban, and populations show a tendency to concentrate in or around larger cities (ESPON, 2018, p. 3). Regional attractiveness and the quality of life in European territories tend to be rated by the public based on the availability of transport, digital connectivity, and social and economic services (ESPON, 2018, p. 6; see also ESPON, 2017).

As regards regional differences in population processes in the EU in the 2010s, the rural and intermediate regions in Southern and Eastern Europe, particularly those located far from large cities, recorded population losses more frequently. In contrast, the net migration rates in the north-western regions of Europe were relatively high and positive, compensating for the natural decrease in the intermediate and rural areas (Brons, 2024).

Recent years have seen an increased interest in research on population changes in European countries and regions, resulting in numerous publications. Their authors mostly focused on depopulation processes and explaining their causes in different parts of Europe, as well as on the consequences of depopulation and ways of preventing or mitigating them. Depopulation problems are studied in terms of the entire continent of Europe, EU regions (see, e.g., Brons, 2024; ESPON, 2017, 2018, 2020; Eurostat 2020, 2023; Fihel and Okólski, 2019; Potančoková *et al.*, 2021), and individual countries (see, e.g., Czibere *et al.*, 2021; Čipin, 2017; Dahs *et al.*, 2021; Daugirdas and Pociūtė-Sereikienė, 2018; Domachowska, 2021; Ilieva, 2017; Lutz and Gailey, 2020; Marinković and Radivojević, 2016; Pinilla and Sáez, 2017; Potančoková *et al.*, 2021; Rašević and Galjak, 2022; Recaño, 2017; Reynaud and Miccoli, 2018; Shvindina, 2016; Zarins and Paiders, 2020).

The paper presents a broad look at the depopulation problem in Europe but the areas of the positive population change have also been included as a comparative background. The analysis is conducted to identify countries and NUTS-3 units in Europe affected by population loss in the 2010s and the causes of the phenomenon (with this aim, a typology of population change is performed). It also examines the progression of population ageing. The investigation particularly focuses on countries and NTS3 units that report an annual population loss. Additionally, the countries showing population decline are briefly characterised due to the main causes of that process.

The dynamics of changes in the size of Europe's population requires ongoing monitoring of their course. The data thus obtained are critical to designing social and economic policy measures capable of preventing or mitigating the impacts of population loss in depopulating regions.

The analysis is conducted using various research tools, including descriptive statistics, Webb's method, and cluster analysis. Eurostat vital statistics, data on migratory movements, and population age structures in European countries and NTS3 units in the selected years between 2011 and 2020 were examined.

2. METHODS

Most analyses were performed using three measures: a crude rate of natural change (NCR), a crude rate of net migration (NMR), and a crude rate of total population change (TCR), which were calculated for the full periods using the following formulas (1–3), (see Eurostat, 2014):

$$NCR_t = \frac{\sum_{t=1}^{n} NC_t}{\sum_{t=1}^{n} \bar{P}_t} 1000 \tag{1}$$

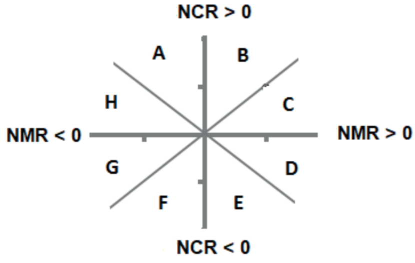
$$NMR_t = \frac{\sum_{t=1}^{n} NM_t}{\sum_{t=1}^{n} \bar{P}_t} 1000 \tag{2}$$

$$TCR_t = \frac{\sum_{t=1}^{n} TC_t}{\sum_{t=1}^{n} \bar{P}_t} 1000. \tag{3}$$

where: NC_t – natural change (the difference between the number of births and deaths), NM_t – net migration (the difference between the number of emigrants and immigrants), and TC_t – the sum of natural change and net migration, P_t – the average population in a year or period *t*.

Population change in a period was also evaluated using a fixed-base index (FBI), which was calculated as a quotient between the sizes of the population at the end and beginning of a period. The differences between the FBI and the value of 1 were calculated and presented as a percentage of population change (PPC).

The causes of depopulation in the selected countries and NUTS-3 in the sample period were determined using Webb's method (Webb, 1963). The relationships between the NCR and the NMR produced eight types of factors in population change (four involving increases and four involving declines) to be identified (see Fig. 1).



Types: A, B, C, D – areas with a positive total population change (a positive TCR = population increase)
Types: E, F, G, H – areas with a negative total population change (a negative TCR = population decrease)

Fig. 1. Webb's typology of population change
Source: own work based on Webb (1963) and Jagielski (1978).

In order to assess population ageing in European countries and NTS3 units, the percentage of the population aged 65 and older and an old-age index (a ratio between the size of the population aged 65 or older and the size of the population aged 0–14 years) were calculated.

Using Ward's method[5] (Ward, 1963) with the Euclidean distance matrix based on 5-year age groups, countries and NUTS-3 units were divided into groups with similar population age structures. All countries were divided based on the 2020 data; in the case of NTS3, 2015–2019 data were used, and only units with annual population loss were grouped.

The Eurostat vital statistics and data on migratory movements in European countries were considered for three time intervals: 2011–2015, 2016–2020, and 2011–2020. The NTS3 units were analysed using the 2015–2019 data. Population age structures in countries and NUTS-3 units are presented according to the 2020 and 2019 data, respectively.[6] All calculations were performed in MS Excel and STATISTICA 13. The data and research results are illustrated with tables, graphs, and choropleth maps prepared in Quantum GIS software.

3. RESULTS

Most post-communist countries experienced population declines in all three analysed periods (see Table 1). The greatest decreases between 2011 and 2020 occurred in Ukraine (8.7%), Lithuania, and Latvia (7.7% each), and from 2016 to 2020 in Latvia, Croatia, Bulgaria, and Lithuania (2.6–3.0%). Among non-post-communist countries, Greece and Portugal suffered population declines in all three periods, Spain and Cyprus from 2011 to 2015, and Italy from 2016 to 2020. It is noteworthy that in Bulgaria, Croatia, Greece, Hungary, Latvia, Romania, Serbia, and Ukraine,

[5] "Ward's method is agglomerative; thus, it partitions elements into a dedicated number of clusters in several steps. First, each element is independent, and then step by step, more elements are ordered to a cluster. At each step, the method includes those elements which are the 'closest' (according to a metric) to the existing clusters. The number of steps may reach from 1 to n (number of analysed elements). In [the] case of 1, only one single cluster contains all elements, while in the case of n, all elements form [their] own cluster. Once a cluster is created as a result of a step, the elements of the new cluster cannot be separated again. The algorithm tries to find the optimal number of clustering steps" (Eszergár-Kiss and Caesar, 2017, p. 26).

[6] The analyses were conducted in 2010s because in many regions population processes dynamically changed during that decade, especially in its second part. The author decided to finish the regional analysis (at the NUTS-3 level) with 2019 because of the Covid-19 pandemic outbreak at the end of that year. The pandemic disturbed the demographic processes that had been observed so far, and some demographic data for 2020 were particularly unusual in many regions.

depopulation was observed in all years of the period 2011–2020. According to demographic projections, Latvia, Lithuania, Romania, Bulgaria, Croatia, Greece, Poland, and Portugal will see the greatest population losses in the decades up to 2050 (see Table 1).

Countries where populations increased the most in both 2011–2020 and 2016–2020 included Malta (23.8% and 13.2%, respectively), Luxembourg (21.6% and 8.3%), and Iceland (14.9% and 9.2%). These countries, as well as Ireland, Cyprus, Norway, Sweden, and Switzerland, will probably have the greatest population increases until 2050 (see Table 1).

With regard to NTS3 units (see Fig. 2), the biggest declines in population (from 8% to 12%) occurred between 2015 and 2019 in Albania (Gjirokastër (AL033), Berat (AL031), and Dibër (AL011)), Croatia (Vukovarsko-srijemska zupanija (HR04C), Pozesko-slavonska zupanija (HR049), Sisacko-moslavacka zupanija (HR04E), Brodsko-posavska zupanija (HR04A), and Viroviticko-podravska zupanija (HR048)), Lithuania (Taurages apskritis (LT027), Utenos apskritis (LT029), Panevezio apskritis (LT025), and Marijampoles apskritis (LT024)), and Estonia (Kirde-Eesti (EE007)).

Post-communist countries, particularly those located in the easternmost part of Europe, have higher mortality rates than other European countries and thereby the lowest life expectancies at birth (e_0) on the continent. The lowest e_0 was found for Ukraine, Bulgaria, Romania, North Macedonia, Belarus, and Serbia (below 75 years for both genders).

A low total fertility rate (TFR) is a problem in most European countries. In no European country is it high enough to ensure the replacement of generations. The countries with the lowest TFR (1.1–1.3) in 2020 were Malta, Ukraine, Spain, Italy, North Macedonia, and Albania.

Although many countries had the same or similar TFR (e.g., Ukraine and Italy in 2020), fertility patterns varied regionally, and most involved postponing childbearing decisions. The youngest fertility patterns, a natural consequence of relatively early family formation, characterised post-communist countries in Eastern Europe (Belarus, Ukraine, Bulgaria, and Romania), while the oldest were in Spain, Italy, Luxembourg, Greece, Ireland, and Switzerland (see Majdzińska, 2021).[7]

An analysis the countries' NCR, NMR and TCR from 2011 to 2020 shows that the lowest NCR values were in Bulgaria, Serbia, and Ukraine (deaths exceeded births by around 5–6 per 1,000 population). The lowest NMR was in Albania, Lithuania, and Latvia, and the lowest TCR was in Latvia, Bulgaria, and Croatia (see Table 1).

[7] European countries differ significantly in family formation and fertility patterns because they are determined by country-specific demographic, social, cultural, and economic factors (Kirk, 1996; Willekens, 2015; Kohler *et al.*, 2002).

Table 1. European countries by population increase/decline (PPC) (in %), crude rates of total population change (TCR), natural change (NCR), and net migration (NMR) per 1,000 population in the periods 2011–2015, 2016–2020, and 2011–2020, and by total fertility rate (TFR) and life expectancy at birth for both sexes (e0) in 2020

Country	Population increase / decline (PPC; %)						TCR			NCR			NMR		
	2011–2015	2016–2020	2011–2020	2020–2030	2020–2040	2020–2050	2011–2015	2016–2020	2011–2020	2011–2015	2016–2020	2011–2020	2011–2015	2016–2020	2011–2020
Albania (AL)	-0.8	-1.3	-2.3	:	:	:	-2.2	-3.2	-2.7	4.8	2.3	3.6	-7.0	-5.5	-6.3
Austria (AT)	3.0	2.1	6.3	2.6	4.2	4.8	7.7	5.3	6.4	0.1	0.1	0.1	7.5	5.1	6.3
Belarus (BY)	-0.1	-0.8	-0.7	:	:	:	0.0	-0.5	-0.3	-1.6	-1.7	-1.6	1.6	1.1	1.4
Belgium (BE)	2.1	1.9	4.6	1.9	3.0	3.3	5.6	4.5	5.0	1.6	0.5	1.1	3.9	4.0	3.9
Bulgaria (BG)	-2.3	-2.7	-5.6	-7.0	-13.2	-18.4	-5.9	-6.8	-6.3	-5.5	-7.0	-6.3	-0.4	0.3	-0.1
Croatia (HR)	-1.7	-3.0	-5.5	-5.4	-10.7	-16.2	-4.7	-7.5	-6.1	-2.7	-4.1	-3.4	-1.9	-3.5	-2.7
Cyprus (CY)	-0.4	4.7	4.8	7.9	13.5	17.3	2.0	10.9	6.5	4.7	4.0	4.3	-2.7	6.9	2.2
Czechia (CZ)	0.5	1.2	1.9	0.6	-0.7	-1.6	1.3	2.8	2.0	0.1	-0.2	-0.1	1.2	3.0	2.1
Denmark (DK)	2.0	1.8	4.7	2.3	3.8	4.6	5.2	4.6	4.9	0.9	1.3	1.1	4.3	3.3	3.8
Estonia (EE)	-0.9	1.0	0.2	-1.6	-3.6	-5.5	-2.3	2.1	-0.1	-1.1	-1.3	-1.2	-1.3	3.4	1.1
Finland (FI)	1.7	0.6	2.6	-0.2	-1.9	-4.3	4.1	1.7	2.9	1.2	-1.0	0.1	2.9	2.7	2.8
France (FR)	2.2	1.0	3.5	2.0	3.6	3.9	4.4	2.4	3.4	3.8	2.1	2.9	0.6	0.3	0.4
Germany (DE)	1.8	1.0	3.6	0.4	0.0	-0.6	4.8	2.4	3.6	-2.3	-1.9	-2.1	7.2	4.3	5.7
Greece (EL)	-2.6	-0.7	-3.6	-3.7	-7.4	-11.2	-6.2	-1.9	-4.1	-1.6	-3.4	-2.5	-4.6	1.5	-1.6
Hungary (HU)	-1.3	-0.7	-2.2	-1.3	-3.2	-4.9	-2.6	-2.0	-2.3	-3.8	-3.9	-3.9	1.2	1.9	1.5
Iceland (IS)	3.7	9.2	14.9	13.8	24.4	33.5	8.7	20.6	14.9	7.1	5.6	6.3	1.6	15.0	8.5
Ireland (IE)	2.7	4.8	8.9	10.4	18.4	24.6	6.7	11.5	9.2	8.7	6.0	7.3	-2.0	5.5	1.9
Italy (IT)	2.3	-1.9	0.1	0.8	-0.1	-2.2	4.3	-2.9	0.7	-1.6	-3.6	-2.6	5.9	0.7	3.3
Latvia (LV)	-4.0	-3.0	-7.7	-9.9	-19.2	-26.6	-10.5	-7.9	-9.2	-4.0	-4.6	-4.3	-6.5	-3.3	-4.9
Lithuania (LT)	-4.1	-2.6	-7.7	-7.8	-16.3	-23.5	-11.1	-6.6	-8.9	-3.6	-4.4	-4.0	-7.5	-2.1	-4.9
Luxembourg (LU)	9.9	8.3	21.6	9.9	17.2	22.0	23.6	18.3	20.8	3.9	3.2	3.5	19.7	15.1	17.3
Malta (MT)	6.9	13.2	23.8	14.2	23.2	29.7	16.5	27.1	22.1	2.0	1.5	1.7	14.6	25.6	20.4
Montenegro (ME)	0.3	-0.2	0.2	:	:	:	0.8	-0.5	0.1	2.3	1.0	1.6	-1.5	-1.5	-1.5
Netherlands (NL)	1.5	2.4	4.5	3.0	4.3	4.0	3.8	5.8	4.8	2.0	0.9	1.4	1.8	4.9	3.4

Country	Population increase / decline (PPC; %)						TCR			NCR			NMR		
	2011–2015	2016–2020	2011–2020	2020–2030	2020–2040	2020–2050	2011–2015	2016–2020	2011–2020	2011–2015	2016–2020	2011–2020	2011–2015	2016–2020	2011–2020
N. Macedonia (MK)	0.6	0.0	0.7	:	:	:	1.4	-0.2	0.6	1.7	-0.2	0.7	-0.3	-0.1	-0.2
Norway (NO)	4.8	2.8	8.6	7.2	13.3	18.1	11.4	6.8	9.1	3.6	2.8	3.2	7.8	4.0	5.9
Poland (PL)	-0.2	-0.2	-0.4	-2.3	-5.9	-10.0	-0.5	-0.7	-0.6	-0.2	-1.0	-0.6	-0.3	0.3	0.0
Portugal (PT)	-1.9	-0.3	-2.5	-2.0	-5.0	-9.0	-4.4	-0.8	-2.6	-1.8	-2.7	-2.2	-2.6	1.8	-0.4
Romania (RO)	-1.6	-2.3	-4.4	-7.5	-13.9	-19.5	-4.4	-5.9	-5.1	-2.9	-3.6	-3.2	-1.5	-2.3	-1.9
Serbia (RS)	-1.9	-2.3	-4.6	:	:	:	-4.9	-5.9	-5.4	-5.0	-5.9	-5.4	0.1	0.0	0.1
Slovakia (SK)	0.5	0.5	1.1	-0.3	-2.7	-5.7	1.2	1.2	1.2	0.7	0.5	0.6	0.5	0.7	0.6
Slovenia (SI)	0.5	1.8	2.4	0.2	-1.0	-2.8	1.4	4.3	2.8	1.0	-0.7	0.2	0.3	5.0	2.7
Spain (ES)	-0.6	1.9	1.3	2.9	4.3	4.2	-1.0	4.1	1.6	0.9	-1.3	-0.2	-1.8	5.3	1.8
Sweden (SE)	3.7	4.3	9.6	7.2	12.9	18.4	9.1	10.4	9.7	2.4	2.2	2.3	6.6	8.2	7.4
Switzerland (CH)	4.7	3.1	9.2	5.1	10.5	15.3	11.3	8.0	9.6	2.3	2.2	2.3	9.0	5.8	7.3
Ukraine (UA)	-6.3	-2.2	-8.7	2.6	4.2	4.8	-3.0	-5.6	-4.2	-3.6	-5.9	-4.7	0.7	0.3	0.5
United Kingdom (UK)	2.9	2.6	6.5	:	:	:	7.4	6.6	7.0	3.6	2.2	2.9	3.7	4.4	4.1

Note 1: ':' stands for 'data not available'.

Note 2: Regarding population change, TCR, NCR and NMR: data on the UK and Belarus from 2010–2014, 2015–2019, and 2010–2019.

Source: own work based on EUROSTAT data.

Among the NTS3 units, those with the lowest TCR (-32 to -20) between 2015 and 2019 were Gjirokastër (AL033), Berat (AL031), and Dibër (AL011) in Albania, Vukovarsko-srijemska zupanija (HR04C), Pozesko-slavonska zupanija (HR049), Sisacko-moslavacka zupanija (HR04E), Brodsko-posavska zupanija (HR04A), and Viroviticko-podravska zupanija (HR048) in Croatia, Taurages apskritis (LT027), Utenos apskritis (LT029), Panevezio apskritis (LT025), and Marijampoles apskritis (LT024) in Lithuania, Vidin (BG311) in Bulgaria, and Kirde-Eesti (EE007) in Estonia (see Fig. 3). The TCR of more than one-third of NUTS-3 units (554 out of 1,441) was negative in all sample years.

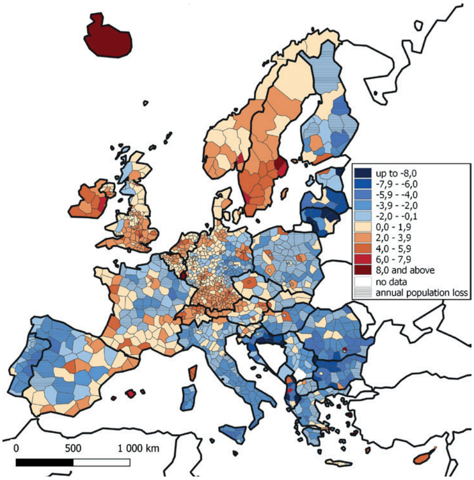


Fig. 2. NTS3 units according to population change (%), 2015–2019

Note 1: United Kingdom: 2014–2018 data (UKM7, UKM8 and UKM9 data from 2017–2018); Serbia: 2017–2018 data
Note 2: min = -12.2; max = 16.3

Source: own work based on EUROSTAT data.

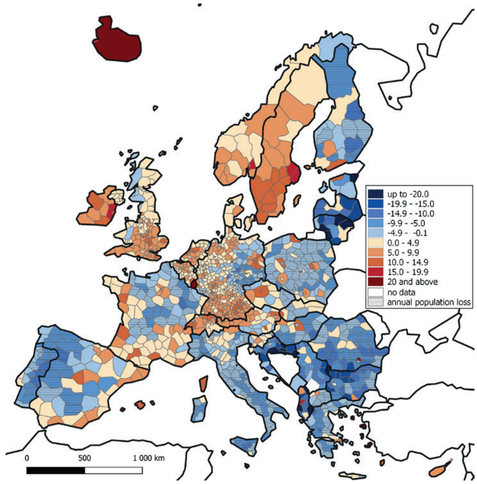


Fig. 3. NTS3 units according to TCR (per 1,000 population), 2015–2019

Note 1: see Note 1 for Fig. 2
Note 2: min = -31.5; max = 36.6

Source: own work based on EUROSTAT data.

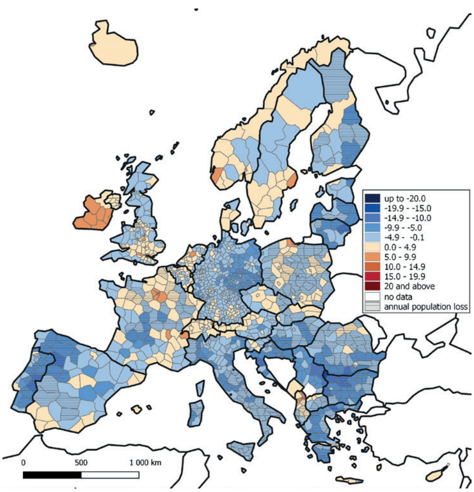


Fig. 4. NTS3 units according to NCR (per 1,000 population), 2015–2019

Note 1: see Note 1 in Fig. 2
Note 2: min = -16.5; max = 34.5

Source: own work based on EUROSTAT data.

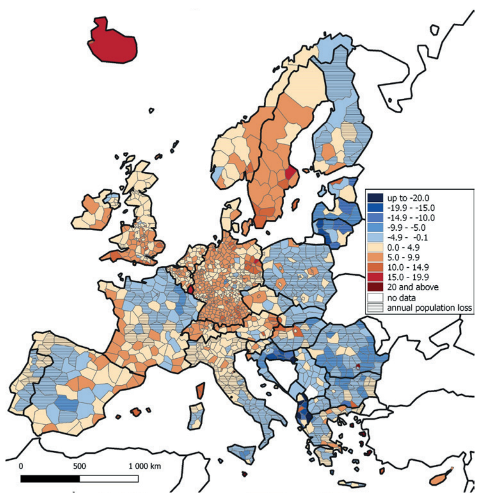


Fig. 5. NTS3 units according to MNR (per 1,000 population), 2015–2019

Note 1: see Note 1 for Fig. 2
Note 2: min = -30.7; max = 37.2

Source: own work based on EUROSTAT data.

The lowest NCR values (-16 to -11) were found for Vidin (BG311), Montana (BG312), Gabrovo (BG322), Kyustendil (BG415), Pernik (BG414), Lovech (BG315), and Vratsa (BG313) in Bulgaria, the Zajecarska oblast (RS223), the Borska oblast (RS221), and the Branicevska oblast (RS222) in Serbia, and the Utenos apskritis in Lithuania (see Fig. 4).

The NTS3 with the lowest NMR (-31 to -14) were Dibër (AL011), Gjirokastër (AL033), Berat (AL031), Kukës (AL013), Elbasan (AL021), and Lezhë (AL014) in Albania, the Vukovarsko-srijemska zupanija (HR04C), the Pozesko-slavonska zupanija (HR049), the Brodsko-posavska zupanija (HR04A), the Viroviticko-podravska zupanija (HR048), and Sisacko-moslavacka zupanija (HR04E) in Croatia, and the Taurages apskritis (LT027), the Telsiu apskritis (LT028), the Marijampoles apskritis (LT024), and Panevezio apskritis (LT025) in Lithuania (see Fig. 5).

Most NTS3 units with negative TCR, NCR, and NMR in 2015–2019 experienced annual population losses in all years of this period; in many of them, depopulation continued for decades.

In the next step, using Webb's method, countries and NTS3 units were grouped based on their NCR and NMR values. In this way, the types of population change were created according to the main cause of population increase or decrease (see Fig. 1).

Most sampled countries belonged in particular years and periods to types with population increase (see Table 2 and 3). The majority were type C (a natural increase with a more significant migratory increase). The ranking of types with a population decrease changed during that decade: type G (a natural decrease and a stronger migratory decrease), which was the most common in the first half, was replaced in subsequent years by types E (a natural decrease and a migratory increase) and F (a natural decrease and a distinctive migratory decrease). This shows that in the 2010s, a natural decrease gradually intensified its role in depopulation in European countries.

In Albania, migration was the single cause of depopulation in almost all years of the sample. Annual population losses resulting exclusively from a natural decrease occurred in Hungary, Ukraine, Serbia, Greece (from 2016), and Italy (from 2015 to 2019). In Bulgaria (excluding 2020), Croatia, Latvia, Romania, and Lithuania (before 2018), annual population declines were caused by a combination of a natural decrease and migration.

Slightly more than 60% of the NTS3 units had population increases from 2015 to 2019 (most belonged to Type D). Among the other units, the majority were type E or F (see Tab. 3 and Fig. 7). The types of units with population increases (A, B, C, and D) mainly occurred in western and northern Europe, whereas types representing population decreases (E, F, G, and H) were characteristic of eastern and southern Europe. NTS3 units that lost population as a result of a natural decrease and migration (types F and G), which constitute 20.3% of all NTS3 units in the sample, were mostly situated in Poland, Lithuania, Latvia, Estonia, Romania, Hungary, Greece, Serbia, Bulgaria, Croatia, North Macedonia, southern Italy, central Spain, and northern and eastern Finland.

Table 2. European countries arranged by type of population change from 2011 to 2020

Country	Type												
	2011–2015	**2016–2020**	**2011–2020**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Albania (AL)	H	H	H	H	H	H	H	H	A	H	H	H	H
Austria (AT)	C	C	C	C	D	D	C	C	C	C	C	C	D
Belarus (BY)	D	E	E	E	E	D	D	D	D	E	E	E	:
Belgium (BE)	C	C	C	C	C	C	C	C	C	C	C	C	D
Bulgaria (BG)	F	E	F	F	F	F	F	F	F	F	F	F	E
Croatia (HR)	F	F	F	F	F	F	F	G	G	G	F	F	F
Cyprus (CY)	A	C	B	C	A	H	H	A	B	C	C	C	C
Czechia (CZ)	C	D	D	C	C	F	C	D	C	C	C	D	D
Denmark (DK)	C	C	C	C	C	C	C	C	C	C	C	C	C
Estonia (EE)	G	D	E	G	G	G	F	D	E	D	D	D	D
Finland (FI)	C	D	C	C	C	C	C	C	D	D	D	D	D
France (FR)	B	B	B	B	B	B	B	A	A	B	B	B	B
Germany (DE)	D	D	D	D	D	D	D	D	D	D	D	D	E
Greece (EL)	G	E	F	G	G	G	G	G	E	E	E	E	E
Hungary (HU)	E	E	E	E	E	E	E	E	F	E	E	E	E
Iceland (IS)	B	C	C	A	A	B	B	B	C	C	C	C	C
Ireland (IE)	A	B	B	A	A	A	B	B	B	B	C	C	B
Italy (IT)	D	E	D	D	D	D	D	E	E	E	E	E	F
Latvia (LV)	G	F	G	G	G	G	G	G	G	F	F	F	F
Lithuania (LT)	G	F	G	G	G	G	G	G	G	G	F	E	D
Luxembourg (LU)	C	C	C	C	C	C	C	C	C	C	C	C	C
Malta (MT)	C	C	C	C	C	C	C	C	C	C	C	C	C
Montenegro (ME)	A	H	A	A	A	A	A	A	A	H	H	H	G
Netherlands (NL)	B	C	C	B	B	B	B	C	C	C	C	C	C
North Macedonia (MK)	A	F	A	A	A	A	A	A	A	B	B	F	F
Norway (NO)	C	C	C	C	C	C	C	C	C	C	C	C	B
Poland (PL)	G	E	F	A	H	G	G	F	D	D	E	E	E
Portugal (PT)	G	E	F	G	G	G	G	F	F	E	E	D	D
Romania (RO)	F	F	F	F	F	F	F	F	G	G	F	F	F
Serbia (RS)	E	E	E	E	F	EF	E	EF	EF	EF	EF	EF	EF
Slovakia (SK)	B	C	B	B	C	B	B	C	B	B	C	B	D
Slovenia (SI)	B	D	C	B	B	B	A	B	C	D	D	D	D
Spain (ES)	H	D	D	B	H	H	H	G	C	D	D	D	D

Country	Type												
	2011–2015	2016–2020	2011–2020	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Sweden (SE)	C	C	C	C	C	C	C	C	C	C	C	C	C
Switzerland (CH)	C	C	C	C	C	C	C	C	C	C	C	C	C
Ukraine (UA)	E	E	E	E	E	E	E	E	E	E	E	E	E
United Kingdom (UK)	C	C	C	B	B	C	C	C	C	C	C	C	:

Note 1: The orange, green, and blue cells denote countries with an annual population loss in 2011–2015, 2016–2020 and 2011–2020, respectively.

Note 2: United Kingdom and Belarus: data from 2010–2014, 2015–2019, and 2010–2019.

Note 3: White and grey cell backgrounds denote a population increase and a population decrease, respectively.

Source: own work based on EUROSTAT data.

Table 3. The number of countries and NTS3 units by type of population change from 2011 to 2020

YEARS	Type of increases					Type of decrease					
	A	B	C	D	∑	E	EF	F	G	H	∑
COUNTRIES											
2011–2015	4	5	11	3	23	3	0	3	6	2	14
2016–2020	0	2	13	6	21	9	0	5	0	2	16
2011–2020	2	4	13	4	23	5	0	6	2	1	14
2011	5	6	11	2	24	4	0	3	5	1	13
2012	5	4	10	3	22	3	0	4	5	3	15
2013	3	5	9	4	21	2	1	4	6	3	16
2014	3	5	11	3	22	3	0	4	5	3	15
2015	4	3	12	4	23	3	1	4	5	1	14
2016	4	3	14	4	25	4	1	3	4	0	12
2017	0	4	13	6	23	6	1	2	3	2	14
2018	0	2	15	5	22	7	1	5	0	2	15
2019	0	2	13	7	22	7	1	5	0	2	15
2020	0	3	8	10	21	6	1	5	1	1	14
NTS3 UNITS											
2015–2019	48	61	289	489	887	211	0	180	113	50	554

Note: see Note 2 for Tab. 2 and Note 1 for Fig. 2.

Source: own work based on EUROSTAT data.

Three countries are particularly interesting – Croatia, Germany, and Poland. In Croatia, the east was undergoing depopulation as a result of migration, while the west was affected by a natural decrease. In Germany, depopulation only occurred in the eastern regions (the former German Democratic Republic). In Poland, population declines in the east and north were mainly driven by migration, while in the centre and west, they were caused by a natural decrease (see Fig. 7).

Out of the 1,441 NUTS-3 units considered in the study, 367 experienced population declines in all years between 2015 and 2019.

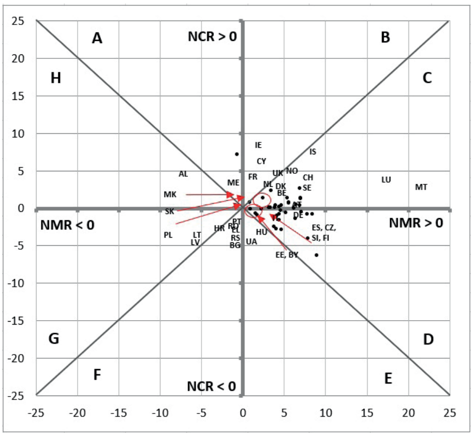


Fig. 6. Countries arranged by NCR, NMR and type, 2011–2020

Note 1: For the symbols of the countries, see Tab. 1.

Note 2: see Note 2 for Tab. 2.

Source: own work based on EUROSTAT data.

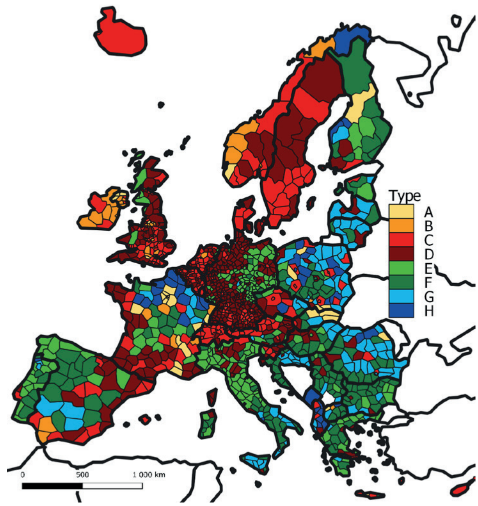


Fig. 7. NTS3 units arranged by type, 2015–2019

Note: see note 1 for Fig. 2

Source: own work based on EUROSTAT data.

As already mentioned, Europe has the oldest population of all the continents. The countries that had the highest percentages of people aged 65 and older (see Table 4) in 2020 were Italy, Finland, Greece, Portugal, Germany, Bulgaria, Serbia, and Croatia (from 21% to 23%; an average of 140–180 seniors per 100 children). Over the 2010s, population ageing progressed in all countries in the sample, and the most in Finland, Poland, Czechia, and Slovakia (the countries' rates of seniors increased by 4.0–4.8 p.p.).

In almost all countries with annual population declines, ageing indices were relatively high, the highest being noted in 2020 for Greece and Bulgaria (see Table 4).

Table 4. European countries by proportion of people aged 65+ years and ageing index in 2011, 2015, and 2020

Country	People aged 65+ (%)			Ageing index			Country (*cont.*)	People aged 65+ (%)			Ageing index		
	2011	**2015**	**2020**	**2011**	**2015**	**2020**		**2011**	**2015**	**2020**	**2011**	**2015**	**2020**
Albania (AL)	11.0	12.4	14.8	50.9	65.3	88.1	Lithuania (LT)	17.9	18.7	19.9	120.1	128.1	131.8
Austria (AT)	17.6	18.5	19.0	119.7	129.4	131.9	Luxembourg (LU)	13.9	14.2	14.5	79.0	85.0	90.6
Belarus (BY)	13.8	14.2	15.2	92.6	88.8	89.9	Malta (MT)	15.7	18.2	18.5	104.7	127.3	138.1
Belgium (BE)	17.1	18.1	19.1	100.6	106.5	113.0	Montenegro (ME)	12.8	13.7	15.6	66.7	74.1	87.2
Bulgaria (BG)	18.5	20.0	21.6	140.2	143.9	150.0	Netherlands (NL)	15.6	17.8	19.5	89.1	106.6	124.2
Croatia (HR)	17.7	18.8	21.0	115.7	127.9	146.9	N. Macedonia (MK)	11.7	12.7	14.5	66.9	75.6	89.5
Cyprus (CY)	12.7	14.6	16.3	75.6	89.0	101.9	Norway (NO)	15.1	16.1	17.5	80.7	89.4	101.2
Czechia (CZ)	15.6	17.8	19.9	107.6	117.1	124.4	Poland (PL)	13.6	15.4	18.2	88.9	102.7	118.2
Denmark (DK)	16.8	18.6	19.9	93.9	109.4	121.3	Portugal (PT)	18.7	20.3	22.1	123.8	141.0	162.5
Estonia (EE)	17.4	18.8	20.0	113.7	118.2	121.2	Romania (RO)	16.1	17.0	18.9	101.9	109.7	120.4
Finland (FI)	17.5	19.9	22.3	106.1	121.3	141.1	Serbia (RS)	17.2	18.5	21.0	119.4	128.5	146.9
France (FR)	16.7	18.4	20.4	89.8	98.9	114.0	Slovakia (SK)	12.6	14.0	16.6	81.8	91.5	105.1
Germany (DE)	20.7	21.0	21.8	152.2	159.1	159.1	Slovenia (SI)	16.5	17.9	20.2	116.2	120.9	133.8
Greece (EL)	19.3	20.9	22.3	132.2	144.1	155.9	Spain (ES)	17.1	18.5	19.6	114.0	121.7	135.2
Hungary (HU)	16.7	17.9	19.9	114.4	123.4	137.2	Sweden (SE)	18.5	19.6	20.0	111.4	113.3	112.4
Iceland (IS)	12.3	13.5	14.4	58.9	66.2	77.0	Switzerland (CH)	16.9	17.8	18.7	111.9	119.5	124.7
Ireland (IE)	11.5	12.9	14.4	54.0	60.3	70.9	Ukraine (UA)	15.3	15.6	17.1	107.7	103.3	111.8
Italy (IT)	20.5	21.7	23.2	145.4	157.2	178.5	United Kingdom (UK)	16.4	17.7	18.4	93.2	100.0	102.8
Latvia (LV)	18.4	19.4	20.5	129.6	129.3	128.1							

Note: See Notes 1 and 2 in Table 2.

Source: own work based on EUROSTAT data.

The NTS3 units with the highest ageing indices in 2020 (see Fig. 8) included the prefecture of Evrytania (EL643) (37%) in Greece and Arr. Veurne (BE258) (32.5%) in Belgium. In Suhl (DEG04), Dessau-Roßlau (DEE01), Altenburger Land (DEG0M), and Vogtlandkreis (DED44) in Germany, Ourense (ES113) and Zamora (ES419) in Spain, Alto Tâmega (PT11B), Terras de Trás-os-Montes (PT11E), and Beira Baixa (PT16H) in Portugal, Creuse (FRI22) and Lot (FRJ25) in France, and Etelä-Savo (FI1D1) in Finland, the proportion of the population aged 65 and over in these units ranged from 30 to 32%. The populations of seniors in Evrytania, Alto Tâmega, Zamora, Ourense, Suhl, and Terras de Trás-os-Montes in 2020 were three times larger than the populations of children aged 0–14 years.

The majority of the demographically oldest NTS3 units (including almost all of those mentioned above) had annual population declines between 2015 and 2019 (see Fig. 8 and 9).

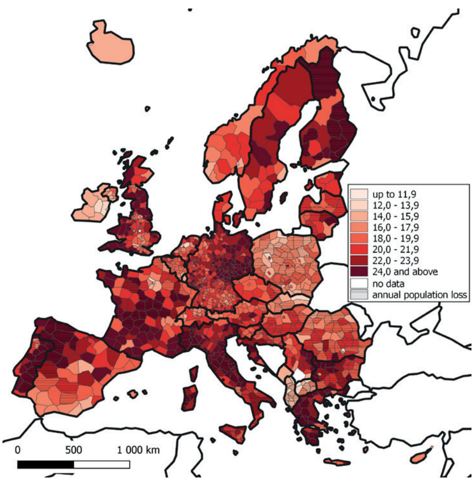


Fig. 8. NTS3 units by percentage of people aged 65 and older, 2019

Note 1: see Note 1 for Fig. 2

Source: own work based on EUROSTAT data.

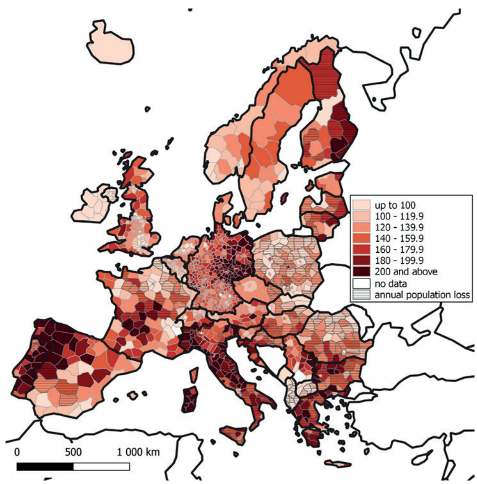


Fig. 9. NTS3 units by ageing index, 2019

Note: see Note 1 for Fig. 2

Source: own work based on EUROSTAT data.

The aggregation of countries and NTS3 units into groups with similar population age structures was performed using Ward's method, assuming that the optimal group sizes for countries and NTS3 units were 3 and 9, respectively.[8] The majority of the countries that experienced annual population declines in the

[8] The optimal group sizes were determined based on the outcomes of the analysis of amalgamation schedule graphs in Statistica software. The scale applied to Euclidean distances (Fig. 10) was appropriately modified using the following formula: (linkage distance)/(maximum linkage distance) *100.

2010s or in the subperiods of the decade (they were also the demographically oldest countries) were in Group 2. The pairs of countries with the most similar population age structures in 2020 were Greece and Portugal, the UK and Norway, Austria and Switzerland, and Latvia and Estonia. In a number of cases similar age structures were found for countries lying in the same part of Europe (viz Spain, Italy, Portugal and Greece in southern Europe, and Ukraine, Belarus, Poland, and Slovakia in Eastern Europe).

NTS3 units with annual population loss between 2015 and 2019 (Fig. 10) and with similar population age structures were concentrated in the same country or in adjacent countries.

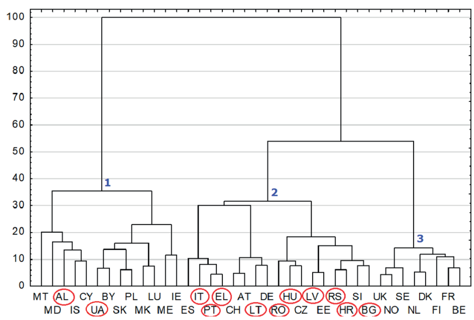


Fig. 10. European countries aggregated by Ward's method according to population age structure, 2020

Note 1: The red circles denote countries with annual declines in population (see Note 1 for Table 2).
Note 2: see Note 2 for Table 2.

Source: own work based on EUROSTAT data.

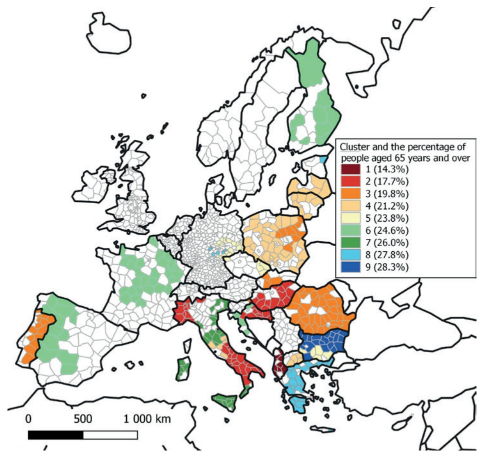


Fig. 11. NTS3 units with annual population loss from 2015 to 2019 aggregated by Ward's method according to the 2019 population age structure

Note: see Note 1 for Fig. 2

Source: own work based on EUROSTAT data.

4. DISCUSSION

The results of the study correspond to the findings published by other authors. They, too, reveal differences in demographic processes in Europe, particularly in terms of population change and population ageing (see, for instance, Brons, 2024; Deimantas *et al*., 2024; Eurostat, 2020; Espon, 2017, 2018; Kiniorska *et al*., 2023; Newsham and Rowe, 2022; Truskolaski and Bugowski, 2022).

Depopulation in Europe mainly occurs in countries and regions in the eastern and southern parts of the continent. Many have been affected by population loss for several decades. Rural areas remote from conurbations are the most prone to depopulation, but towns and cities also increasingly lose populations, mainly due to suburbanisation.

"Rural shrinkage is simultaneously a demographic and economic phenomenon and has been interpreted as part of wider trends in European territorial restructuring, where agriculture has become less labour intensive and economic and employment growth has become progressively tertiarised, favouring larger urban centres. […] Rural shrinkage therefore becomes indicative of a broader structural crisis of economic and labour market decline, peripheralization and a deepening urban-rural divide – intensifying the inherent disadvantages of rural areas," (ESPON, 2017, p. 3).

The problem of urban shrinkage mainly affects eastern European cities (particularly those in Poland, Lithuania, Latvia, Croatia, Hungary, Bulgaria, and Romania), but it is also present in Eastern Germany, Spain, Greece, and Portugal. "In Europe, urban shrinkage has been predominantly associated with deindustrialisation (linked to globalisation and global economic conditions), ageing and population outmigration from the mediterranean and east peripheries into the central 'blue banana'.[9] The process of suburbanisation is also important at the local scale […]. Declining cities were almost always concentrated in declining regions, with economic factors being a key driver," (Aurambout *et al*., 2021).

The demographic and socio-economic situation is relatively the least favourable in areas with a comparatively low level of economic development, where a natural decrease frequently coincides with a negative net migration rate. Among these areas are post-communist countries (or some of their regions) and some regions in South Europe. The majority of NUTS-3 units that had type F or G of population change (i.e., units depopulating as a result of a natural decrease and migrations) in the 2010s lagged in economic development[10] (see European Commission, 2017; Ganau and Kilroy, 2023; see also Pilati and Hunter, 2020; ESPON, 2020).

[9] The "Blue Banana" or "Bluemerang" is a banana-shaped area formed by linking the economically vibrant metropolitan centres in England, Belgium, the Netherlands, the western part of Germany, Switzerland, and Italy (see, for instance, Hospers, 2003; Zimny and Zawieja-Żurowska, 2015).

[10] In the European Commission's Report of 2017, regions located in the eastern part of the EU (particularly those in eastern Poland, Bulgaria, Romania, and in southern and eastern Hungary) were described as "low income lagging regions" ("regions with a GDP per head in PPS below 50% of the EU average in 2013"), and regions in Portugal, southern Spain, southern Italy, and southern Greece as "low growth lagging regions" ("that did not converge to the EU average GDP per head at PPS between the years 2000 and 2013"), (European Commission, 2017, pp. 4 and 16–17). Ganau and Kilroy (2023, p. 46) classified NTS3 units located mainly in the Baltic States, Poland, Romania, Bulgaria, Croatia, and Serbia as "lagging low income" areas, and regions in Portugal, Spain, southern Italy, and southern Greece ad "lagging low growth" areas.

A major problem and challenge that the long-term depopulating countries with stagnant or inefficient economies and high unemployment face is the outflow of well-skilled employees (see, e.g., Guzi *et al*., 2021; Hasselbalch, 2017). "Regions combining a low share of highly skilled people and outward migration of the young and educated may fall into a talent development trap, limiting their capacity to build sustainable, competitive and knowledge-based economies" (Brons, 2024, pp. xxiv and 206–208). The problem is observed in regions "which are mostly in Bulgaria, Romania, Hungary, Croatia, the south of Italy, Portugal, eastern Germany and the north-east and outermost regions of France" (Brons, 2024, pp. 206–208).

An important role in family formation processes is played by economic factors and worldviews, which can potentially cause people to marry at an older age, postpone having the first child (both decisions contribute to low fertility), or not start a family at all. These problems are particularly distinct in post-communist countries, as most of them have ineffective family policies. The biggest demographic challenges in most post-communist countries occur in rural areas that are remote and poorly communicated with large cities. The demographic problems of Serbia and Croatia are partly determined by their recent history and ailing economies (see, e.g., Čipin, 2017; Czibere *et al*., 2021; Dahs *et al*., 2021; Daugirdas and Pociūtė-Sereikienė, 2018; Domachowska, 2021; Fihel and Okólski, 2019; Frejka and Gietel-Basten, 2016; Ilieva, 2017; Juska and Woolfson, 2014; Kotowska *et al*., 2008; Koytcheva and Philipov, 2008; Lerch, 2018; Levchuk, 2009; Lutz and Gailey, 2020; Marinković, 2020; Marinković and Radivojević, 2016; Muntele *et al*., 2023; Mureşan *et al*., 2008; Perelli-Harris, 2008; Philipov, 2002, 2003; Pinilla and Sáez, 2017; Pires de Almeida, 2017, 2018; Rašević, 2017; Recaño, 2017; Reynaud and Miccoli, 2018; Stankuniene and Jasilioniene, 2008; Szukalski, 2019; Tatarenko, 2021; Ubarevičienė and Burneika, 2020; Zarins, 2020).

The distinctiveness of social phenomena and demographic changes in Eastern Europe seems to be associated with those countries being controlled by the USSR for almost fifty years after the Second World War and, consequently, being cut off from the exchange of people, commodities, and ideas. The demographic trends in post-communist countries can be briefly described as: "a decrease in population, low birth rates, ageing, a concentration of population in the large agglomerations, an upsetting of the principal structures of the population, a deepening of regional demographic differences, as well as higher rates of mortality and intensive external migration, the last two being typical of the countries in transition," (Ilieva, 2017, p. 8).

Differences in the mortality, health, and wellbeing of European populations (see WHO, 2018) are largely related to their history (see Zatoński *et al*., 2016). Higher mortality rates from cardiovascular diseases and cancers in Eastern European countries, particularly in the ex-Soviet Union republics, than elsewhere are also caused by the overuse of alcohol and tobacco, unhealthy lifestyles, including eating habits, and the limited awareness of healthy behaviours (see Doniec *et al*., 2018; Santucci *et al*., 2022; Stefler *et al*., 2021; Stefler *et al*., 2018; Yakovlev, 2021).

Despite many eastern EU Member States being affected by depopulation, the region does and should fare better in terms of age dependency than the south, and it is on par with the west (Potančoková, 2021, p. 1317). The challenges arising from high age dependency will be greater in southern EU countries than in eastern and western Europe, as their adaptability to population ageing is hindered by relatively low education levels (Potančoková *et al*., 2021, p. 1345).

5. CONCLUSIONS

Depopulation in the 2010s occurred mostly in eastern and southern Europe. In many of these countries or their regions, this phenomenon has gone on for decades. The most affected were countries and NTS3 units whose populations were reduced annually by natural decrease and migrations.

The findings of the study can be summarised as follows: the populations of eight countries (Bulgaria, Croatia, Greece, Hungary, Latvia, Romania, Serbia, and Ukraine) declined in all years between 2011 and 2020. In Albania, Lithuania, and Portugal, there were only one or two years in that period without population declines. Belarus, Estonia, Montenegro, Spain, and Poland had negative TCRs in several of the sample years. The greatest variety of the types of population change was found for Poland and Spain (six and five, respectively). It is notable that the populations of Bulgaria, Latvia, Lituania, Serbia, Croatia, Romania, Ukraine, and Hungary decreased annually (the countries' TCRs were negative) after political transition and that in almost all the countries depopulation was a combined effect of migration and a natural decrease.

The worst demographic problems occurred in Bulgaria, Croatia, Latvia, and Romania, where natural causes and migration contributed to population loss in all (or almost all) years in the 2010s.

Emigration was the single reason for population decline in Albania, while natural decrease was in Ukraine, Hungary, Serbia, and Greece (since 2016), and Italy (since 2015).

One-fourth of the NUTS-3 units had a negative TCR in all years from 2015 to 2019. Most of them were in Romania, Portugal, Poland, Hungary, Latvia, Croatia, Spain, Greece, Germany, and Bulgaria.

The majority of NTS3 units with annual population declines from 2015 to 2019 were classified as 'lagging regions'. Additionally, most of the NTS3 units that recorded population losses between 2015 and 2019 had the oldest populations in 2019, and they belonged to Portugal, Spain, Greece, Italy, and Germany.

Most of the annually depopulating countries were relatively similar in terms of population age structure. NTS3 units with annual population loss and similar population age structures usually occurred within the same country or occupied neighbouring areas in adjacent countries.

Many European regions or countries have reached a point where depopulation cannot be reversed and can only be slowed down. Thus, a policy change towards investments in education or health is necessary to mitigate the negative impact of population shrinkage. It is also needed to increase workers' human capital enough for productivity gains to offset a likely decrease in the number of workers (Luts and Gailey, 2020, p. 29). Long-term strategies to counter population declines should also address the economic, social, and environmental issues associated with depopulation (ESPON, 2018, p. 9).

It is almost certain that the demographic picture of Europe in the third decade of the 21st century will be different from that in the 2010s, as many regions will be affected by further consolidation of the existing demographic trends. Depopulation processes in areas that have been losing populations for decades will continue in most cases. Also, substantial demographic changes in Europe, especially in its eastern and central parts, can be expected as a result of the war in Ukraine and the exodus of Ukrainian refugees to European countries.

The demographic situation of Europe will also be influenced by Brexit and the COVID-19 pandemic (by temporarily increasing mortality rates, it slightly shortened life expectancy and affected demographic structures), as well as by other developments that may unexpectedly occur in the future (see European Commission, 2023, p. 2).

The ageing of Europe's population will accelerate in the 2020s, as a result of low fertility rates, increasing life expectancy, migrations, declining percentages of children and working-age people in many countries, and further ageing of the baby-boom generations. These unfavourable trends will require intervention from national and regional social and family policies and labor markets (see, e.g., Brons, 2024; see also European Commission, 2024). "The shrinking working-age population puts pressure on labour markets and welfare states; increases the old-age dependency ratio; and raises the per-capita burden of public debt," (see European Commission, 2023, p. 2, and European Commission, 2024).

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BLUE BANANA DYNAMICS AND THE PERSPECTIVE OF ITS EDGES

Abstract. This paper investigates the positioning of the UK and Northern Italy within the Blue Banana, which the literature considers as the productive core of Europe. We compare the main economic characteristics of the two regions with the rest of the Blue Banana by analysing several indicators, ranging from urbanisation and infrastructure development to unemployment, productivity, competitiveness, and attractiveness. Based on our findings, in terms of population, urbanisation, and infrastructure, the Blue Banana and the two edges are still an integral part of Europe's core. However, in terms of employment structure, productivity, competitiveness and attractiveness, its significance can be questioned due to the weaker performance of Northern Italy and the negative effects of Brexit.

Key words: Blue Banana, Northern Italy, Brexit, European integration, NUTS-2 regions.

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1. INTRODUCTION

Brunet (1989) was the first geographer to identify a European productive core in a relatively narrow area, stretching from Northern Europe, including part of Great Britain, the Netherlands, Belgium, France, and Germany, to most of Northern Italy, while covering also Switzerland and Austria. He initially defined the area as '*the European Backbone*', but since the late 1980s it has become commonly known as '*the Blue Banana*', due to its shape. The Blue Banana is home to between 90 and 110 million people (out of Europe's total population of 730 million) and covers 1,500 to 1,700 kilometres between its northern and southern edges. Different studies by scholars and academics have focused on the causes of the region's remarkable levels of industrialisation and development (Kunzmann and Wegener, 1991; Hospers, 2003; Loriaux, 2008; Faludi, 2015; Nagy and Tóth, 2019).

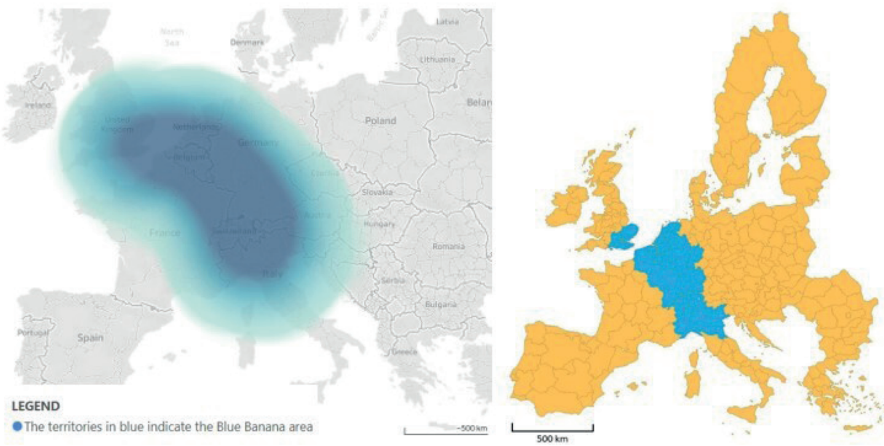

Fig. 1. The European Blue Banana area (left) and the partially or completely overlapping NUTS-2 regions (right) of Europe

Source: own work.

Before delving into our analysis, it is essential to provide a brief overview of the Blue Banana concept. Initially, the Blue Banana served as a springboard for studying the broader European development pattern. Nonetheless, over time, a new discussion on the historical context of European urbanisation emerged, a fact we will discuss in the next section. In our analysis, the Blue Banana emerges as a nexus of local production networks, where the clustering of industrial hubs catalyses the flow of capital and human resources, thus driving economic, industrial, and cultural advancements. However, the relevance of these districts extends beyond their mere size and population; it translates into a dynamic interplay of commerce and innovation that shapes the territory's development trajectory.

Our research is driven by the need to update and refine the understanding of the economic and political dynamics within the Blue Banana. In particular, we will focus on its northern and southern extremities, whose features appear to be significantly peculiar. In this context, Italian industrial districts have risen to prominence over the past two decades, becoming central to discussions in business and economic forums. If we shift our focus to the other tip of the Blue Banana, it is worth considering the case of the UK as well. Approximately half of all jobs in the city of London are provided by over 800,000 small and medium-sized enterprises (SMEs), which account for 99.8% of the city's businesses (Hutton, 2024). Outside the Central Activities Zone – the very centre of the city of London – the capital's industrial areas account for 11% of all jobs, or around 556,000 positions spread across 34,720 businesses (Hutton, 2024).

Nonetheless, recent developments, especially Brexit negotiations and Italy's economic vulnerability, have underscored the need for a nuanced analysis of this area's trajectory. Italy's potential drift from its position within the Blue Banana – related to its loss of competitiveness in the market – and the repercussions of Brexit that are currently affecting the UK, present critical challenges with far-reaching implications for EU Member States. These developments are in fact reshaping the economic landscape of the area (see further). Thus, the article discusses these aforementioned current events in both the southern and northern edges of the Blue Banana, with a particular focus on Northern Italy and London and South East England. Moreover, our research will lead to interesting findings on Eastern Europe's backbone as well, highlighting it as one of the most dynamic and transformative regions in Europe.

The paper is structured as follows: After a brief overview of the Blue Banana concept and its historical evolution, we analyse and compare the basic characteristics of the area with those of Northern Italy, expressing our concern about whether the territory can still be considered part of the region. The specific focus is on the north of the country, where technological districts are larger, closer to the local economic structure, and exhibit greater sectoral diversity compared to those in the rest of the country (Bertamino *et al.*, 2016). Regarding the position of London and South East England within the Blue Banana, the final section of our paper shows potentially serious concerns raised by the Brexit negotiations, as productivity is expected to fall and the interconnections with the rest of the Blue Banana are destined to become more difficult (Bloom *et al.*, 2019; Sedláček *et al.*, 2019).

2. HISTORY OF THE BLUE BANANA

The concept of the Blue Banana was first introduced in a study conducted in 1987 by the Interministerial Delegation of Land Planning and Regional Attractiveness (DATAR) and, as mentioned, presented by Brunet and his geographers in 1989. Brunet's work was developed in a period of significant advancements in the establishment of a European single market and in the strengthening of European integration, namely through the Schengen Agreement and the signing of the Single European Act.[1]

Over time, criticisms of the Blue Banana concept have nonetheless intensified. Firstly, after the fall of the Iron Curtain in 1989 and in the early stages of the creation of the EU economic and monetary union, the determination of an economic core within Europe was said to reduce the cooperation and increase rivalry between Member States (Kunzmann and Wegener, 1991; Dunford, 1994). Furthermore, recent studies have challenged Brunet's argument, as the manufacturing and logistics core of the European Union is moving eastwards (Naudé *et al.*, 2019, p. 6; Csomós and Tóth, 2016). Additional studies have been directed at the shape of geographical areas, such as Nagy and Tóth's (2019) discussion on an alleged "New Banana", a promising European economic core consisting of seven capital cities and their agglomerations: Berlin, Prague, Bratislava, Vienna, Budapest, Ljubljana, and Zagreb. Other studies have examined a potential "Sunbelt" from Milan to Valencia, and a "Yellow Banana" from Paris to Warsaw (Hospers, 2003; Nagy and Tóth, 2019).

In the early 1990s, Kunzmann and Wegener (1991) proposed an opposing theory introducing the concept of the Bunch of Grapes. This idea identifies a different pattern of European development based on multiple centres, where new areas of development were integrated by simply adding more berries to the original 'grape'. In this way, countries and regions of Eastern Europe could easily be combined into the picture, giving shape to a clear and straightforward framework, in line with a new polycentric European development strategy (Faludi, 2015). However, despite the emergence of new dynamic corridors of economic development, the Blue Banana continues to be seen as the core of the European economy.

[1] Other names have been proposed for Brunet's European backbone, including the term "blue banana", partly attributed to Jacques Chérèque. According to Brunet himself, the "blue" color came from the geographical representation in an article by Alia (1989) in the French magazine *Nouvel Observateur*. According to other interpretations, the color could also recall the flag of the European Union, or the clothes worn by the so-called blue collars.

3. MODERN INDICATORS OF THE BLUE BANANA

Throughout the analysis, we consider four main areas to measure whether Northern Italy, London and South East England can still be considered part of the Blue Banana: productivity and competitiveness, urbanisation and infrastructure, employment – especially in capital-intensive sectors – and the related attractiveness of high-skilled migrants. In this paragraph, we illustrate the reasoning behind the choice of these key features and metrics in order to define the economic and productive core of Europe.

The growth of this area and its internal competitiveness are essential features of the European landscape. According to the EU Regional Competitiveness Index, which will be discussed later, most of the European Backbone regions score well above the European Union average in this regard (Table 1). However, new production centres are gradually emerging in the East, particularly in the industrial sector. According to Hospers (2003), if manufacturing is shifting eastwards, it is easy to see how the major European centres have made the transition from manufacturing-oriented societies to service-oriented types of economies (Faludi, 2015). By the late 1980s, a new urban geography with a focus on tertiary jobs and advanced manufacturing developed, particularly in the wake of the deindustrialisation crisis in Western Europe. London and Paris were at the top of the new international paradigm, and other cities, which chose to pursue service-oriented local policies, could be found along the "Blue Banana axis", starting from Manchester (Kazimierczak, 2014) down to Turin (Scamuzzi, 2022). In the expanding eastern centres, where primary and secondary industries have historically predominated, services have also become increasingly important. The internationalisation of these countries' economies is mainly responsible for the growing importance of services such as marketing, finance, and consultancy.

The second factor worth considering is the phenomenon of urbanisation, which has always been one of the most prominent features when identifying the Blue Banana. This factor, alongside other economic and infrastructural characteristics, distinguishes the area from other European regions. First and foremost, it is densely populated and urbanised, with 40% of the EU's population residing in numerous large and medium-sized cities within the delimited area. In this respect, it has also been referred to as the *European Megalopolis* by some scholars (Kunzmann, 2007; Faludi, 2015). The Blue Banana is visible on the regional map of Europe by connecting the darker blue areas in Fig. 1: these are the most densely inhabited centres, and they include major cities like Amsterdam, Dortmund, and Düsseldorf.[2] In addition, Milan, Varese, and Monza-Brianza can be considered as some of the most populous provinces.

[2] There are other densely populated NUTS-2 regions, which are mainly the agglomerations of capital cities, beyond the Blue Banana. However, they are rather isolated areas and geographically less continuous than the Blue Banana.

To fully grasp the extent of the influence of urbanisation, it is instructive to consider the theory of growth poles, a concept that has been pivotal in understanding the dynamics of regional growth. As articulated by Perroux (1950), growth poles are catalysts within an economy, consisting primarily of influential enterprises, industry sectors, or academic and research institutions. These poles serve as epicentres of economic activity, exerting a ripple effect that spurs expansive growth throughout their surrounding areas. Jacobs (1969) contributes to this strand of literature by associating technological progress with the benefits of urban economies. Urban centres are crucibles of diversity, offering a confluence of new opportunities that can be harnessed into tangible economic growth. This synergistic relationship between urbanisation and technological innovation is a fertile ground for economic development. Although these effects might not be immediately apparent, they are of paramount importance. On this subject, Florida (2002) has envisioned cities as engines of wealth through technology, talent, and tolerance, where, however, patterns of inequality tend to emerge: only a small number of neighbouring cities have gained the benefits of economic development (Florida, 2017).

Moreover, according to Hospers' (2003) analysis, the development of physical and telecommunications infrastructure is a key feature of the Blue Banana. For instance, this area exemplifies how urbanisation, population density, and economic growth drive the demand for a well-developed transport system (Van Wee *et al.*, 2013). Consequently, investing in infrastructure is key to economic development, especially when it comes to trade and GDP (Gross Domestic Product) growth (Röller and Waverman, 2001). We can assess both direct and indirect effects in sectors related to construction, civil engineering, electronics, real estate, and environmental preservation. For example, political instability, variations in maintenance, and discontinuous investments have a detrimental influence on railway usage; in contrast, continuous investments and proper maintenance assure a progressive growth in the number of people and products moved. This is a consistent trend, and from an economic and ecological standpoint, it can be regarded also as a positive phenomenon (Cermakova *et al.*, 2015).

Measuring innovation through employment indicators is challenging as well. For example, the unemployment rate by itself does not provide a comprehensive picture of the regional economic situation in terms of sectoral balance. On the contrary, metrics like the proportion of employment in knowledge and high-tech industries relative to the overall occupation are more systematic parameters (see Appendix), which can lead to the achievement of an accurate representation of the regional employment landscape. For instance, central-eastern European regions seemingly perform better than most of the western European regions when only considering the employment rate. However, this is due to the higher dependence on FDI and the less productive industrial manufacturing sectors in the eastern periphery compared to the core of Europe. Concerning the rate of employment in high technology and knowledge-intensive sectors, the picture is geographically more dispersed. In other words, it can be said that the Blue Banana is not the main and only European core according to this indicator.

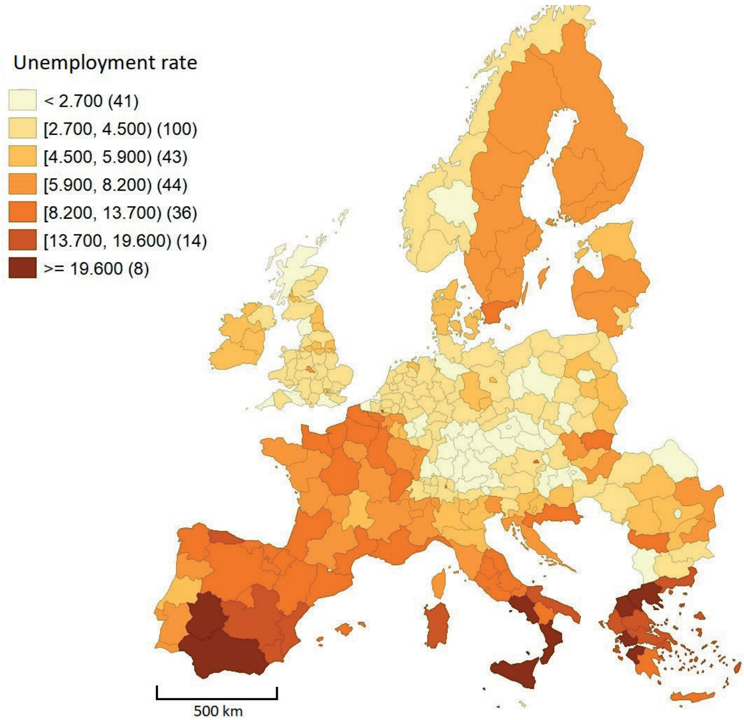

Fig. 2. Unemployment rate in the NUTS-2 European regions in 2019
Source: own work based on Eurostat data.

An additional and relevant indicator for our research purpose concerns the concept of attractiveness. Although mobility is mutually beneficial for both mobile workers and employers, it is a zero-sum game across sending (brain-drain) and receiving (brain-gain) entities, as clearly detailed in the "war for talent" argument (Michaels *et al.*, 2001). According to Marini (2024), this dynamic is also evident at the EU level for semi-peripheries. Besides wages and other socio-economic motives, the literature identifies additional soft elements influencing international mobility. Musolino and Kotosz (2024) have identified various factors that influence territorial attractiveness, ranging from financial resources, such as investment flows, to the movement of people, including tourists, immigrant workers, and specific groups like researchers, talents, and university students. The latter categories, specifically immigration and talents, will be the focus of our indicator of attractiveness.[3]

In conclusion, another indicator considered to assess whether an area belongs to the Blue Banana is its efforts in tackling pollution and other initiatives related

[3] The authors indicate that the concept of territorial attractiveness is different from that of territorial competitiveness (Musolino and Kotosz, 2024).

to the models of circular and green economies. Indeed, as previously examined, there is a positive correlation between economic growth and urbanisation. However, it is worth noting that these two variables will contribute to pollution in urban areas. This phenomenon will be further examined through the subsequent analysis of the cases of Northern Italy and London.

4. IS NORTHERN ITALY FACING THE RISK OF EXITING THE BLUE BANANA AREA?

Since the European financial and economic crisis of 2008, the transformation of the Blue Banana area has been both profound and multifaceted. This once predominantly linear economic corridor has evolved, adopting a more polycentric structure that extends beyond its original borders. This shift has been particularly pronounced with respect to the Mediterranean regions, which have seen their influence fluctuate in recent years within the Blue Banana landscape.

Indeed, while many of the northern countries included in the Blue Banana have succeeded in following the path of stability, Italy has not moved in such a direction, raising questions about whether its presence inside the Blue Banana is still well-founded. We will investigate this inquiry in the following section of the paper, by separately examining each determinant presented in the previous section. As mentioned earlier, the Blue Banana has several distinctive characteristics that contribute to its reputation as the beating heart of Europe.

4.1. Productivity and competitiveness

This first section focuses on labour costs and productivity in Italy. Although the Southern country's related units are significantly higher than those in other Eurozone countries, labour costs are still rising (De Grauwe, 2007) due to decreased productivity, despite the fact that Italian salaries are lower than in the broader area. Additional empirical evidence comparing Italy to other EU members with similar GDPs, such as France and Germany, shows that the country is an exception (Calcagnini and Travaglini, 2014; Lotti and Santarelli, 2001; Sterlacchini and Venturini, 2014). Indeed, Italy is the only country where labour productivity growth rates have consistently slowed down over the past three decades (see Fig. 3). This is further evidenced by the decline in technological improvement within the same time framework (Sgherri, 2005). According to Eurostat data, Italy's labour costs have risen less than those of France and Germany (Fig. 3), despite its labour productivity decreasing more (Fig. 6) over the last one and a half decades.

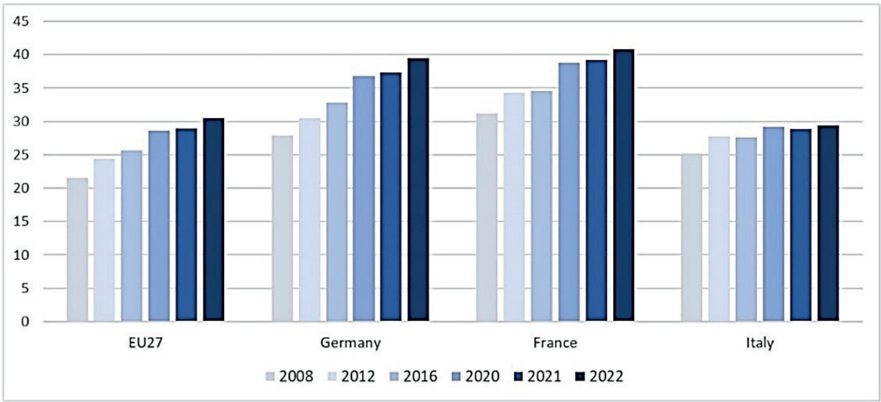

Fig. 3. Labour cost in euros in the EU27 (average), Germany, France, and Italy between 2008–2022
Source: own work based on Eurostat data.

Labour market reforms can be quite important in boosting employment. However, resulting from policies favouring flexible labour arrangements, the capital-to-labour ratio has decreased and the proportion of unskilled workers working shorter shifts has increased (Saltari and Travaglini, 2008). Malcolm Abbott (2018) have noted that there are various methods to assess productivity, depending on the justification for their measurement. Among them, one can assess the business birth rate, which is defined as follows:

$$\frac{enterprise's\,births_t}{active\,enterprises_t} \tag{1}$$

In the equation above, the number of enterprises founded in one year is divided by the total number of active enterprises over the same year in order to measure entrepreneurial activity. In relation to our study, the regions in Eastern Europe have the highest birth rates in enterprises, while the Blue Banana finds itself on the same level as the average European score (Table 1). Nevertheless, Northern Italy's birth rate is located below the Blue Banana average (Table 2), seemingly supporting the concept of "lock-in context" (Calcagnini and Travagnini, 2014; De Noni *et al.*, 2017). This makes them risk-averse, as they are unable to take advantage of the process of creative destruction by experimenting with fresh growth prospects.

A commonly accepted definition of competitiveness includes the willingness and aptitude to gain and maintain a place in the market, to increase market share and profitability, and ultimately to combine operations that are profitable at a commercial level (Annoni and Dijkstra, 2017). However, there are some nuances to consider. Firstly, the concept was initially developed to compare firms and not regions, thus raising the question of its possible applicability at the regional level to explain economic performance. Some scholars (Cellini and Soci, 2002; Krugman, 1994) argue that countries or regions, unlike firms, have different objectives beyond profit and that international trade is not a zero-sum game. However, other authors (Boschma, 2004; Turok, 2004) point out that investments and key resources are exiguous, and territories (either countries or regions) seek to attract them through competitive behaviour. The definition adopted by the EU Regional Competitiveness Index 2019 (Annoni and Dijkstra, 2019) partly helps to balance these two perspectives, as it integrates the well-being of both firms and citizens in the region without focusing only on the former (as highlighted by Schwab, 2012; Porter *et al.*, 2007), or only on the benefits of the latter (as pointed out in Meyer-Stamer, 2008). As competitiveness is a compound indicator, it should include various factors that can be empirically tested, such as human capital and institutional quality, as well as productivity-related aspects like R&D expenditure or the number of NEETs.[4]

Bristow (2010) has pointed out that sources of competitiveness can be found not only at the regional level, but also at local (as in the case of a city) and national ones. For example, the effect that federal laws have on states or similar territories may be significant. To achieve this, the Regional Competitiveness Index (RCI) considers several indicators, including labour market efficiency, institutional quality, research, technological infrastructure, health, education, market size, macroeconomic stability, and GDP per capita. It also uses a system of different weights to account for different types of legislation (Annoni and Dijkstra, 2019). It is extremely important to consider the concept of competitiveness, since in recent years our society heavily relies on creativity in a variety of fields, including science and engineering, technology-based businesses, as well as in art and music, or even in knowledge-based professions like finance, law, and healthcare (Florida and Tinagli, 2004). Nowadays, creativity is not just a method to enhance output, but it has become a driving force behind business (Hightower, 2003) and the key to gain competitive advantage (Junarsin, 2009).

From a historical perspective (see Table 2 in the Appendix), we can observe how the deterioration of competitiveness in Italy is anything but a recent phenomenon. In both the 2000–2009 and 2010–2019 decades, Northern Italy performed worse than the rest of the Blue Banana in several fields: enterprise birth rate, gross value added at basic prices, fixed capital formation and compensation of employees. However, for the last two factors, the gap with the Blue Banana is lower in the 2010–2019 period compared to 2000–2009. The only exception to this trend is the employment in technology and knowledge-intensive sectors, which is higher in the North of Italy than in the rest of the Blue Banana.[5]

[4] An acronym that stands for young people "Not in Education, Employment or Training".

[5] While the 2000–2009 and the 2010–2019 periods cannot be compared, as the classification of the jobs considered as technology and knowledge-intensive changed in 2008, in the two separate periods Italy has a higher rate than the rest of the Blue Banana.

As suggested by Bull (2018), the reasons for these inefficiencies can be found in the country's long-lasting structural weaknesses, dating back to the 1990s and further exacerbated by the sovereign and debt crises. In 2016, the region Lombardy scored between 0 and 0.2 on the index, while the other northern areas scored slightly higher, between 0.2 and 0.5. Comparing these values with the 2013 index, we can see that the score for Lombardy has remained essentially unchanged (0–0.2), while the other regions in Northern Italy have become slightly more competitive in 2016, since in 2013 their average score was -0.2–0. In the 2010 edition of the RCI, Lombardy and Emilia-Romagna seemed to belong to the Blue Banana, as their indices were almost in line with the rest of the most developed regions (0.2–0.4).

From a methodological perspective, as far as the different index's components are concerned, we can identify three RCI sub-indices – Basic, Efficiency, and Innovation. The first group includes fundamental enablers of competitiveness, such as infrastructure, health, and education, some of which are nationally computed. The Efficiency sub-index more closely measures dimensions linked to productivity, such as lifelong learning, market size, and labour market efficiency. In all these areas, the aforementioned 'lock-in effect' of Italian enterprises had a primary role, since the academic pressure to promote competitiveness by shifting the support from traditional industries to the increased size of national firms has gone largely unheeded (Calcagnini and Travagnini, 2014).[6] Finally, the Innovation sub-index measures more specific factors, such as business sophistication (the percentage of small and medium-sized enterprises that introduce marketing or organizational advancements) and innovation.

In the Italian case, the significant number of small and medium-sized enterprises has further limited the various facets of innovation, culminating in low-interest rates and therefore low investment in research and education (Bull, 2018). Northern Italy lacks adequate education standards as well as macroeconomic stability. In this respect the 2018 report of the Programme for International Student Assessment (PISA) provided student learning outcomes assessment in reading, mathematics, and science (OECD, 2019). It is important to note that the RCI's methodological framework has changed since 2022.[7] Figure 4 displays the EU NUTS-2 regional data for 2022 based on the current edition, in relation to RCI 2.0, even though we have already studied the data based on earlier editions.[8] According to the new dataset, Lombardy still performs better than most of the EU regions, but

[6] Indeed, larger Italian firms have been deemed more competitive than their international counterparts, see Calcagnini and Travagnini (2014).

[7] For more information about the changes in the RCI methodological framework, see the 2022 edition of the EU Regional Competitiveness Index 2.0: https://ec.europa.eu/regional_policy/sources/work/rci_2022/eu-rci2_0-2022_en.pdf.

[8] Due to Brexit, UK areas are not included in the dataset.

worse than other neighbours within the Blue Banana area, thereby suggesting that the region represents a borderline case.

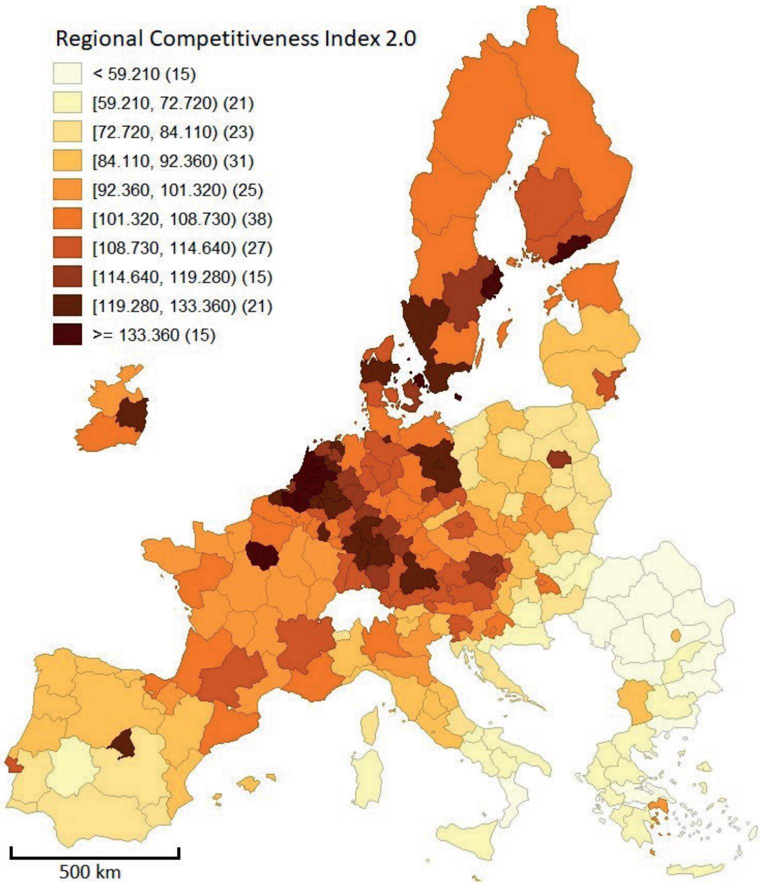

Fig. 4. Regional Competitiveness Index (2.0) Map of Europe in 2022

Source: own work based on European Commission (n.d.) data.

4.2. Urbanisation and infrastructures

Regarding the development of urbanisation and infrastructures, coherently with Klasen and Nestman (2006), data clearly shows that variations in productivity and occupation are fast moving processes compared to, for example, changes in population density. Given that the inhabitants of these areas do not move to different regions as a direct response to economic development, it is not surprising that Northern Italy still has a considerable density of cities, despite lower competitiveness, especially considering how long ago urbanisation started (Faludi, 2015).

In terms of infrastructures, when examining comparative data among European nations, the focus often falls on metrics like the extent of the railway network. In this aspect, Italy's railway infrastructure has traditionally trailed behind its Blue Banana counterparts. Yet, this disparity has shown signs of narrowing in the decade spanning from 2010 to 2019, as opposed to the previous decade, a trend highlighted in Table 2. Beyond the basic measurement of rail length, Northern Italy's integration into the Blue Banana is more comprehensively understood through its capabilities in passenger transport and the linkage of urban centres. Lombardy stands out as a seamlessly integrated region within the Blue Banana framework. This is attributed to the presence of pivotal intermodal centres in locations such as Busto Arsizio-Gallarate and Milano-Melzo. These nodes have gained recognition as substantial logistical pivots, contributing to the fabric of transportation and commerce across the area, as detailed by Pastori *et al.* (2014). These intermodal hubs exemplify Northern Italy's strategic role in enhancing connectivity and facilitating the flow of goods and people within the Blue Banana.

The Northern Italian area is also an advantageous location for connecting shipment flows from Austria, Germany, and France. This characteristic, along with its industrial progress over decades, accounts for the growth of the area's logistics industry (Lupi *et al.*, 2018). Hence, we can state that Northern Italy still finds its place in the productive region of the Blue Banana according to the infrastructure parameter (Schade *et al.*, 2016). However, Italy's potential exclusion from the Blue Banana area is primarily due to other economic factors identified in Section 3, such as productivity, introduced in the previous paragraph, and employment, which will be analysed in the following one. Moreover, a crucial component worth considering when addressing the parameter of urbanisation is the issue of environmental pollution, as environmental risks may affect individuals' residential choices. A negative and statistically significant relationship between local air pollution and the net migration rate is found among Italian provinces (Germani *et al.*, 2021), highlighting that environmental variables must be taken into account as an indicator of quality of life when analysing the phenomenon of internal migration (Bonasia and Napolitano, 2012).

4.3. Employment and welfare

From 1996 onwards, Italy experienced an employment rate growth of an average of 1.1% (Faini, 2003). Moreover, the later introduction of the euro seemed to balance not only Italy's unemployment rates, but also those across the whole Eurozone. However, even before the 2008 crisis, there was an increase in joblessness disparity (Puga, 2002; Beyer and Stemmer, 2016), resulting in heterogeneity in unemployment rates within the region.

Therefore, is the unemployment rate different in Italy than in the other Blue Banana countries? To analyse the heterogeneity peculiar to the Blue Banana, factors such as flexible labour markets, interregional transport connectivity, and local access to skilled workers, should be considered as well (Andersson *et al.*, 2015). In this context, the relatively low unemployment rate may be attributed to a territory's well-developed infrastructure network and highly skilled workforce.

Evidence suggests that, after the introduction of the single currency, while Southern European countries, such as Spain and Greece, experienced a decline in their unemployment rates, but this was not the case in Italy (De Grauwe, 2007). Indeed, the 2014–2015 Jobs Act in Italy was intended to bring the labour market institutions closer to the standards of the EU and those of the Blue Banana (Pinelli *et al*., 2017). At least for the first period, the hoped-for positive consequences were reached. However, it is worth considering that regional differences in unemployment rates led to unequal effects across the country, and Northern Italy particularly enjoyed most of these positive consequences (Marino and Nunziata, 2017). Comparing the Blue Banana and Northern Italy between 2011 and 2013, it could be assessed that the share of unemployed people in the latter was approximately in line with the statistics of the rest of the area. Nevertheless, it was still 1–2% higher than in other Blue Banana countries, confirming the literature on the longer-lasting effects of the 2011 Italian crisis. However, unemployment rebounded, reaching pre-crisis unemployment levels in 2017 and 2018 (Bull, 2018; Moschella, 2017; European Commission, 2017). Despite all this, it should be recalled that these figures come from the most productive part of Italy: the rate remained significantly higher in the Centre and in the South of the country (Marino and Nunziata, 2017). Finally, in 2019, before the COVID-19 pandemic, the unemployment rate in Northern Italy was not different from the percentages of Western European regions *outside* the Blue Banana, but it was higher than in the countries inside it (Fig. 2). However, as mentioned earlier, it should be emphasized that the unemployment rate alone does not give a good picture of the regional economy in terms of sectorial balance.

4.4. Attractiveness and migration

As mentioned in Section 3, territorial attractiveness plays a pivotal role when assessing Italy's position in the context of the industrialised core of Europe. This section focuses on the analysis of the attractiveness determinant and the resulting migration patterns based on the most recent literature.

According to a study from Musolino and Kotosz (2024), Lombardy consistently ranks at the top and far above the other northern regions throughout the whole time period under analysis.[9] Besides being the main gateway for multina-

[9] Musolino and Kotosz (2024) used the data from the application of the BAP (Budget Allocation Process) method from 2010 to 2017 and the application of the factor analysis as an aggregating method in the same time interval.

tional companies in Italy (Mariotti, 2017), Lombardy is well-known for attracting both foreign labour force and university students. By scrutinising the broader northern area, we can identify a group of regions following Lombardy's example, namely Trentino-Alto Adige, Friuli-Venezia Giulia, Piedmont, and Emilia-Romagna. Besides the good level of attractiveness for foreign immigrants, the strong tourist vocation of many of these Italian regions is a determining factor for the outstanding rankings of these regions.[10] Moreover, many of them are also rather attractive for FDIs, albeit at a lower level than Lombardy. From an academic perspective, the presence of important and prestigious universities, such as the historic university of Bologna in Emilia-Romagna, surely contributes to increasing the appeal of these regions.

In order to better assess the position of the Italian northern regions within the broader industrialised core of Europe, it is worth mentioning the status of the country's southern regions, which rank at the bottom of the list. They are neatly divided from the rest of Italy: only Calabria obtains a higher score, due to the good performance in attracting university students and foreign workers from abroad (Musolino and Kotosz, 2024). In this respect, Musolino and Kotosz (2024) have found that the two macro-regions (Central-North and South) do not differ so neatly in terms of multidimensional international attractiveness. Instead, disparities and different patterns within the country continue to grow more complex, as also recent works on the middle-income trap and development trap of the European regions, including in the Italian context, have highlighted (Diemer *et al.*, 2022).

5. BREXIT AND SOUTH EAST ENGLAND'S EXIT FROM THE BLUE BANANA

This section provides an overview of the consequences of Brexit negotiations for the Blue Banana, focusing on the effect of negotiations rather than on Brexit itself. This focus is due to the lengthy withdrawal process from the European Union, which ended only on 31st January 2020. Furthermore, it is undoubtable that the worldwide pandemic presented a serious risk to the economies of the United Kingdom and the Blue Banana. Given the interwoven consequences of Brexit and COVID-19, determining the event's repercussions is difficult. Our analysis' first step includes the evaluation of the impact of Brexit, bargaining on the indicators that we have identified in Section 3, namely productivity and competitiveness,

[10] Additional regions in central Italy can be identified, namely Tuscany and Lazio. It is evident that tourism could also foster the attractiveness of these northern and central regions in terms of cultural and artistic heritage, food and wine tourism, winter tourism, etc. (Musolino and Kotosz, 2024).

infrastructures, attractiveness and migration. The second step involves considering the consequences of Brexit on the free flow of goods and people. The evidence indicates that Brexit had a significant and irreversible impact on the regional cohesion of the Blue Banana, despite the UK's economic recovery.

5.1. Productivity and competitiveness

The direct consequences of the Brexit bargaining process on national trade should be initially acknowledged in terms of productivity and competitiveness.

Since 2015, trade has been a major concern, as the EU has always been the largest trading partner for the UK until Brexit (Dhingra *et al.*, 2016). In this regard, the agreement reached on 30th December 2020 assured that no tariffs or quotas would be implemented by either party (Part III: Separation Issues), with minor exceptions. At the borders, though, customs declarations and security checks would be implemented. Coupled with origin rules and regional variations in product safety and standard laws, these are some of the primary causes of non-tariff barriers (Dhingra *et al.*, 2016). Furthermore, policies affecting small businesses have an impact on exports since they now have to comply with paperwork and customs rules (Bailey *et al.*, 2023). In addition, the most significant impact in the services sector is that British firms will lose their automatic right of access to EU markets and will have to comply with different regulations in each country. Although inherently more complex to measure, the impact is far-reaching: Byrne and Rice (2018) estimated a 9.6% decline in trade flows, and a similar result (10%) was found by Ottaviano *et al.* (2014), taking into account the potential loss from further non-tariff barrier reduction for EU Member States. However, some scholars consider these figures to be overvalued, as the benefits from the single market have been weaker for the UK than for the average of EU Member States (Coutts *et al.*, 2018).

Competitiveness is directly related to the parameter of productivity: in fact, a smaller market would reduce competitive pressure. According to classical international trade theory (Krugman *et al.*, 2009), the results would consist in the survival of the less efficient firms in the market and a decline in productivity growth. The latter, in its value-added measure, is estimated to have fallen by about 1% per year after 2016, when Brexit negotiations began, for firms less affected by them. On the one hand, as employment did not fall, labour productivity decreased (Bloom *et al.*, 2019). On the other, as expected, the most productive firms were the most affected by the Brexit bargaining process (Krugman *et al.*, 2009). Indeed, these firms typically have the highest propensity to trade. Therefore, Brexit negative effects on trade led to a decline in their productivity, with several sectors experiencing decreases up to 2.27%, including textiles, chemicals, motor vehicles, and electronics (Latorre *et al.*, 2020).

Brexit-related challenges have resulted in a considerably smaller market for UK businesses to offer their goods and services which has caused them to lose economies of scale and negatively influenced their efficiency (Mathieu, 2020). Since significant investments may only be amortised in the event of strong sales, a lower degree of economic openness would hence hinder the kind of technological innovation and the ability to import it. As a result, uncertainty becomes a crucial factor affecting the scale of investment decisions (Fuss and Vermeulen, 2008). The unpredictability generated by the Brexit deal bargaining has gradually reduced investments by approximately 11% over the three years following the June 2016 vote (Bloom *et al.*, 2019). Additionally, preparations to complete all the time-consuming Brexit processes, which opened different scenarios, also had a negative impact on firms' time management. In this respect, Bloom *et al.* (2019) have pointed out that between November 2018 and January 2019, 10% of the CFOs and 6% of the CEOs spent more than 6 hours per week preparing for Brexit. As a consequence, less productive companies entered the British market due to protectionist policies and lower levels of imports, resulting in less competition (Latorre *et al.*, 2020). On the one hand, this would have a lasting impact not only on the current GDP level, but also on the GDP growth rate. On the other, productivity growth is already slowing down in more advanced countries (Bergeaud *et al.*, 2016). Therefore, the impact of economic openness on productivity may be lower than expected (Mathieu, 2020). However, while comparable data on the gross value added at basic prices, gross fixed capital formation, and compensation of employees are not available for the UK, the share of human resources in science and technology is still lower than in the rest of the Blue Banana, but with a significant increase in the 2010–2019 period compared to 2000–2009 (see Tables in the Appendix). In this respect, as in the case of Italy, it is worth considering the issue of pollution as well. Since Brexit, water corporations have been allowed by the government to discharge untreated wastewater into the environment due to the lack of treatment chemicals. Consequently, raw sewage has been circulating in UK rivers and in the sea.

5.2. Infrastructures

In terms of infrastructure, the agreement on transport commits both parties – the EU and the UK government – to continue to provide air, road, rail, and maritime connectivity, although market access is now more difficult for the UK than for the EU member states participating in the single market. This is clear in the domain of air transport, which is crucial for the UK, with Heathrow being the first international airport in Europe by number of passengers before Brexit (Airports Council International, 2015). Indeed, it is worth remembering that the UK has left the 2007 Open Skies agreement between the US and the EU, which ensured that aircrafts did not require extra regulatory clearance to operate between participating nations. The EU continues to play a significant role in this domain, even though the matter is frequently governed at the United Nations (UN) level.

As far as standards on interoperability in the railway sector are concerned, trains should be able to run on all EU rail systems. Nevertheless, the UK may find it convenient to use its different local infrastructures. The new Intercity Express Programme train, for example, has been specifically designed to run on British railways (Rosewell, 2017). In this respect, most of the UK's infrastructure is owned and operated by private entities. While these entities may see it as advantageous to avoid EU standardisation practices to enhance their profits, in turn, such a choice would undoubtedly reduce connectivity with the rest of the Blue Banana region and across Europe.

5.3. Employment and welfare

The phenomena analysed above have a direct impact on the living standards of British citizens. This can be seen in the reduced availability of inexpensive imported goods produced by European companies, leading to a greater reliance on less efficient domestic firms. In addition, leaving the EU has hit the country in terms of prosperity, as measured by GDP per capita. According to Dhingra *et al.* (2016), the savings from lower fiscal contributions to the EU budget are outweighed by the drop in per capita income from decreased trade. As previously mentioned, the effects of the COVID-19 pandemic and the Brexit process are intertwined, thus focusing solely on the decline in one aspect would be deceptive. However, prior to the pandemic, most studies concurred that the GDP should decline by 1% to 6%. For instance, Latorre *et al.* (2020) modelled a welfare loss of 3.17% in 2020 in the '*hard Brexit*' scenario, while Booth and Shankar (2018) predicted a loss of 2.2% (a similar reduction of 3.2% was predicted by Kierzenkowski *et al.*, 2016).

The consequences for the labour market are evident: when the employment rate in the UK is higher than in the rest of the Blue Banana, the gap will narrow due to both an increase in unemployment in the European Backbone areas and a decrease in the UK regions (Table 3). Moreover, while the involved UK regions had a significantly lower share of NEETs[11] and early leavers from education[12] in the 2000–2009 period, this advantage is no longer significant as the timeframe in 2010–2019 shows (Table 3).

[11] "Not in employment, education or training", young people aged 15 to 29.

[12] Defined as persons aged 18 to 24 who meet the following two conditions: (a) the highest level of education or training they have completed is ISCED 2011 level 0, 1 or 2 (ISCED 1997: 0, 1, 2 or 3C short), corresponding to lower secondary education, and (b) they have not received any education or training (i.e. neither formal nor non-formal) in the four weeks preceding the survey.

5.4. Attractiveness and migration

Migration was one of the main issues prompting British voters to choose against the permanence in the European Union (Burrell and Hopkins, 2019).

On top of the consequences of UK companies leaving the Blue Banana, Brexit has introduced visa fees for European citizens who want to move to the UK, leading them to no longer consider the UK as part of the common area in which the core European characteristic of free movement of people is enacted (Galpin, 2017). In this sense, the Brexit negotiation process has posed a threat to the concept of the Blue Banana itself, not only in terms of the UK's alleged reduced competitiveness, but especially concerning the connectivity and the subsequent common sense of belonging to a European productive area.

The consequences of lower migration are negative in terms of the labour force, which is expected to experience a reduction of 2.5% by 2030 (Mathieu, 2020), thus leading to a decreased productivity rate, due to the lack of skilled workers. Moreover, even low-skilled wages are not expected to grow significantly (Portes and Forte, 2017). Therefore, the UK launched brand new visas to propel attractiveness to highly skilled individuals – the "Global Talent visa". This scheme received a number of applications from EU countries which was below expectations (Torjesen, 2020). A more focused and restricted scheme for Nobel prizes instead received zero applications, with academics and Nobel laureates themselves sarcastically labelling such an initiative (Murugesu, 2021). Although the UK's attention to the topic of attractiveness is to be praised, probably any new beneficial visa scheme is less favourable than the EU freedom of movement per se, both in terms of economic and social security conditions, as well as the general sense of being welcome (Marini, 2024).

Another contributing factor influencing migration patterns is the current trend of internationalised education. Delving into this matter, the UK national economy has recently placed an increasing amount of value on higher education institutions' competitiveness. This phenomenon augments the prospects of long-term viability for the institutions, distinguishing them from those lagging behind in the competitive landscape (Labas *et al.*, 2016).

After years of uncertainty about which status, if any, the UK would have in the future within EU funding schemes, on 7th September 2023, the UK re-entered the EU Horizon and Copernicus (but not Euratom) schemes as an Associate Country – a status already in place for non-EU members like Norway and the Swiss Confederation. Whilst this agreement ends one of the most pernicious elements of the post-Referendum period (uncertainty), and potentially restores the UK reputation, it does not give back FoM. At the same time, these first seven years of post-Referendum exacerbate the need for empirical analysis about its effects (Martini, 2024).

6. CONCLUSIONS

A full analysis of the Blue Banana concept necessitated considering recent events in both the southern and northern sections of the area, that is Brexit and Northern Italy's declining competitiveness in the market. We attempted to project these two regions' future roles within the European economic framework and inquired as to whether they can still be regarded as parts of Europe's most productive core. As far as Northern Italy is concerned, we found a positive answer in terms of urbanisation and infrastructure, but both negative and positive in terms of (un)employment. Finally, the answer was negative for productivity and competitiveness, together with a short insight into the problem of pollution.

Despite the preliminary nature of our findings for London's region, we can conclude that the UK's new immigration and infrastructure policies pose a serious threat to the cohesion of the entire Blue Banana area, in addition to making the country less productive and competitive. Considering the pandemic's effects on the economy, it has been demonstrated that these deficiencies have an impact on the productive centres of all participating nations.

Therefore, a more prominent role for the EU institutions, together with the coordination of its Member States in the harmonization of the competition policy, seems inevitable. First and foremost, European monies ought to support the development of infrastructure and the linkage of the Italian regions with the rest of the Blue Banana. Furthermore, the Trade and Cooperation Agreement between the United Kingdom and the European Union may strengthen regional cohesion if the competition policy is properly implemented and monitored. In this context, the restrictions of the post-Brexit immigration policy should be lifted, or at least reduced, to allow a smoother circulation of labour across the regions. In addition to the evolving contexts of the fields analysed in the present paper, ranging from urbanisation to competitiveness, future studies could examine the wage gaps in the territory under consideration, as well as the different levels of poverty and other factors that hinder the full cohesion of the area. A thorough analysis of the Blue Banana's eastward dynamics is also necessary. These components can offer some hints about future development in the area.

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APPENDIX

Table 1. Descriptive statistics for NUTS-2 regions in the Blue Banana and outside of the area for the decades 2000–2009 and 2010–2019.

2000–2009	Mean (not in Blue Banana)	Std. Dev.	Mean (in Blue Banana)	Std. Dev.	Difference in Means	Std. Error	Unit
Labour market							
Employment rate	64.63	8.29	68.23	5.37	3.60***	0.02	%
NEET rates	13.75	6.74	10.95	2.84	-2.80***	0.01	%
Early leavers from education	17.11	10.45	15.46	4.73	-1.65***	0.02	%
Innovation							
GERD	165.55	268.66	250.92	327.87	85.38***	1.33	
Patent applications	88.09	112.63	205.02	138.59	116.93***	0.55	Number/mn inhabitants
High-tech patent applications	18.98	36.84	33.14	26.54	14.16***	0.11	Number/mn inhabitants
EUTM applications	95.14	143.99	132.44	58.27	37.29***	0.29	Number/mn inhabitants
Productivity							
Gross VA at basic prices	102,630.71	337,408.25	110,481.23	124,375.98	7,850.52***	663.48	
Employment in technology and knowledge-intensive	16.27	21.85	16.66	21.60	0.39***	0.08	% of total employment
HRST	1,000.56	3,290.50	757.88	905.23	-242.68***	4.99	% of total population
Gross fixed capital formation	1,000.56	3,290.50	757.88	905.23	-242.68	4.99	
Compensation of employees	54,675.82	180,899.66	57,539.74	66,541.84	2,863.92***	358.13	
Competitiveness-enhancing characteristics							
Manufacturing firms	24,525.24	57,114.95	13,148.51	26,313.08	-11,376.73***	147.83	Number
Population density	360.20	842.92	323.93	232.57	-36.27***	1.28	Inhabitants/km^2
Motorways	722.54	1,623.35	678.16	696.49	-44.38***	3.92	km
Railways	2,792.24	5,193.99	1,469.63	1,087.02	-1,422.62***	9.70	km

2010–2019	Mean (not in Blue Banana)	Std. Dev.	Mean (Blue Banana)	Std. Dev.	Difference in Means	Std. Error	Unit
Labour market							
Employment rate	64.50	5.51	70.48	9.79	5.98	0.00	%
NEETs rates	15.90	4.01	12.07	8.09	-3.84	0.00	%
Early leavers from education	13.74	3.10	11.18	9.86	-2.56	0.00	%
Innovation							
GEERD	288.40	203.45	541.12	249.86	252.72	0.00	
Patent applications	178.14	224.70	376.44	192.92	198.30	0.00	Number/mn inhabitants
High-tech patent applications	34.38	35.03	48.65	48.51	14.28	0.00	Number/mn inhabitants
EUTM applications	128.49	72.25	193.63	125.20	65.15	0.00	Number/mn inhabitants
Productivity							
Enterprise birth rates	10.38	1.84	7.33	3.01	-3.05	0.00	See Notes
Gross VA at basic prices	84,352.36	155,379.72	110,403.05	187,434.57	26,050.69	0.04	
Employment in technology and knowledge-intensive	3.48	1.08	2.99	1.81	-0.49	0.00	% of total employment
Gross fixed capital formation	19,553.99	34,457.52	24,525.79	43,397.40	4,971.79	0.08	
Compensation of employees	43,567.58	81,152.66	55,418.73	99,595.28	11,851.15	0.08	
Competitiveness-enhancing characteristics							
Manufacturing firms	573.63	75.03	730.30	361.69	156.67	0.00	Number
Population density	163.35	180.83	300.91	167.06	137.56	0.00	Inhabitants/km^2
Motorways	12,050.73	57,796.91	18,960.46	24,678.87	6,909.73	0.00	km
Railways	1,174.27	3,689.17	2,036.06	752.47	861.79	0.00	km

Source: our work from Eurostat database.

Table 2. Descriptive statistics for NUTS-2 regions in the Blue Banana and in the part of Northern Italy belonging to the Blue Banana for the decades 2000–2009 and 2010–2019.

2000–2009	Mean (in B.B. except Italy)	Std. Dev.	Mean (North Italy)	Std. Dev.	Diff. in Means	Std. Error	Unit
Labour market							
Employment rate	69.45	5.55	65.01	3.12	-4.44***	0.03	%
NEET rates	10.97	3.06	10.88	2.15	-0.10***	0.02	%
Early leavers from education	14.08	3.35	19.24	5.78	5.16***	0.04	%
Innovation							
GERD	303.24	368.60	125.52	131.22	-177.72***	1.96	
Patent applications	242.65	144.93	108.95	42.17	-133.70***	0.72	Number/mn inhabitants
High-tech patent applications	41.57	26.42	11.61	8.67	-29.96***	0.13	Number/mn inhabits
EUTM applications	136.09	57.47	123.12	59.23	-12.97***	0.50	Number/mn inhabitants
Productivity							
Gross VA at basic prices	126,358.85	138,456.14	81,493.30	86,098.25	-44,865.56***	914.39	
Employment in technology and knowledge-intensive	16.65	21.66	16.68	21.43	0.04	0.18	% of total employment
HRST	865.51	998.53	474.53	490.98	-390.98***	5.38	% of total population
Gross fixed capital formation	865.51	998.53	474.53	490.98	-390.98***	5.38	
Compensation of employees	70,470.00	75,237.44	33,932.82	36,256.99	-36,537.18***	453.96	
Competitiveness-enhancing characteristics							
Manufacturing firms	6,522.09	11,913.60	45,634.90	46,049.11	39,112.81***	511.36	Number
Population density	374.57	245.40	190.58	115.81	-183.99***	1.30	Inhabitants/km^2
Motorways	2,421.09	850.68	414.06	223.16	-465.86***	5.63	km
Railways	2,421.09	991.68	868.88	611.75	-1,552.22***	9.91	km

2010–2019	Mean (in B.B. except Italy)	Std. Dev.	Mean (North Italy)	Std. Dev.	Diff. in Means	Std. Error	Unit
Labour market							
Employment rate	68.61	6.42	66.10	2.88	-2.51***	0.30	%
NEET rates	12.57	4.10	16.09	3.63	2.01***	0.23	%
Early leavers from education	10.83	2.79	12.85	3.63	2.01***	0.23	%
Innovation							
GERD	680.70	151.18	407.28	134.95	-273.42***	25.01	
Patent applications	212.97	125.03	109.66	45.85	-103.31***	13.90	Number/mn inhabitants
High-tech patent applications	30.37	16.61	9.76	5.12	-20.61***	1.82	Number/mn inhabitants
EUTM applications	202.17	67.00	168.20	64.57	-33.97	9.32	Number/mn inhabitants
Productivity							
Enterprise birth rates	9.65	0.89	6.10	0.60	-3.56***	0.08	See Notes
Gross VA at basic prices	133,107.93	204,553.18	92,743.70	97,665.32	-40,364.23***	13,263.92	
Employment in technology and knowledge-intensive	2.80	1.25	3.16	0.87	0.36***	0.09	% of total employment
HRST	19.82	3.51	18.37	1.52	-1.45***	0.22	% of total population
Gross fixed capital formation	31,143.44	46,330.33	19,378.72	19,353.27	-11,764.72***	2,950.67	
Compensation of employees	74,197.06	109,488.81	40,813.35	43,149.49	-33,383.71***	6,927.15	
Competitiveness-enhancing characteristics							
Population density	218.46	154.89	192.40	118.22	-26.06*	10.67	Inhabitants/km^2
Motorways	21,351.24	33,916.34	5,144.32	6,521.63	-16,206.92***	1,995.51	km
Railways	1,557.11	727.20	936.79	631.93	-620.33***	55.77	km

Table 3. Descriptive statistics for NUTS-2 regions in the Blue Banana and in the part of the Blue Banana in the UK for the decades 2000–2009 and 2010–2019.

2000–2009	**Mean (in B. B. except UK)**	**Std. Dev.**	**Mean (UK)**	**Std. Dev.**	**Diff. in Means**	**Std. Error**	**Unit**
Labour Market							
Employment rate	66.17	4.14	75.44	1.81	9.27***	0.02	%
NEET rates	11.32	2.85	9.64	2.37	-1.68***	0.02	%
Early leavers from education	15.80	4.75	14.38	4.48	-1.42***	0.04	%
Innovation							
GERD	197.89	267.96	429.98	431.79	232.09***	3.74	
Patent applications	221.66	153.30	156.05	58.01	-65.61***	0.81	Number/mn inhabitants
High-tech patent applications	28.83	24.64	45.82	27.84	16.99***	0.24	Number/mn inhabitants
EUTM applications	134.78	59.44	125.53	54.09	-9.25***	0.49	Number/mn inhabitants
Productivity							
Employment in technology and knowledge-intensive	16.61	21.31	16.84	22.57	0.24	0.20	% of total employment
HRST	847.52	1,006.20	443.63	126.18	-403.89***	4.20	% of total population
Competitiveness-enhancing characteristics							
Manufacturing firms	16,437.36	31,043.35	5,735.03	1,218.84	-10,702.33***	169.63	Number
Population density	292.77	189.48	432.94	320.07	140.17***	2.55	Inhabitants/km²

2010–2019	Mean (in B-B. except UK)	Std. Dev.	Mean (UK)	Std. Dev.	Diff. in Means	Std. Error	Unit
Labour market							
Employment rate	68.99	5.25	73.53	2.99	4.54***	0.18	%
NEET rates	12.19	4.14	12.22	2.42	0.04	0.14	%
Early leavers from education	12.38	3.54	12.52	4.03	0.14	0.19	%
Innovation							
GERD	243.74	333.44	350.87	391.01	107.13***	24.88	
Patent applications	194.84	126.94	114.14	53.79	-80.71***	5.33	Number/mn inhabitants
High-tech patent applications	21.28	17.62	27.89	15.10	6.61***	1.05	Number/mn inhabitants
EUTM applications	201.12	68.23	150.14	66.63	-50.98***	4.43	Number/mn inhabitants
Productivity							
Employment in technology and knowledge-intensive	3.60	1.26	6.19	2.17	2.59***	0.09	% of total employment
HRST	861.81	1,030.94	631.02	180.65	-230.78***	26.80	% of total population
Competitiveness-enhancing characteristics							
Manufacturing firms	18,482.45	23,442.45	4,383.02	1,105.25	-14,099.43***	624.82	Number
Population density	281.08	186.95	1,904.68	3,068.07	1,623.61***	127.92	Inhabitants/km^2

Source: our work from Eurostat database (2021).

OTHER FIGURES

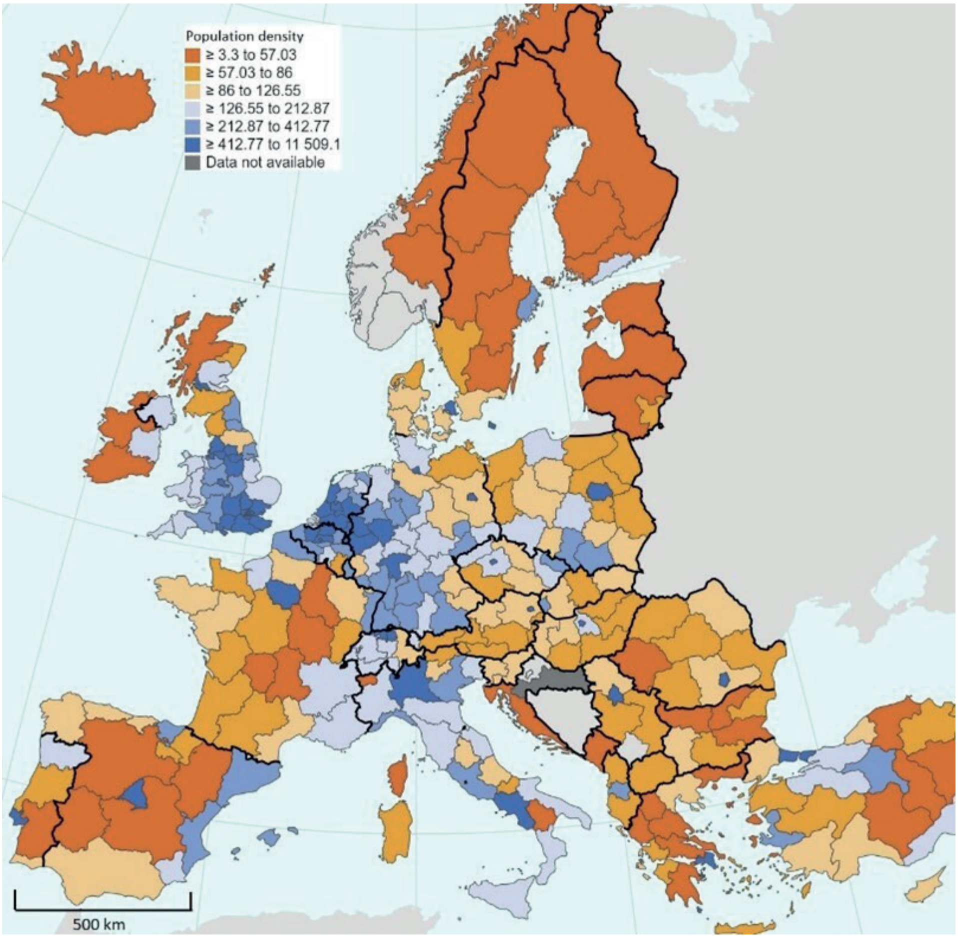

Fig. 1. European population density map in NUTS-2 regional breakdown in 2019
Source: own work based on Eurostat data.

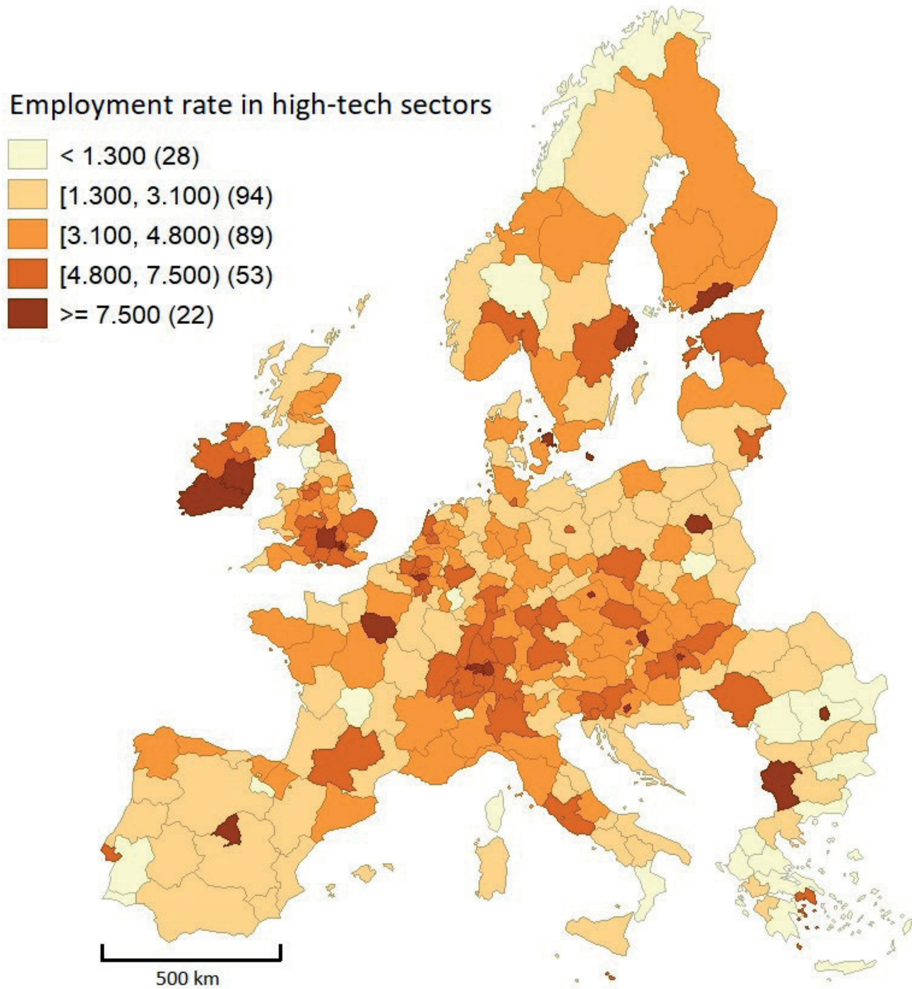

Fig. 2. Employment in high technology and knowledge-intensive sectors as the percentage of total employment in the NUTS-2 European regions in 2019

Source: own work based on Eurostat data.

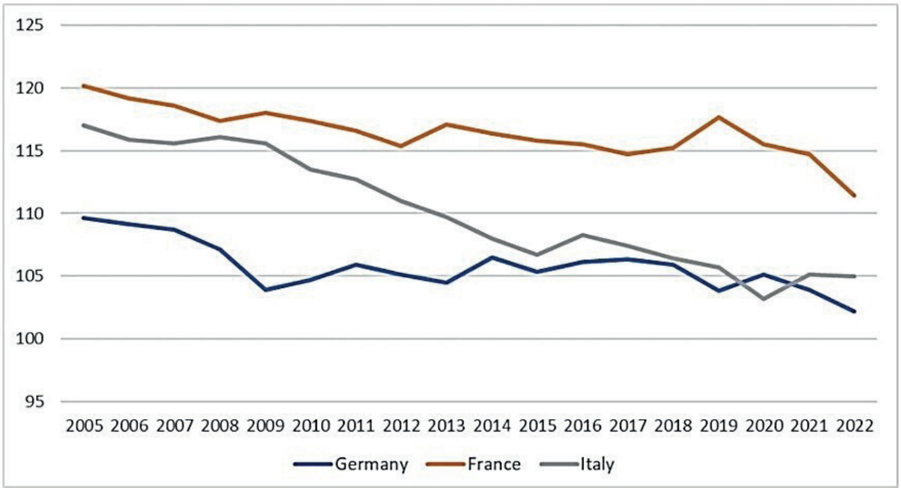

Fig. 3. Labour productivity in Germany, France, and Italy as the percentage of the EU27 average each year between 2005–2022

Source: own work based on Eurostat data.

Notes: Regions of the NUTS-2 area included in the Blue Banana are described in Fig. 1 (right). It is worth considering that the regions of Switzerland also were not considered as they are not part of the Eurostat database. NEET stands for "Young people (aged 15–29) neither in employment nor in education and training", GERD stands for Gross domestic expenditure on Research and Development, EUTM for European Union trademarks, HRST for Human Resources in Science and Technology. Birth rate is defined as the number of enterprise births in the reference period divided by the number of enterprises active in the same period (in percentage). For the exact definition of the variables, see Eurostat website. The (unweighted) means are calculated over the 2000–2009 period (Table 1) and 2010–2019 (Table 2) for all NUTS-2 regions, except for Patent applications and GERD and patent application (for which the latest data refers to the mean refers to 2002–2012) and EUTM applications (for which the latest data refers to 2005–2015). Data on the enterprise birth ratio is collected from 2011 on. The NACE classification of economic activities changed in 2008, so data for the employment considered as technology and knowledge-intensive and the share of manufacturing firms cannot be compared for the 2000–2009 and 2010–2019 periods (but they can still be compared in the same period). Moreover, there is comparable data for the UK until 2019 for the Employment rate, the NEET rate and the early leavers from education, while the other data is collected only until 2016, when the Brexit referendum took place.

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THE GEOGRAPHY OF INDUSTRY 4.0 IN A POST-TRANSITION COUNTRY: COMPARING FIRMS ACROSS POLISH REGIONS

Abstract. The ubiquitous nature of the technologies of Industry 4.0 (I4.0) might seemingly make geographic location not matter, leaving regional aspects unimportant. This is due to the common assumption that I4.0 technologies and solutions are agnostic about regional equipment and that their peculiarities are space neutral. In this paper, we conduct a comparative analysis of the regional aspects of the fourth industrial revolution in Poland.

The results of our comparative study indicate that the highest degree of saturation in new technologies of I.40 (RDM) is in these regions which are successful in representing high / medium-high technology industries – successfully selling advanced products in high and medium-high technology sectors and are locations of firms that care for their staff and train employees, invest in HR development.

Key words: regions, Industry 4.0, Poland, digital technology, comparison.

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1. INTRODUCTION

The ubiquitous nature of the technologies of Industry 4.0 (I4.0) might seemingly make geographic location not matter leaving regional aspects unimportant. This is due to the common assumption that I4.0 technologies and solutions are agnostic about regional equipment and their peculiarities are actually space neutral – they can be applied anytime, anywhere. Smit *et al.* (2016) defined the term I4.0 as novel products, processes and technologies applied in the management and organisation of firms' value chains. Laffi and Boschma (2021) have argued that technological paradigm 4.0 is not characterised by a single and easily identifiable technology but it stands for a set of very different technologies (Ménière *et al.*, 2017; Popkova *et al.*, 2019). I4.0 technologies often combine advanced 3.0 technologies (both hardware and software) with technologies pertaining to different application domains. They offer flexibility, improve efficiency alongside the value chain and enable production to be synchronised by integrated ICT systems, replacing traditional isolated production with fully automated and integrated industries (Pelle *et al.*, 2023).

Scholars have a growing perception that the regional dimension along the qualitative study approach needs to be incorporated to fully reflect the far-reaching consequences of the ongoing trends (De Propris and Bellandi, 2021). The literature on the regional dimension of digital transformation is slowly increasing, yet it is evidently dominated, if not monopolised, by studies on advanced regions. It is widely known that all industrialised countries have defined their national programs to facilitate the development of Industry 4.0. In Asia, the leading countries are South Korea, China, and Japan. In 2014, South Korea launched its "Innovation of Manufacturing 3.0" (Kang *et al.*, 2016), China developed the "Made in China 2025" program, and in 2015 Japan announced the "Super Smart Society" plan (Kang *et al.*, 2016; Phuyal *et al.*, 2020). Quite similar attempts are visible in European Union countries. In the EU the Digital Single Market industry-related initiative package has been established and resonates with the EU agenda priorities for 2019−2024. Particularly, EU countries being on the route to Industry 4.0 have established their national programs − Italy has implemented the Piano Industria 4.0, Portugal the i4.0 program, Spain the Industria Conectada 4.0, Austria the Industrie 4.0, Germany the Digital Hub program, the UK the Catapult program, France, in Poland − national program oriented to digitise manufacturing. The development of such programmes at the national and supranational levels reflects the significance of digitisation, especially for the manufacturing sector. These programmes need to be translated to lower levels and their priorities need to be incorporated into the strategies of regions. We hope to address the existing literature gap with our exploration devoted to Poland – a CEE country.

Poland is regarded as a post-transition or semi-periphery country affected by the legacy of communism, described as representing Dependent Market Economy (DME) model of capitalism, heavily based on FDI (Drahokoupil-Myant, 2015). Poland, with its pre-1990 legacy, is below the European average in terms of innovation and digitalisation in manufacturing and is characterised by huge internal differences between the more developed western part of the country and the east (Churski *et al.*, 2021). These differences, which are reflected in the current spatial diversity of socio-economic development levels in Poland, are significantly influenced by historical conditions, especially those resulting from the 18th-century partitions of Poland between three powers (Russia, Prussia, and Austria). Moreover, the spatial differentiation of socio-economic development in Poland at the local level is increasingly influenced by the polarisation of development processes in cities and their functional areas, which results in the marginalisation of many rural areas and contributes to their marginalisation (Churski *et al.*, 2021).

In our opinion, Poland indeed deserves special attention as the (post) transition economy of CEE. According to the DESI 2022 Poland performs quite poorly being positioned 24th among 27 EU countries [EU (2022)], DESI Poland (https://digital-strategy.ec.europa.eu/en/policies/countries-digitisation-performance, accessed on: 23.02.2024).

In this paper, we conduct a comparative analysis of the regional aspects of the fourth industrial revolution in Poland. We want to examine the factors determining the geography of Industry 4.0 in the country, in particular, by establishing if there are any differences and regularities in I4.0 performance among Polish regions or rather geographic distribution is irrelevant to firms' performance in terms of their digital maturity. If yes, then would like to go deeper and check if there is a pattern suggesting that strong regions help and offer a booster for I4.0 development or rather weak regions cast a shadow – i.e., being embedded in an unpleasant and unfavourable environment hinders the implementation of Industry 4.0.

2. LITERATURE REVIEW AND CONCEPTUAL UNDERPINNINGS

2.1. The adoption of I4.0 technologies among regions – what do we know up until now

In our investigation, we adopted a traditional/narrative literature review of previous studies in line with Grant and Booth (2009). This involved collecting existing relevant research, then excluding papers of inferior quality, and synthesising the key findings from the field to date. This approach, as emphasised by Grant and Booth (2009), allowed for a fairly wide range of topics to be covered with varying degrees of depth and breadth, with different narrative lenses being adopted, and consequently allowed for some advancement of knowledge in a given area of research. As highlighted by Andersen *et al.* (2024), a narrative literature review relies on expert knowledge and is suitable for exploratory evaluations and the synthesis of findings from different perspectives, thus also allowing for the creation of new perspectives (Gancarczyk, 2019; Sovacool *et al.*, 2018; Torraco, 2005).

The term Industry 4.0 is associated with the fourth industrial revolution. That revolution manifests itself by the adoption of a bundle of new technologies, such as cyber-physical systems (CPS – a combination of physical and digital spaces) (Ciffolilli and Muscio, 2018), the Internet of Things (IoT) and the Internet of Systems (Morrar *et al.*, 2017), additive Manufacturing, Big Data, Artificial Intelligence, Cloud Computing, Augmented and Virtual Reality and Blockchain, Cybersecurity, and 3D printing. These technologies facilitate a profound transformation in the corporate sector which is reflected in the changes in the relationships within and across ecosystems in which companies operate and in how firms run their businesses. The firms are established in particular locations which may be linked to the regional dimension. Thus, the level of the adoption of the I4.0 technologies by firms in a particular region translates to regional digital maturity. The exploitation of those novel solutions reflects how mature in terms of digitalisation a region is.

It is not a novel message that the territory matters for firms' innovativeness (Beaudry and Shiffauerova, 2009). Corradini *et al.* (2021) have, by focusing on patent data for four technologies at the core of I4.0 between 2000 and 2014, provided evidence of their uneven distribution across NUTS-2 European regions and confirm the role of regional absorptive capacity, and cognitive and spatial proximity as drivers of I4.0 knowledge flows.

Micek *et al.* (2022) have investigated whether the fourth industrial revolution or I4.0, do not provide new opportunities for old industrial regions to dynamise new paths of development. One of the Polish regions, i.e., Silesia, represents an atypical transformation towards a high-technological Industry 4.0 path. An active innovation policy and system-level agency enabled the dynamic growth of the Industry 4.0 subsector as the conjuncture of the IT sector and the automotive industry. Crucial for the Silesian path diversification towards the I4.0 pathways are the related variety, existing regional assets, knowledge flows from the outside, and the development of a public-driven side of RIS; in short, new policy instruments and tailor-made organisations.

Götz (2021) conducted a qualitative study on 36 clusters in Germany and demonstrated that local knowledge and the presence of local institutions had been crucial factors that made the I 4.0 solutions attractive for cluster companies. Isaksen *et al.* (2020) focussed on two clusters in Norway that dealt with three categories of digitalisation. Those studies have revealed that mature districts can move more towards digitalisation in the presence of strong policies that support the cooperation among firms and universities and the training programs for firms' employees (Isaken *et al.*, 2020). Ingaldi and Ulewicz (2020) studied the adoption of automation and robotics by the metal and metallurgical SMEs belonging to the district of Czestochowa region in Poland and pointed to difficulties related to that process. It appeared that within a cluster operating in that region humans were substituted by I4.0 technologies and robots. That calls for investment to adjust production processes to these new technologies. Other authors express that the existence of clusters or traditional industrial districts, and in particular inter-firm linkages matter for the adoption of I4.0 technologies (De Propris and Bailey, 2020; Hervás-Oliver *et al.*, 2019; Lepore and Spigarelli, 2020). The adoption level may be even more upgraded when there are linkages with foreign entities. These linkages play a role in terms of knowledge exchange.

A case study of Ontario, Canada, and Massachusetts, USA, shows how adequate policies and collaboration can facilitate I4.0. Baker, Gaspard and Zhu (2021) stressed the role of four principal factors: industrial clusters, context, collaborative synergies, and network intermediaries. Balland and Boschma (2021) have showed that European regions with a high potential in terms of I4T-related technologies are more likely to diversify successfully in new I4Ts. Case studies of regions show how I4.0 is transforming local productive systems (Bellandi *et al.*, 2020; De Propris and Bailey, 2020). German, French, and British regions reveal the highest probability of developing I4Ts in the future, while many European regions show a weak potential to contribute to new knowledge production in I4Ts. Nevertheless, these authors found no single geography of I4T in Europe, but many because I4Ts rely on different related technologies that are also located in different regions in Europe. In other words, the geographies of specific I4Ts in Europe tend to reflect the geographical distributions of their most relevant regional capabilities. Thus, it is recommended that public policy intervention that aims to develop I4Ts takes the particular I4T potentials that the region possess as a point of departure. Thus, since the risk of policy failure is high, Balland and Boschma (2021) have argued that regions with a low or no I4T potential should think twice before investing public funds in I4Ts. Public policy should target those regions that have related I4T capabilities as these provide local assets that might be exploited to make the policy effective. The existence of an ecosystem of related technologies is the prerequisite for the effective exploitation of I4T technologies. The growth of those technologies needs to draw on the specific knowledge bases in regions (Balland *et al.*, 2019).

Hervás-Oliver *et al.* (2021) provided a deep dive into the nascent European Commission (EC) digital innovation hub (DIH) program designed to foster transition into Industry 4.0. The obtained results suggest that DIHs despite their trial-and-error stage are designed to stimulate the advancement of I 4.0 by promoting place-based collaboration alliances that respond to local contextual specificities and demands. DIHs launched in 2016, aimed at creating digital innovation ecosystems in all member nations for the purpose of facilitating digital change. DIHs as "one-stop-shop" help companies to become more competitive with regard to their business/production processes, products or services using digital technologies and operate as if they were digital-dedicated regional clusters or ecosystems to help regional firms to transit towards digitisation. When focusing solely on EU Member States, the countries with the largest number of supportive hubs are as follows: Spain (68), Germany (55), Italy (51), and France (56). These hubs range from those led by accelerators, public universities, regional governments, and public technology transfer organisations to others led by clusters and even SMEs.

Ciffolilli and Muscio (2018) have deployed for studying the geography of I4.0 as a specific proxy of such I4.0 technologies the facts and figures on related Horizon 2020 programmes implemented across EU regions. They showed that research networks in Europe, even in the case of I4.0 were rarely evenly distributed, which raised some concerns considering that the EC for years has been trying to reduce the wide regional differences in R&I performance across the EU. Hence, the H2020 programme besides helping Europe to produce world-class science and technology that drives economic growth aims to contribute to reducing the significant R&D disparities within the EU. Regional EU exploration by Ciffolilli and Muscio (2018) has revealed that capacities in I4.0 remain strongly concentrated not only at an international level but also within Member States. The divide between North-Central Europe and South-Eastern Europe, which is a weakness of the EU framework programmes for R&I, is exacerbated in terms of I4.0 as many if not most Eastern European regions are excluded from these competitive research projects financed by Horizon 2020.

Dyba *et al.* (2022) found significant differences in 'digital readiness'. Their study showed that there are significant differences between European regions, mainly related to regional GDP and innovation levels. Unfortunately, the gap in industrial progress and productivity between the most innovative regions and the less prosperous European regions is likely to widen (see Orłowski, 2014). In order to learn more about the regional dimension of digital transformation, the efforts within ESPON are essential. ESPON is an EU-funded programme that bridges research and policy (https://www.espon.eu/about). It aims to support EU development policies, in particular the Cohesion Policy, and to help public authorities benchmark their regions or cities, identify new challenges and potentials, and design successful development policies for the future. ESPON, in cooperation with the European Commission and the Committee of the Regions, has developed LORDIMAS, an interactive digital maturity assessment tool to help local, metropolitan, and regional governments understand where they are in their digital transition journey (https://gis-portal.espon.eu/arcgis/apps/experiencebuilder/experience/?id=975e0dd3bcf84aa9810f0f5b5f7b9b65&page=page_18&views=view_104). However, this tool is not used for Poland due to the lack of appropriate data.

Given what we know so far about the regional dimension of digital transformation, we would like to draw attention to the following issues – key findings that emerge from our analysis. Firstly, it is striking that most studies use proxies for Industry 4.0, such as General Purpose Technologies (GPT) or Key Enabling Technologies (KET), data from HORIZON projects, etc., which interacts with the lack of a concrete definition of Industry 4.0 and reflects the multidimensionality of the issue. Secondly, although studies show that there is no single geography of Industry 4.0, which is a consequence of the lack of specific terminology and the above-mentioned multidimensionality, at the same time most reports confirm persistent regional disparities and growing spatial discrepancies with core-periphery patterns. Thirdly, it should also be stressed that, in addition to studies that describe the general landscape and geography of Industry 4.0 and assess the potential or maturity of regions, there are also studies that propose what should be done to make regions reorient themselves towards I4.0, to change their profiles, highlighting in particular what public support is needed in this regard, what resources are required, etc., and thus addressing regional issues in the context of the transformation of these regions, supported by appropriate policies.

2.2. Facilitators and inhibitors of I4.0 adoption – what are the factors within regions

The disruptive novelty brought about by the 4.0 paradigm relies on the appropriate recombination that leads to a radical change previously not affected by the 3.0 paradigm. Laffi and Boschma (2021) have showed that the relationship between 4.0 technologies and 3.0 technologies is quite heterogeneous, with some 4.0 technologies being technologically closer to the previous 3.0 technological paradigm than others. The diagnosed cumulative dimension between these two streams bears significant implications for the geography of I4.0 innovation in Europe as the probability of developing 4.0 technologies seems larger in those regions that are specialised in the production of 3.0 technologies. Pinheiro *et al.* (2022) found that low-income and low-complexity regions across Europe tended to be close to simpler technologies and industries, while high-income and high-complexity regions tended to be close to more complex technologies and industries. This implies that diversification may galvanise economic inequalities and polarisation processes across European regions. Peripheral regions need to explore opportunities to diversify into new activities that are related to local activities, preferably in new activities that would lift the overall complexity of their regional economies and policymakers should encourage the development of less complex activities that build on existing local capabilities (Balland *et al.*, 2019).

Those considerations suggest that regions whose economy is penetrated by industries exploiting more advanced technologies and providing products embedding more sophisticated technologies pretend to be leaders in terms of the fourth industrial revolution. The level of technological sophistication in an industry is important for the successful implementation of digital transformation for several reasons. More technologically advanced industries are better able to use cutting-edge technologies to outperform their competitors. They often have well-established systems that make it easier to integrate new digital solutions, while less advanced industries may require more effort to connect to modern technologies. Companies representing high-tech industries may already have a data-driven culture, which is essential for digital transformation (Kinkel *et al.*, 2022; Maroufkhani *et al.*, 2023). In such companies, one is more likely to find skilled professionals with expertise in digital technologies. In addition, technologically advanced industries may have more experience and resources to comply with new regulations on digital transformation, as well as more experience with demanding customers who expect digital engagement. In fact, companies belonging to high-tech industries are part of broader innovation ecosystems, making it easier to access resources, research, and collaboration opportunities for digital projects. It can, therefore, be argued that the level of technological sophistication of an industry influences the readiness, infrastructure, and culture required for successful digital transformation. Thus, the authors formulate the hypothesis (H1):

H1: The operation of firms in technologically sophisticated industries in a region is correlated with the adoption of I4.0 solutions in the region.

Isaksen and Rypestøl (2022) have argued that progress in the fourth industrial revolution of regions' industries requires relevant assets in firms and in the regional innovation system (RIS). Drawing on two dimensions, firm-level and system-level assets, four types of regions can be identified, which bear obvious implications for policymakers. Firstly, "low-potential regions" that have a low stock of relevant digital assets in both firms and the RIS; secondly, regions with a high stock of assets relevant for digitalisation in firms while without supportive RIS labelled as "firm-driven potential for digitalisation"; thirdly, the opposite "system-driven potential for digitalisation "regions showing a significant volume of RIS but not firm-level digital assets"; and fourthly, "high-potential regions" that are characterised by large stock of relevant assets in firms and RIS. Given the "potential" differences, distinction between actor-based and system-based policy approaches is necessary (Isaksen *et al.*, 2018). Whereas actor-based policy approaches include equipping actors such as firms, universities, or vocational schools, with the required capabilities to adopt or develop digital technologies, system-based policy approaches imply adapting the functioning of RISs so that they provide better support for digitalisation in existing and new firms for instance by ensuring that formal and informal institutions support digitalisation activities and contribute to resolving potential innovation system failures (Klein Woolthuis *et al.*, 2005). As digitalisation is "complex and involves a diverse set of actors it calls for a systemic approach" (Edler and Bonn, 2018, p. 433), "requires continuous adjustments and reflexivity among several involved stakeholders" (Bugge *et al.*, 2018, p. 468), and active governance. Labory *et al.* (2021) have reckoned that regions have to develop dynamic capabilities to successfully adapt to big disruptions such as I4.0. Dynamic capabilities can mediate between structure and agency in regional path development and promote value creation and capture. Since particular capabilities are embedded in particular actors, much in human resources the quality of them and the investment in the development of human resources is not to be overestimated. Appropriate human resource management plays a crucial role in the successful implementation of Industry 4.0, as these technologies often require employees to acquire new skills, such as data analytics, artificial intelligence and robotics (Behrens *et al.*, 2014; Benhabib and Spiegel, 2005). Successful implementation of I4.0 requires individuals with the right digital skills and knowledge, who can understand the specific roles and competencies required for digital transformation. This is even more important as the introduction of new technologies and processes can be disruptive, requiring support to help employees adapt to new ways of working, manage resistance to change, and ensure a smooth transition. In addition, successful digital transformation requires a shift in an organisation's culture towards innovation, adaptability and collaboration. Therefore, this culture needs to be shaped and nurtured by promoting values and behaviours that are aligned with the transformation goals. It also requires effective leadership that can guide the organisation through change and inspire its teams. Attracting and retaining talent is essential to keep employees motivated and committed to the organisation's digital journey. Finally, as digital transformation often involves the handling of sensitive data, ensuring compliance with data privacy and security regulations and educating employees on these issues is paramount. In summary, HR training and management appears to be key to the success of digital transformation initiatives, ensuring that the organisation has the right talent, culture and strategies in place to embrace change and maximise its benefits.

That is why the authors formulate the hypothesis (H2):

H2: The organisation of training for employees by firms in a region to improve the automation of production processes is correlated with the adoption of I4.0 technologies in the region.

Industrial districts (IDs), clusters, and urban agglomerations work as innovation systems. For IDs and clusters to facilitate the adoption of I4.0 technologies by incumbent firms the development of initial territorial conditions is crucial as they will enable the substitutions of the local workforce by machines. These aspects were indicated by Hervás-Oliver *et al.* (2019) in a paper on the ceramic tile district in the province of Castellon (Spain). Firms in that ID managed to implement digital solutions in their traditional manufacturing processes thanks to the support of *ad hoc* place-based industrial policies which helped to further develop the system of private and public relationships between the ceramic manufacturing industries and institutions. Clusters are conducive to I4.0 technology adoption since they are founded and value chains of entities which give rise to connectivity (Seetharaman *et al.*, 2019; Szalavetz, 2019). The adoption of I4.0 needs collaborations and compatibility among agents, thus the links to suppliers, customers, competitors, substitute providers, and other cluster incumbents may facilitate the adoption of I4.0 solutions (Schuh *et al.*, 2014; Crupi *et al.*, 2020; Ganzarain and Errasti, 2016). If a location is characterised by the presence of knowledge-intensive business services (KIBS), it can sustain the implementation of Industry 4.0 technologies within manufacturing firms (Corrocher and Cusmano, 2014; Shearmur and Doloreux, 2015) and it provides specialised support in the form of territorial servitisation (Lafuente *et al.*, 2017). The literature presents that regional features may help implement I4.0 solutions in manufacturing SMEs thanks to the promotion of multi-partner collaboration (Hervás-Oliver *et al.*, 2020). And the context supporting the multi-partner collaboration is the context of clusters. Regions may become the foundation for an innovation ecosystem to implement new technologies. The dynamics of adoption of I4.0 technologies may be influenced by the financial support and collective knowledge provisions which are institutional factors at the regional level (Pagano *et al.*, 2020) and clusters work often as repositories of that collective knowledge. There is a huge literature on how the existence of clusters may matter for the adoption of I4.0 solutions (see Table 1) and their importance is well documented in extant literature (Mackiewicz and Götz, 2024).

Table 1. Importance of clusters for the adoption of I4.0 solutions within regions and by companies

Dimensions and aspects of possible cluster role in advancing I4.0	**Research**
the technological maturity of companies requires not only access to technology but the proper organisation and context; integration of advanced technologies into manufacturing processes can be done quickly in a conducive environment offering technological, entrepreneurial, and government competencies; including social competencies and the digital literacy of staff.	Giuliani *et al.*, 2020; Mackiewicz and Pavelkova, 2022; Pelle *et al.*, 2020; Naudé *et al.*, 2019
I4.0 as a consistent combination of both technological and business aspects, contingent on an enabling industrial ecosystem and policy regime; adaptation of significant disruptions such as I4.0 requires the right structure and the agency for value creation and capture.	Labory and Bianchi, 2021; Ortt *et al.*, 2020
skilfully guided public policies; adoption of policy instruments; the network structure and government subsidy's role in crossing the valley of death (transformation of scientific and technological achievements); clusters as organisational vehicles for the diffusion of innovation achievements.	Teixeira and Tavares-Lehmann, 2022; Yin *et al.*, 2022
boundaries between firms are blurring; traditional value chain configuration implies joint participation, increased attention to competition and cooperation.	González-Torres *et al.*, 2020

Dimensions and aspects of possible cluster role in advancing I4.0	Research
changing market needs and increasing pressure for innovation; geographical proximity and interaction with other companies and external agents; micro-geographic proximity for the formation of knowledge transfer relationships and different types of inter-organisational relationships; the importance of the "neighbourhood effect"; cognitive proximity between firms; collaboration between businesses and industries, an alternative inter-organisational network driven by competition and cooperation.	Tavares *et al.*, 2021; Ferretti *et al.*, 2021; Molina Morales *et al.*, 2012; Yström and Aspenberg, 2017; Strand, Wiig, Torheim, Solli-Sæther, and Nesset, 2017
the positive effects of agglomeration related to knowledge transfer; the importance of social capital and local institutions; intermediaries in open innovation, mutual trust, compatibility, close cooperation, and standard rules; overcoming barriers; raising awareness of industrial associations, business organisations and cluster initiatives as knowledge gatekeepers, transfer intermediaries and mediators of spontaneous diffusion.	Jankowska *et al.*, 2021; Capello and Lenzi, 2014; Belussi, Sammarra, and Sedita, 2010; Molina-Morales, Capó-Vicedo, Teresa Martínez-Fernández, and Expósito-Langa, 2013; Ortega-Colomer, Molina-Morales, Fernández de Lucio, and Lucio, 2016; McPhillips 2020; Dyba, De Marchi, 2022

Source: adopted after Mackiewicz, M. and Götz, M. (2024), Table 1. Why & how clusters (cluster organisations) matter for I4.0.

Thus, the authors formulate the hypothesis (H3):

H3. The presence of clusters in the region is correlated with the adoption of I4.0 technologies among firms in the region.

3. RESEARCH SETTING AND DESIGN

3.1. Data, research variables, and research method

In our study, we purposefully explored factors determining the geography of I4.0, establishing the pattern of relations and defining the role of selected factors in advancing I4.0 in Polish regions.

We combine a critical literature review with quantitative empirical research. The literature review process used the SALSA (Search, Appraisal, Synthesis and Analysis) framework (Grant and Booth, 2009). To collect the primary data, we conducted Computer-Assisted Telephone Interviews (CATIs) and used a questionnaire. The questionnaire had 24 questions; the 5-point Likert and nominal dichotomous scales were applied. Since the aim was to investigate the geography of I4.0 in Poland, we tried to map the regions in Poland according to the I4.0 technologies adoption. The investigation on adopting I4.0 solutions across Polish regions somehow reflects certain initial conditions, i.e., in some areas, it is easier to implement, but in others, it is more complicated. And the level of that adoption may be associated with the regional digital maturity index (RDMI). That is a new measure created and applied for the purpose of that research (details how the index was developed are in Table 2). Thus, the empirical studies were based on primary and secondary statistical data. Information about the use of modern solutions in I4.0 published by Polish public statistics is very vague. It mainly is reduced to using computers and the Internet in their activities. Hence, it was reasonable to conduct our own survey considering modern solutions of I4.0. It was conducted on a representative sample of 400 industrial enterprises.

CATIs were conducted from November 2019 to January 2020 among large and mid-sized companies in Poland that operate in the manufacturing industry – according to the NACE Rev. 2.0. They followed the random selection of those entities. Prevalence (p) (a proportion of a population who have a specific characteristic in a given time period) – in our case, 0.663, i.e., a share of the largest (in terms of the number of employees) enterprises in the population. The margin of error (e) (a percentage that describes how close we can expect a survey result to be relative to the actual population value) – we took 5%. The sampling confidence level shows the reliability of the research (it is expressed as a percentage, which shows a level of certainty regarding how accurately a sample reflects the population within a chosen confidence interval) – in our case it's 90%.

The dependent variable is the adoption of particular I4.0 technologies by firms established in specific regions of Poland, which corresponds with the regional digital maturity index (RDMI) proposed by the authors (Table 2). The set of I4.0 technologies embraced eleven different solutions: Big Data Analytics, Digital Twin, Internet of Things, Cybersecurity, Cloud Computing, Additive Manufacturing, Virtual Reality, Mobile Technologies, and social media. In that matter, we followed the approach developed by Rüßmann *et al.* (2015).

Table 2. Research variables

Variables	Definition and measures
The regional digital maturity (RDMI)	The regional digital maturity is measured by an index. It is calculated on the basis of the level of adoption of eleven different I4.0 technologies – Big Data Analytics, Digital Twin, Internet of Things, Cybersecurity, Cloud Computing, Additive Manufacturing, Virtual Reality, Mobile Technologies, and social media by firms from a particular region. While investigating the level of adoption of I4.0 technologies we

Variables	Definition and measures
The regional digital maturity (RDMI) (cont.)	referred to the list of I4.0 technologies indicated in the literature (Rüßmann *et al.*, 2015) − big data, autonomous robots, simulation; integration; Internet of things; cybersecurity, cloud computing; additive manufacturing; augmented reality; mobile technologies and social media. Managers representing the companies were asked to use the 5-point Likert scale while assessing the adoption of eleven I4.0 technologies, where 1 stood for – we don't use it at all − never, 2 − we use it hardly ever, 3 − we use it seldom, 4 – we use it often, 5 – we use very often. The index was calculated as a weighted arithmetic average, where the weight was the frequency of using I4.0 technologies.
The operations of firms in technologically advanced industries in the region	The level of technological sophistication of the industry was based on NACE Rev. 2 3-digit level: high technology, medium--high technology, medium-low technology, low technology and coded accordingly. The presence of the technologically sophisticated industries in the region was measured with the share of net income from sales of products of entities included in high and medium-high technology in net income from sales of products of entities included in the section "Manufacturing".
The organisation of trainings for employees by the firm	It was measured by the 5-point Likert scale where 1 means I absolutely don't agree; 2 – I don't agree; 3 – I neither agree, nor disagree; 4 – I agree; 5 – I absolutely agree.
The presence of clusters in region	It was measured with the number of clusters per 10 million residents in a region, data from the Statistics Poland.

Source: own work.

The survey data and the secondary empirical data were entered into IBM SPSS Statistics and analysed with selected descriptive statistics, the Pearson correlation coefficient (see 4.2). Then, we used a stepwise linear regression model to examine the relationship between regional maturity (measured by RDMI) and various regional characteristics. In this analysis, only variables that were statistically significantly correlated with RDMI and uncorrelated with each other were included (see 4.3). Stepwise regression is a method for building predictive models by adding or removing predictor variables based on their statistical significance. The model iteratively selects the most relevant variables to explain the dependent variable (RDMI) while excluding less relevant or redundant predictors (Draper and Smith, 1998). The full set of explanatory variables included:

- GDP per capita,
- Number of universities per 10 million inhabitants,
- Number of university graduates per 10,000 inhabitants,
- Number of technology parks per 10 million inhabitants,
- Number of clusters per 10 million inhabitants,

– Total industrial enterprises that cooperated in the scope of innovation activity as % of all enterprises,
– Internal R&D staff per 1,000 professionally active persons,
– Total service sector enterprises that cooperated in the scope of innovation activity as % of all enterprises,
– Entities with foreign capital per 10,000 inhabitants,
– Value of foreign capital per 1 inhabitant in production age (Poland = 100),
– Industrial enterprises cooperating within the framework of a cluster initiatives or other form of cooperation as % of all innovation-active enterprises,
– Share of net revenues from the sale of products of entities classified as high and medium-high technology in net revenues from the sale of products of entities, classified in the section "Industrial processing".

3.2. Research population and sample

The research population comprised Polish firms located within 16 regions of Poland (NUTS-2) and represented the whole industrial manufacturing sector according to NACE Rev. 2.0.

Most of the firms under the study (66.3%) are large entities – employing 500 or more persons. Then, 5.6% are entities employing from 10 to 49 persons, 15.4% – from 50 to 249 persons, and 12.8% – from 250 to 499. The size structure of the sample reflects the involvement of particular types of enterprises in R&D operations, according to the Central Statistical Office of Poland (2018). The manufacturing firms represented 21 industries NACE Rev.2. Among them, 31 entities belonged to the high-tech industries. The highest number of companies belongs to the manufacturing of food products (18.2%) and the manufacturing of fabricated metal products, except machinery equipment (12.0%). The studied firms are generally private (97.3%) and possess a 100% share of the Polish capital in the ownership structure (76.3%). Most firms operate in the Polish market for 11 to 15 years. Urban agglomerations are the central location of the firms' manufacturing facilities. Nearly 90% of them are active exporters.

4. FINDINGS

4.1. Digital transformation across the regions in Poland

It appears that there is a considerable variation in the use of I4.0 solutions in different regions of the country. Considering the solutions used, the regions differ to the greatest extent in the use of augmented reality solutions (the coefficient of variation is 142%, 7% of companies in Śląskie (the Lower Silesia) region declare using it, while in 10 regions it is not used at all) and 3D production (the coefficient of variation is 84%), 10% of companies in Zachodniopomorskie (the West Pomeranian) region use it, while in 5 regions not a single company uses it (Table 3).

The technologies used on average by the fewest companies in all regions are augmented reality, 3D manufacturing, and the Industrial Internet of Things, while almost all companies (96%) use cybersecurity. Social media is used frequently or very frequently by 58% of industrial companies, while cloud computing is used by 42%. The use of a cybersecurity solution does not differentiate the development of individual regions, and this variable was eliminated from further analysis.

In the next step, Pearson correlation coefficients were determined between companies using particular I4.0 solutions in specific regions. Diagnostic variables cannot be strongly correlated with each other, as this would mean that they carry the same information. In our case, an excessively strong, statistically significant correlation exists only between mobile technologies and social media. We eliminate social media from further analysis (since technologies differentiate regions more while being less correlated with the other variables).

Since the use of particular I4.0 solutions varies quite a bit, a normalisation of diagnostic features was performed using one method – zeroed unitarisation. Zeroed unitisation formula:

$$z_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}$$

where:
z_{ij} – normalised value of the *j*-th feature for the *i*-th object,
$\bar{x}_j$ – arithmetic mean of the *j*-th feature,
$min x_{ij}$ – minimum value of the *j*-th feature for the *i*-th object,
$max x_{ij}$ – maximum value of the *j*-th feature for the *i*-th object.

Then, the standardised characteristics for a given spatial unit (region) were summed, and a ranking of the regions' digital maturity was obtained (Regional Digital Maturity Index – RDMI) (Table 3). The regions were then divided into groups similar to each other, considering the average level of the maturity index (x) and the standard deviation (σ), adopting the following rule of thumb:

- regions most mature, i.e., above average: maturity index > [$x + \sigma$],
- mature regions: maturity index (from x to $x + \sigma$]
- underdeveloped regions: (x to $x - \sigma$]
- least developed regions: maturity index < $x - \sigma$].

Table 3. The adoption of particular I4.0 technologies across Polish regions

Region	Big data	Autonomous robots	Simulation	Integration	Internet of things	Cybersecurity	Cloud computing	Additive manufacturing	Augmented reality	Mobile technologies	Social media
Dolnośląskie	10.00	6.67	23.33	3.33	6.67	100.00	33.33	3.33	6.67	26.67	73.33
Kujawsko-Pomorskie	4.55	4.55	18.18	4.55	0.00	95.45	36.36	0.00	0.00	9.09	40.91
Lubelskie	0.00	7.69	46.15	7.69	7.69	100.00	46.15	0.00	0.00	7.69	61.54
Lubuskie	7.14	7.14	35.71	14.29	7.14	100.00	64.29	7.14	0.00	28.57	71.43
Łódzkie	13.51	2.70	29.73	5.41	5.41	94.59	40.54	5.41	5.41	13.51	56.76
Małopolskie	9.68	3.23	16.13	9.68	6.45	93.55	45.16	3.23	0.00	16.13	48.39
Mazowieckie	9.09	6.82	29.55	4.55	0.00	100.00	47.73	4.55	4.55	11.36	47.73
Opolskie	25.00	18.75	25.00	12.50	6.25	100.00	31.25	0.00	0.00	25.00	81.25
Podkarpackie	9.09	13.64	36.36	9.09	4.55	100.00	36.36	9.09	4.55	18.18	50.00
Podlaskie	7.14	14.29	14.29	0.00	14.29	78.57	28.57	0.00	0.00	7.14	42.86
Pomorskie	0.00	13.64	36.36	4.55	9.09	100.00	50.00	4.55	0.00	13.64	63.64
Śląskie	6.12	10.20	30.61	14.29	8.16	97.96	46.94	4.08	2.04	16.33	65.31
Świętokrzyskie	9.09	13.64	36.36	13.64	0.00	100.00	50.00	0.00	4.55	18.18	59.09
Warmińsko-Mazurskie	12.50	6.25	18.75	6.25	0.00	100.00	50.00	6.25	0.00	6.25	62.50
Wielkopolskie	5.26	13.16	21.05	10.53	2.63	97.37	42.11	5.26	0.00	7.89	52.63
Zachodniopomorskie	0.00	10.00	30.00	10.00	10.00	80.00	30.00	10.00	0.00	10.00	60.00
SD	6.15	4.61	8.96	4.29	4.15	6.92	9.49	3.29	2.47	7.13	11.22
Mean	8.01	9.52	27.97	8.14	5.52	96.09	42.42	3.93	1.73	14.73	58.58
Coefficient of variation	76.707	48.4	32.042	52.718	75.11	7.198	22.4	83.6	143	48.388	19.15

Source: own work.

Table 4. Ranking of the Polish regions regarding the adoption of I4.0 technologies

Position in the ranking	Level of maturity	Region	Regional maturity index
1	The most mature regions – Digital Champions	Lubuskie	5.449
2		Podkarpackie	5.036
3	Mature regions – Digital Followers	Opolskie	4.564
4		Świętokrzyskie	4.509
5		Śląskie	4.476
6		Dolnośląskie	4.012
7		Łódzkie	3.794
8		Pomorskie	3.714
9		Zachodniopomorskie	3.556
10	The less mature regions – Digital Mediocre	Mazowieckie	3.319
11		Wielkopolskie	2.974
12		Lubelskie	2.945
13		Małopolskie	2.836
14		Warmińsko-Mazurskie	2.524
15	The least mature regions – Digital Loser	Podlaskie	2.048
16		Kujawsko-Pomorskie	1.083

Source: own work.

4.2. The relationship between regional maturity and the characteristics of the regions

In the next step, an attempt was made to determine the correlation between the determined regional digital maturity index and the operations of firms that represent the high and medium-high technology sector, the existence of clusters in the region and the organisation of special trainings for employees by firms in the area. Table 5 presents the correlation coefficients between the regional digital maturity index for particular areas and those selected variables. The regional digital maturity index is statistically significantly correlated with the operations of firms that represent the high and medium-high technology sector in the region (0.545) (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:High-tech_classification_of_manufacturing_industries, accessed on: 23.02.2024) with the organisation of trainings for employees (0.609). And the regional digital maturity index is not correlated with regional clusters. However, it should be underlined that correlation does not show cause-and-effect relationships but only the co-occurrence of two phenomena.

Table 5. Pearson correlation coefficients between the RDMI and selected variables characterizing regions in Poland

	Pearson Correlation	**Sig. (2-tailed)**
Number of clusters per 10 million residents	0.025	0.927
Share of net income from sales of products of entities included in high and medium-high technology in net income from sales of products of entities included in the section "Manufacturing."	0.545*	0.029
The company organises special training to improve the automation of production processes	0.609*	0.012
* Correlation significant at the level of 0.05 (two-sided).		

Note: statistically insignificant variables are not included in the table.

Source: own work.

4.3. The relationship between the regional maturity index and companies' and regions' characteristics

The analysis assumed a directional relationship and used a linear regression model to determine the relationship between the regional maturity index and the explanatory variables (Table 6). The resulting model included two variables: the organisation of special training to improve the automation of production processes and the share of net product sales revenue of entities classified as high and medium-high technology in net product sales revenue of entities classified in the Manufacturing section (NACE Rev. 2.0). Both of these variables have an additive effect on the explanatory variable. A comparison of standardised coefficients (beta) allows us to conclude that the studied variable (RMI) is more sensitive to changes related to the organisation of training than to the share of net revenues from sales.

Table 6. The linear regression model

Model	**Unstandardised Coefficients**		**Standardised Coefficients**	**t**	**Sig.**
	B	**Std. Error**	**Beta**		
(Constant)	–0.298	0.801		–0.372	0.716
The company provides special training to improve the automation of production processes	0.063	0.017	0.607	3.707	0.003

Model	Unstandardised Coefficients		Standardised Coefficients	t	Sig.
	B	Std. Error	Beta		
Share of net income from sales of products of entities included in high and medium-high technology in net income from sales of products of entities included in the section Manufacturing (acc. To NACE Rev. 2.0)	0.038	0.014	0.458	2.794	0.015
Model summary					
R	0.811				
R Square	0.658				
Adjusted R Square	0.606				
Std. Error of the Estimate	0.71720				
F statistics	12.528 *(Sig.<.001)*				

Source: own work.

The regression model is statistically significant throughout (F = 12.528, p < 001) and explains 65.8% of the variation in the phenomenon (R2 = 0.658). VIF and "tolerance" tests show no collinearity between the variables. The model also has the property of coincidence – there is a correspondence between the signs of the parameter ratings and the signs of the correlation coefficients.

5. DISCUSSION

In our paper, we provide insights on comparing the adoption of eleven I4.0 technologies across regions in Poland (NUTS-2). In doing so, we refer to De Propris and Bellandi's (2021) claim to incorporate the regional dimension of the fourth industrial revolution to fully reflect the far-reaching consequences of the disruptive processes.

The I4.0 technologies impact how and when corporate activities occur and where. New wave technologies affect companies and their locations. Impacting the firms' locations, they contribute to the digital transformation of companies. Thus, our study contributes to the discussion on how the I4.0 may affect firms and how firms may be impacted by locational factors in these new circumstances. Companies do not operate within particular contexts that may facilitate or hinder their efforts to become innovative businesses and digitally mature organisations. To mature digitally, firms need to introduce I4.0 technologies, but their attempts need to be complemented by features from external settings. Territories equipped with particular socio-economic and institutional solutions may shape the level of I4.0 technology adoption. In conducting the study on the sample of 400 Polish firms located across the 16 regions in Poland, we have indicated how the location of firms impacts their propensity to adopt I4.0 technologies. It is noticeable that most of the previous studies used proximate variables (proxies) of I4.0, such as GPT or KET, HORIZON 2020 projects data, etc., which interact with the lack of a concrete definition of I4.0 and reflect the multidimensionality of the issue. Thus, in our study, we purposefully focused on eleven I4.0 technologies and their adoption to address the challenge of the lack of a concrete definition of I4.0 and, second, not to lose the multidimensionality of the fourth industrial revolution. The review of the literature confirms persistent regional inequalities, and growing spatial discrepancies with core – periphery patterns. And that is visible in our research since we identified four types of regions – the so-called digital champions, digital followers, digital mediocre, and digital losers. The results of our comparative analysis point to the significance of the share of net income from sales of products of entities included in high and medium-high technology in net income from sales of products of entities included in the section "Manufacturing". Thus, the findings demonstrate that it is the technological intensity of the Manufacturing section (according to NACE Rev. 2.0) in the region that matters.

The results of our study resonate with the voices indicating the need to foster cohesion and reduce disparities among regions in Europe. Our findings bear essential policy implications as they illuminate that the nature of Europe's diversification process is disproportionately benefitting already advanced regions. Whereas it might be right that some I4.0 adoption activities are spatially concentrated, as it may help Europe to gain leadership and compete with the US and China, it could become a critical policy challenge to promote innovation and diversification in peripheral regions and tackle spatial inequality. This is because related diversification is not a natural process. Still, it needs to be activated and promoted by public policy, as there might be severe bottlenecks in peripheral regions that block related diversification, such as a lack of finance, low education, lack of entrepreneurial culture, or missing regulations. The challenge for firms, regions or individuals remains to develop, create, and adopt the I4.0 technologies and adapt to the disruptive nature of I4.0. Hence, voices indicating that the ambitious goal of European Policy to foster cohesion and reduce disparities in research and technological development may be at risk, and it must be ensured that European regions have adequate capacities to anticipate and adapt to the disruptive nature of I4.0 technologies. Thus, seeking excellence and supporting technological development must be accompanied by actions aiming at reducing the existing divide between European regions and helping them raise capacities to adapt and apply such modern technologies. Most important for the fourth industrial revolution is probably the development of new competencies and skills in the workforce, new firm competencies, new public attitudes, and know-how. I4.0 is all about the business model change, not just the adoption of some technologies; it inevitably requires adjustment in the Human Resources area, including the appropriate parallel transformation of skills, competencies, job descriptions, etc.

Our study aligns with what Laffi and Boschma (2021) have argued about the 4.0 paradigm: it is not associated just with one technology but rather with a set of technologies. Thus, different technologies may be adopted to varying levels across regions. Referring to eleven different technologies, our research shows that almost all companies use cybersecurity solutions; many use social media and cloud computing technologies, while augmented reality, 3D manufacturing and the Industrial Internet of Things are often overlooked.

Previous studies suggested what should be done to make regions reroute towards I4.0 and transit their profiles, in particular stressing what state support was necessary in this regard, what the required resources were, etc., and thus they looked at regional issues in the context of the transformation of these regions assisted by appropriate policies. In our research, it is clear that companies need to relocate specific human resources to monitor and deal with I4.0 challenges and organise special training to improve the automation of production processes. Those are actions on the side of firms, but particular policy measures can facilitate them at the national and regional levels.

Regional labels which reflect the results of our evaluation might come across as indeed surprising and intriguing, warranting further studies. These results could be interpreted as a sign of an uneven and patchy implementation in Poland, and the fact that equipment in certain technologies or other advances does not necessarily translate into I.40 maturity. These rather non-obvious and even surprising results certainly deserve further research and replication in the years to come, but we suspect that they may be a result of the technologies we have chosen for the survey as variables defining the digital revolution, eliminating those that do not differentiate between regions, on the one hand, and the fact that we rely on the explanations and opinions of respondents, which may not always reflect the actual state of affairs, on the other. Our research focuses on examining the relationship between the saturation of the region with 4.0 technology, as measured by the maturity index, and the characteristics of the region and the characteristics of the companies. The results obtained indicate that the maturity of the region and the saturation with selected Industry 4.0 technologies are related to the conscious training strategy and human resources development pursued at the company level and to the resources they obtain from selling their advanced products and services on the markets.

The results obtained are somewhat different from the commonly expected results, which suggest a simple dependence on a region's endowment with knowledge-related factors, number of universities, patents, and level of GDP, but they do shed light on a new type of dependence, highlighting the conscious strategies adopted by companies and the efforts they put into the process of adopting Industry 4.0. In other words, the saturation of a region with Industry 4.0 technology is not so much the result of general knowledge-related conditions or the level of the economy in a given region but rather the result of more advanced factors and the conscious strategies of companies.

6. CONCLUSION

The results of our comparative study indicate that the highest degree of saturation in new technologies of I.40 (RDM) is in those regions that are successful in representing high/medium-high technology industries – successfully selling advanced products in high and medium-high technology sectors and are locations of firms that care for their staff and train employees, invest in HR development.

In other words, this would confirm the earlier research results (literature findings indicating deepening differences or widening the gap between I4.0 laggards and I4.0 leaders/self-reinforcing mechanisms), indicating that the implementation of Industry 4.0 technologies is more popular among the best performers/champions, the "the winner takes it all". However, the ranking of Polish regions may be surprising (Lubuskie and Podkarpackie are the leaders). Those who successfully sell advanced manufacturing products and take care of their employees, i.e., who have the resources and can strategically invest them, who can consciously implement new I4.0 technologies. Thus, saturation with new I4.0 technologies results from a conscious training strategy/human resources policy and investment at the company level and more at the regional level, resulting from having significant funds from the sale of high-tech goods to invest. It appears that there is a correlation between the presence of high-tech and medium-high-tech firms in the region and the level of regional digital maturity. In areas where the share of net income from sales of products of entities included in high and medium-high technology in net income from products of entities included in the section "Manufacturing" is higher, the level of I4.0 technologies adoption among the firms in the region is also higher. Thus, the technological sophistication of the firms in the region contributes to the eagerness and openness for solutions of the fourth industrial revolution. The findings of our comparison may add to the discussion on the, unfortunately, perpetuating and deepening divide between technologically more advanced and technologically backward regions. In that context, instead of increasing inclusiveness I4.0 technologies will further differentiate the opportunities for social and economic progress within areas. A solution to that can emerge from another correlation identified in the study. Since the training of employees on automation of production is linked to adopting I4.0 technologies, further investment in the training and upskilling of human resources is needed. The positive message is that firms' involvement in developing skills can be controlled, and the greater intensity of those developmental activities will translate into adopting I4.0 technologies. Intuitively, we may assume that clusters in a region will determine firms' adoption of I4.0 technologies in the region where a particular cluster is located. Nevertheless, our comparative analysis has not revealed that kind of result. It stands in opposition to literature. But we need to consider the context of Poland – a CEE, post-transition country where the level of cluster development is still relatively low. Thus, even though clusters are related to innovation, knowledge sharing, and diffusion, they are not that obvious in a CEE country – Poland.

As regions tend to vary in their capacity for successful industrial digitalisation due to different historically accumulated innovative assets at the micro and meso-level, policy aiming at stimulating digitalisation processes in industries must also vary between regions. To formulate a well-suited policy, further investigation of regional determinants of I4.0 technology adoption should be the future research.

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ESTIMATING URBAN GROWTH ON MERSIN, TARSUS AND ADANA CORRIDOR IN TÜRKİYE BY USING CELLULAR AUTOMATA AND MARKOV CHAIN

Abstract. In many developing countries, urban growth is often unplanned and haphazard, leading to significant threats to the sustainable use of urban land. This study predicts future urban expansion patterns in the Mersin, Tarsus and Adana corridor in Türkiye using Cellular Automata and Markov Chain models. Analysing Landsat satellite images from 1989 to 2019, we simulated land use changes for 2019, 2031, and 2049. The results indicate a projected increase in urban areas from 3.8% in 2019 to 7.4% by 2049, with significant expansion onto fertile agricultural areas. This unregulated growth highlights the urgent need for a well-planned governance approach that balances economic, social, and environmental factors to ensure resilient and sustainable urban development.

Key words: urban growth simulation, CA_Markov model, land cover/use, Türkiye.

1. INTRODUCTION

Rapid urbanisation in the developing countries triggers significant land use changes which threaten economic and environmental sustainability (Theres *et al.*, 2023). Unplanned urban expansion often leads to deterioration of fertile lands.

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Transformation of agricultural lands into commercial, residential, and industrial areas poses serious threats to the ecosystems, as well as the sustainability of the economic growths (Al-sharif and Pradhan, 2014). Urbanisation is a complex process that requires careful planning. Simulating future urban expansion is essential for improving planning policies.

There is a growing literature on urban expansion and the problems that it causes (Bayrakdar *et al.*, 2020; Belal and Moghanm, 2011; Cai *et al.*, 2015; Ishtiaque *et al.*, 2017; Kaya and Curran, 2006; Mundia and Aniya, 2005; Tariq *et al.*, 2023). Land-use change is one of the most popular topics in the environmental and sustainable development research area. Various studies have examined how rapid alters spatial patterns in cities (Mohan *et al.*, 2011), contributes to environmental pollution (Sun *et al.*, 2019), and results in the overconsumption of natural resources (Ahmad *et al.*, 2017). The conversion of agricultural and forestry lands to built-up areas is another critical issue that threatens ecological and economic sustainability (Theres *et al.*, 2023). These studies collectively suggest that the problems associated with urban expansion will persist, making it essential to predict spatial changes in urban areas. Estimating urban growth is particularly crucial for developing countries to observe and predict the future of urban expansion to improve planning policies for more sustainable economic developments and the ecosystems (Theres *et al.*, 2023).

Urban growth simulations, developed by urban growth models, provide information about the possible directions of urban growth, boundaries, and changes in land use of cities (Kong *et al.*, 2012). These simulations facilitate location-based planning by forecasting the future spatial pattern and preventing the degradation of natural areas beforehand. Urban growth models have been used in developing ideal simulations of spatial sustainability and the conservation of natural areas, in addition to revealing a possible spatial pattern (Liu and Feng, 2011; Martellozzo *et al.*, 2018). They provide well-needed data for local governments and policymakers to design nature-friendly and sustainable urban planning.

There are various computer-based programs that predict urban growth by integrating parameters such as land use, population, employment, and transportation (Bhatta, 2010). Complex urban growth models, including Logistic Regression, Artificial Neural Networks, and Agent-Based Modelling are commonly employed to simulate the future of cities with different spatial dynamics (Ozturk, 2015; Pooyandeh *et al.*, 2007). Logistic Regression is widely used to model the probability of land use change by analysing various spatial factors such as proximity to roads, population density, and land value (Hu and Lo, 2007). Artificial Neural Networks provide an advanced approach to modelling urban growth. They are capable of processing extensive datasets and accommodating the complex interactions, such as those involving economic activities, infrastructure development, and demographic changes (Pijanowski *et al.*, 2002). Agent-Based Modelling adopts a distinct approach by simulating the interactions of individual agents, such as households, businesses, or governments. It provides a valuable framework for exploring how micro-level behaviours and decisions coalesce to generate macro-level patterns of urban growth (Dai *et al.*, 2024; Parker *et al.*, 2003). While these methodologies, each with its unique strengths, offer valuable insights into urban growth, this study utilises the integration of Cellular Automata and Markov Chain methods to capture the spatial and temporal dynamics of urbanisation in greater detail.

Many studies have used the integration of different methods instead of a single modelling method to develop urban growth simulations (Basse *et al.*, 2014; Cagliyan and Dagli, 2022; Guan *et al.*, 2011; Iizuka *et al.*, 2017; Liu *et al.*, 2015; Losiri *et al.*, 2016). Among these, the integration of Cellular Automata (CA) and Markov Chain (MC) models has emerged as a particularly effective method for predicting land use changes and urban growth (Guan *et al.*, 2011; Moghadam and Helbich, 2013; Mohamed and Worku, 2020; Myint and Wang, 2006). The CA model is capable of simulating complex spatial dynamics by considering the local interactions between neighbouring cells, while the MC model provides a statistical framework for predicting future states based on historical data. The foundation of MC is to determine the probability of future situations using the possibilities of change between past and present situations (Mondal *et al.*, 2017). MC performs the probability analysis based on the number of cells in the probability matrix (Arsanjani *et al.*, 2013). It is vital to support modelling spatially because the MC disregards the location and condition of the cells. The incorporation of the CA and MC provides more effective and reliable simulations (Ke *et al.*, 2016; Rimal *et al.*, 2017). CA refers to the state change that the status change of each cell in an image depends on the status of the cells around it for a certain period (Wang, 2012). Each city has its own different physical, socio-economic, and spatial dynamics. Hence, CA-MC integration, which helps to identify many variables in the modelling process, is a significant and effective method for predicting future land use changes.

CA-MC modelling has been widely used in recent years as it is a powerful method for evaluating urban growth (Ghosh *et al.*, 2017). It is particularly significant to use CA-MC modelling in the developing countries to understand the spatial changes of cities with different features (Aburas *et al.*, 2021). CA-MC modelling enables the evaluation of different driving factors together to obtain more accurate simulations. Theres *et al.* (2023) has also emphasised that there is limited data about the future of urban growth in the developing countries, and indicated the need for further research that would consider multiple driving factors together that affect urban growth.

This study aims to simulate potential future urban growth patterns on the Mersin, Tarsus and Adana corridor by using the Cellular Automata and Markov Chain methods. The primary goal is to forecast the spatial implications of urbanisation in this region and provide insights that could guide sustainable urban planning. By doing so, the study seeks to inform local policymakers and urban planners about the probable directions of urban expansion. The study firstly obtained the land cover/use maps and conversion matrices from 1989 to 2019. Using these matrices, the simulation map of 2019 was produced and compared with the actual land cover/use map of 2019 to determine the accuracy of the model. After reaching high accuracy rates, the urban growth of 2031 and 2049 was simulated.

The Mersin, Tarsus and Adana corridor is one of the most populated and developed urban areas in Türkiye, characterised by a unique set of features that make it the ideal study area. The region is densely populated, continues to attract more residents, serves as a major industrial and commercial hub, and includes significant agricultural areas. These factors contribute to rapid urban growth, which poses risks to the region's environmental sustainability. Sustainable urban growth planning is essential, and predicting the future directions of urban expansion is a critical component of this effort.

Numerous studies have examined urban growth in this region (Adiguzel *et al.*, 2015; Akin Tanriover, 2011; Gulersoy *et al.*, 2014; Kara, 1988; Sargin, 1998). These studies are critical in understanding the urban growth of the region. However, when the existing literature is analysed, this study differs from previous studies in some respects. Previous studies focused on one of the cities of Mersin, Tarsus or Adana and analysed them individually. The spatial growth of these cities, which are in close proximity and constantly interact, cannot be considered independently. Studies that examine them individually make it difficult to evaluate the region as a whole and to understand the multi-centred and multi-functional structure of the region (Batman, 2014). This research adopts a holistic approach, analysing Mersin, Tarsus and Adana as an integrated urban region, which is crucial for accurately capturing the complex urban dynamics. Additionally, previous studies have mostly focused on the past and present land use change of the cities and its impacts. An important gap in the literature is the prediction of the future urban growth. There is only one study that focused on the future of the urban growth in the region. Akin Tanriover's (2011) work focuses on only Adana city as the research area and it aimed to determine an accurate modelling method by comparing different urban growth models. Considering all these, this study constitutes valuable and unique research for both considering these three cities as one region and simulating the future urban growth that is well-needed to improve the planning policies for the environmental and economic sustainability of the region.

2. MATERIALS AND METHODS

2.1. Study area

The Mersin, Tarsus and Adana corridor, one of Türkiye's most important urban agglomerations, has a considerably dynamic structure. It covers an area of approximately 7,453 km^2 in southern Türkiye and east of the Mediterranean Sea (Fig. 1). The north-western part of the region is mountainous and rough, while other parts are relatively flat. The study area has a central position in administrative, industrial, commercial, social, cultural, and logistical characteristics. Cukurova, forming the southern part of the cities of Tarsus and Adana, is among Türkiye's largest and most productive plains, which shapes the region's economy with its significant water supply and agricultural potential. The presence of the main transportation lines, the location of the port of Mersin and its airports, and the activities of industrial and commercial enterprises attract the population from different centres to the region.

The conurbation process between Mersin, Tarsus, and Adana in southern Türkiye is rooted in the region's rich historical and geographical significance, which has shaped its modern urban landscape. Adana, with its ancient origins and strategic location on the Seyhan River, has long been a key agricultural and commercial centre, particularly flourishing during the Ottoman period with the development of cotton production (Falay, 2020). Tarsus, one of the world's oldest continuously inhabited cities, has been an important cultural and trade hub since antiquity, notably during the Roman and Byzantine eras (Deniz and Umar, 2023). Mersin, although a relatively newer city, rapidly developed in the 19th and 20th centuries due to its port, which became crucial for regional and international trade (Dönmez, 2022). The conurbation process accelerated in the late 20th century, driven by the expansion of transportation infrastructure, including highways and railways, which facilitated the economic and physical integration of these cities. This integration saw Adana continue as an industrial powerhouse, Mersin as a vital trade port, and Tarsus maintaining its cultural significance. The merging of these urban areas has formed a large, continuous metropolitan region, reflecting both the historical importance of each city and the modern challenges of urban planning, infrastructure demands, and sustainable development in this dynamic region of Türkiye.

Mass housing projects, as well as industrial, transportation, energy, and socio-cultural investments on a national scale have led to both the spatial expansion of the cities in the region and the rapid increase in population. The cities in the study area are connected to each other and functional relationships are maintained and sustained along transportation lines. Especially the transportation lines extending in the southwest-northeast direction are parallel to the spatial distribution of the cities. The cities of Mersin, Tarsus, and Adana provide fast and easy access both to each other and to important centres outside the region in terms of economic relations. Cukurova, one of the largest and most productive agricultural basins in Türkiye, is located within the research area. Cukurova's high agricultural potential and the fact that it is the source of the agro-industries in the region emphasise the importance of this basin in the regional economy.

The data analysis of this study has been conducted in three phases using the IDRISI Selva 17.0 software (Fig. 2). The first was the preliminary preparation phase, which steps for obtaining satellite images and optimising them for classification. The second phase was to produce land cover/use maps with the classification of satellite images and accuracy analyses. The third phase was modelling, consisting of change detection, suitability analysis, CA_Markov, and validation processes.

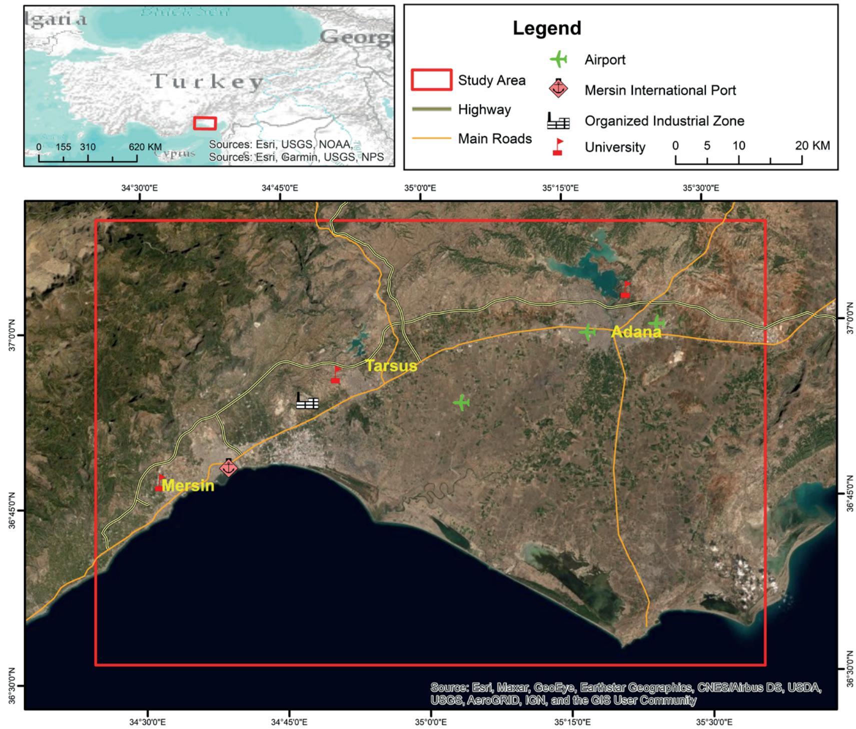

Fig. 1. The location map of the study area

Source: own work.

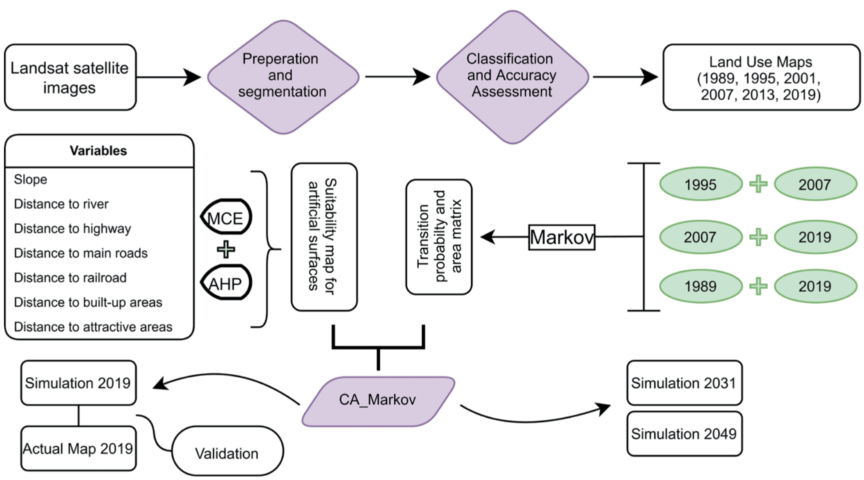

Fig. 2. Framework of the method

Source: own work.

2.2. Preparation of satellite images

The study utilised a variety of data sources to model and predict urban growth in the Mersin-Tarsus-Adana corridor. The primary data consisted of Landsat satellite images spanning 30 years, from 1989 to 2019 (Table 1). These images were obtained from the United States Geological Survey (USGS), specifically from the Landsat 4–5 Thematic Mapper (TM) sensors for the years 1989, 1995, 2001, and 2007, and the Landsat 8 Operational Land Imager (OLI) sensors for the years 2013 and 2019 (USGS, 2020). The spatial resolution of these images was 30 meters, which provided a sufficient level of detail for analyzing land cover/use changes over time. In addition to satellite imagery, the study also incorporated several ancillary datasets, including topographic maps, development plans, Digital Elevation Model (DEM), and various vector datasets representing infrastructure, water bodies, and protected areas. These supplementary datasets were crucial for the land-use suitability analysis and for refining the accuracy of the simulation models. The DEM data was obtained from USGS, while the remaining data were sourced from the local government units in Adana, and Mersin.

Table 1. Landsat satellite images

	1989	**1995**	**2001**	**2007**	**2013**	**2019**
TIME	25 July	12 September	10 July	25 June	13 September	26 June
SENSOR	TM	TM	TM	TM	OLI	OLI

Source: USGS, 2020.

Preparing satellite images for classification consists of data conversion, image fusion, clipping, band combination, and segmentation steps. The segmentation process was implemented to prepare satellite images for classification. This makes it easier for the user to assign pixels that are grouped homogeneously according to spectral similarities to the most appropriate land cover/use class (Eastman, 2016). Six land cover/use classes were then defined based on CORINE (the Coordination of Information on the Environment) land cover system involving artificial surfaces, agricultural areas, forest, semi-natural areas, wetland, and water bodies (Table 2).

Table 2. Definition of land cover/use classes used in the study

Land cover/ use type	**Description**
Artificial Surfaces	Residential areas, public buildings, commercial and industrial areas, roads.
Agricultural Areas	Arable lands, dry and irrigated farming fields, vineyards, orchards, olive groves.
Forest	Forests, green spaces.

Table 2 (cont.)

Land cover/ use type	Description
Semi-Natural Areas	Maquis shrublands, coastal areas, sandy beaches, bare lands.
Wetlands	Marshes, salt fields.
Water Bodies	Sea, rivers, lakes, lagoons.

Source: own work based on CORINE Land Cover (European Environment Agency, 2020).

2.3. Classification and accuracy assessment

The classification of satellite images was conducted using a supervised classification method, specifically the maximum likelihood classification technique. This approach relies on the identification of sample areas (or training datasets) for each land cover/use class. In this study, six land cover/use classes were defined based on the CORINE land cover system: artificial surfaces, agricultural areas, forest, semi-natural areas, wetlands, and water bodies.

The sampling process involved selecting more than 500 sample areas for each dataset year. These sample areas were manually defined on the segmented satellite images based on known land cover/use characteristics (Fig. 3). The selection of these sample areas was guided by expert knowledge, previous studies, and visual interpretation of the satellite imagery. The use of many sample areas ensured that the classification was robust and representative of the actual land cover/use conditions in the study area.

The maximum likelihood technique was used to implement supervised classification through the defined training datasets. Supervised classification is about classifying unknown similar pixels using known similar samples (Campbell and Wynne, 2011). In this way, the pixels identified by the user on a satellite image are grouped in a given range of reflection and assigned to the appropriate class. Maximum likelihood, one of the supervised classification techniques, is a method that uses the mean and variance values of sampled fields and calculates the probability of pixels in each class (Eastman, 2016). Finally, six land cover/use maps obtained for different years from 1989 to 2019.

The accuracy of the classified maps was evaluated using the stratified random sampling method, which relies on selecting independent samples from each group that formed the universe. This involved selecting 300 sample points for each classified map, which were then compared to the actual land cover/use data to determine the classification accuracy. Accordingly, the error matrix and accuracy rates for six land cover/use maps have been obtained (Table 3). The overall accuracy of the classified maps ranged from 90% to 94%, with Kappa values exceeding 85%, indicating a high level of reliability and agreement between the classified maps and actual land cover/use conditions.

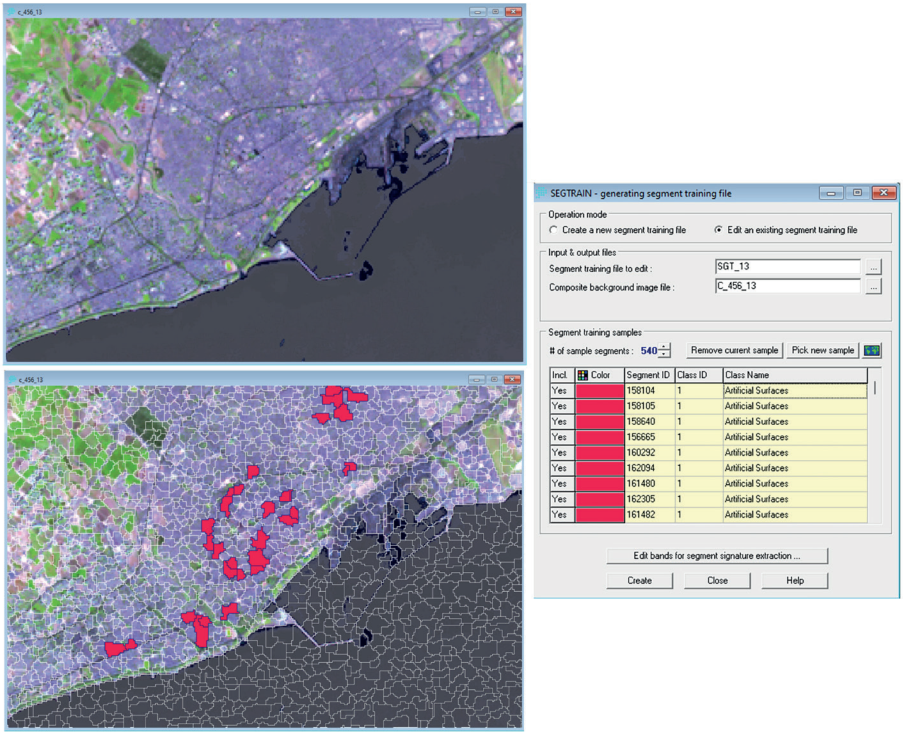

Fig. 3. Segmentation and defining sampling areas for 2013 classification

Source: own work.

Table 3. Accuracy assessment analysis results (%)

	1989	1995	2001	2007	2013	2019
Overall accuracy (%)	90	92	90	93	92	94
Kappa (%)	84	87	83	89	87	89

Source: own work.

2.4. Modelling

We employe Markov Chain and Cellular Automata modelling methods to predict possible urban growth. The Markov Chain determines the future land cover/use by using the transition probability of each land cover/use class to itself and others between years. Collins (1975) emphasised that conversion matrices identify the probability of transition between states. According to the mathematical formula of the Markov Chain, it refers to where Pij is the transition probability matrix, and n is the land use type (Sang *et al.*, 2011) as Eq. 1. A prediction model based on the Bayes probability formula is obtained when the Markov Chain analysis meets the P_{ij} state (Rimal *et al.*, 2017) (Eq. 2). $P(n)$ refers to the probability state of the system on the requested date, the first state vector of the $P_{(n-1)}$ system (Harvey, 2013) (Eq. 3).

$$P = (P_{ij}) = \begin{bmatrix} P_{11} & P_{12} & \dots & P_{1n} \\ P_{21} & P_{22} & \dots & P_{2n} \\ \dots & \dots & \dots & \dots \\ P_{n1} & P_{n2} & \dots & P_{nn} \end{bmatrix} \tag{1}$$

$$\left(0 \le P_{ij} < 1 \text{ and } \sum_{j=1}^{N} P_{ij} = 1,\ (i, j = 1,\ 2,\ \dots,\ n) \right) \tag{2}$$

$$P_n = P_{(n-1)} P_{ij} \tag{3}$$

The cellular automation method that supports the model spatially has five components representing space: cell, state, neighbourhood, transition rule, and time (Liu, 2008). The components of the cellular automation system exist in the mathematical formula below (Eq. 4). Accordingly, $S^{(t+1)}$, S_N, f, and $S^{(t)}$ represent the state of the cell at t+1 time, the neighbourhood state, the function of the transition rules, and the cell's state at t time, respectively (Pooyandeh *et al.*, 2007).

$$S^{(t+1)} = f(S^t, S_N) \tag{4}$$

The prediction of the region's land cover/use change relies on the implementation of modelling by producing conversion matrices and suitability maps and validating the simulation. The study aims to develop three different scenarios: the present, the near future, and the distant future:

1. To perform the land cover/use simulation for 2019 by using land cover/use maps of 1995 and 2007. Therefore, the model can be verified by comparing the actual map with the simulation.
2. To perform the land cover/use simulation for 2031 by using land cover/use maps of 2007 and 2019.
3. To perform the land cover/use simulation for 2049 by using land cover/use maps of 1989 and 2019.

2.5. Change detection

The spatial pattern predictions for the coming years emerge by considering the spatial changes experienced in the past years. For instance, the spatial situation of 2031 was predicted by estimating the spatial changes the had occurred between 2007 and 2019. It is assumed that the spatial changes estimated between 2007 and 2019 will remain the same between 2019 and 2031. The Markov module and Cross-Tabulation analyses were used to identify land-use changes for the three targets. Accordingly, the study has reached the probability-based matrix of the conversion movement of land-use classes to other classes.

2.6. Suitability analysis

The land-use suitability analysis was a critical step in the modelling process, and it involved the fuzzification of various driving factors that influence spatial changes. Fuzzification is the process of transforming input values into degrees of membership within a fuzzy set, which enables more flexible and realistic modelling of spatial phenomena.

In this process, a user should know and define the parameters that will affect spatial changes in a study area. Land-use suitability analysis refers to the process of reaching the most appropriate spatial pattern for a land cover/use class with identification of various variables (Malczewski, 2004). This process enables users to manage the modelling to determine the most appropriate and correct future land uses. Land-use suitability analysis for the artificial area class was conducted for the simulations. The Multi-Criteria Evaluation (MCE) method, which includes the identification of variables, the fuzzy logic for scale standardisation, and the detection of variable weights processes, was employed for the suitability analysis of the artificial areas. MCE, which is widely used in the generation of suitability maps, requires the identification of different variables that may influence spatial changes in the study area (Baysal, 2013). The variables for the land-use suitability analysis were determined by examining previous studies and identifying the regional parameters that influence the region's development (Berberoglu *et al.*, 2016; Dadashpoor *et al.*, 2019; Maithani, 2010; Ren *et al.*, 2019; Shuaibu and Kara, 2019).

In this study, nine variables have been identified for the land-use suitability analysis. There are two constraints: land use and protected areas; and seven driving factors: slope, distance from rivers, distance from highways, distance from main roads, distance from railroad, distance from built-up areas, and distance from attractive areas. The variable of 'distance from attractive areas' is only used in the simulations of 2031 and 2049. It is because the impacts of the ongoing large-scale new regional projects will only occur in the future.

The factors determined for suitability maps of the artificial area class have different reference units (percentage, meter, etc.) and scales (different minimum and maximum value ranges). It is because the factors are not in an absolute value; and they need to be standardised on the same scale (Jiang and Eastman, 2000). By using the fuzzy logic method, each factor standardised is defined by the same scale between a minimum of 0 and a maximum of 255 values. The fuzzy logic method is developed based on the fuzzy set membership approach, represented by a degree of suitability ranging from 0 to 1.

The weights of the variable in the MCE are determined by using the Analytical Hierarchy Process (AHP), which defines how much each factor variable will affect the suitability map. AHP refers to how important a factor variable is compared to another factor to produce a suitability map (Saaty, 2008). It is calculated in a pairwise comparison of the factor variables and consistency ratio. The coherence ratio (*CR*) is the division of the consistency index (*CI*) into a random index (*RI*) in Eq. 5. In the consistency index formula, λ_{max} represents the highest self-value, and *n* is the number of factors in Eq. 6 (Saaty, 1987; Zabihi *et al.*, 2019). A randomness index is a standard scale of consistency indicators with different values depending on the number of factors. The random index value is determined by the number of factors used in producing suitability maps (Table 4).

$$CR = \frac{CI}{RI} \tag{5}$$

$$CI = \frac{(\lambda_{max} - n)}{n - 1} \tag{6}$$

Table 4. Random consistency index

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: adapted from Saaty (1987).

The land cover/use constraint defines whether the urban area can expand on the fields beyond the water bodies and the artificial surfaces in the study area. The artifical areas are already occupied by existing artificial objects; and thus, the artificial area class has been defined as a constraint (Ahmed, 2011). The protected areas in this study consist of the areas with the nature conservation status that are protected by official institutions (Turkish Official Gazette, 1956, 1983). These areas include natural conservation sites, wildlife improvement areas, wetlands, sea turtle nesting areas, ancient cities, archaeological sites, and forest areas defined within the scope of the CORINE project.

For the slope factor, a percentage slope map has been generated using the 30-meter spatial resolution DEM data obtained from the SRTM satellite platform. The slope is one of the most significant factors determining the potential limits of spatial interventions. The possible urban expansion occurs in less inclined (flat) areas than in vertical areas (Chim *et al.*, 2019; Moghadam and Helbich, 2013). We have also considered the Turkish Coastal Law No. 3621 for the control points of the river factor (Turkish Official Gazette, 1990). New urban structures and development areas often emerge near existing urban areas and along the transportation network (Araya and Cabral, 2010; Megahed *et al.*, 2015; Mishra and Rai, 2016). The distance to transportation networks is thus considered as an important variable in this study. Attraction areas include the structures in the project phase, under construction or newly constructed, industrial, trading, and logistics centres. In this study, housing zones, terminals, hospitals, organised industrial areas, universities, ports, and commercial centres are some of the attractions that will affect urban expansion.

A membership function has been defined for each driving factor. A standardised scale, values from 0 to 255, was applied to each driving factor and their weights have been calculated by using the fuzzy logic (Fig. 4). The Consistency Ratio is obtained by calculating the weighting values of the factors through the analytical hierarchy process (Table 5). The consistency ratio of the pairwise comparison matrices used in suitability maps is calculated as 0.06. A consistency ratio of less than 0.10 indicates a high level of consistency (Eastman, 2009). The fact that the coherence ratio has a value of less than 0.10 (0.06 < 0.10) indicates that the comparisons are at a highly acceptable level.

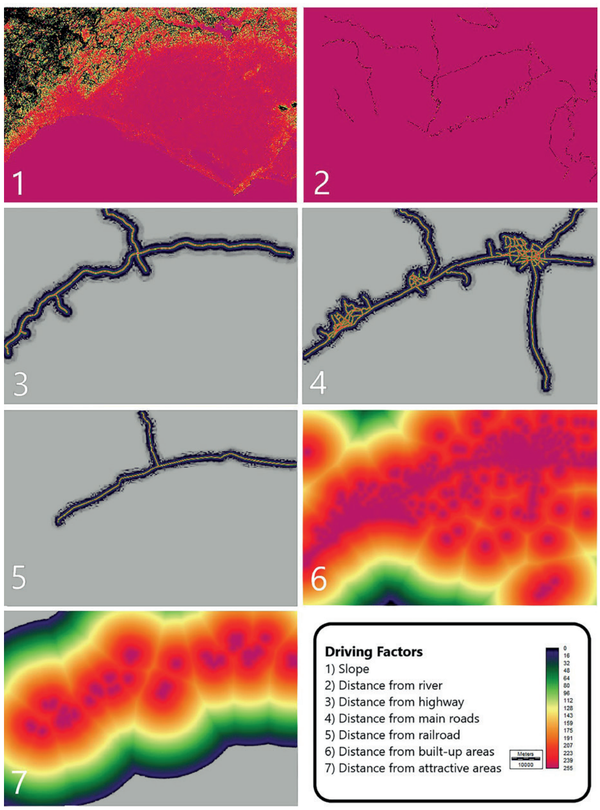

Fig. 4. Standardised maps for suitability analysis

Source: own work.

Table 5. Fuzzy standardisation process of driving factors

Driving factors	Membership function	Control points	Weights	
			2019	2031–2049
Slope	Sigmoidal monotonically decreasing	0%–20%	0.253	0.173
Distance from river	Sigmoidal monotonically increasing	30 m–50 m	0.054	0.040
Distance from highway	J-shaped monotonically decreasing	0 m–30 km	0.211	0.182
Distance from main roads	J-shaped monotonically decreasing	0 m–20 km	0.124	0.089
Distance from railroad	J-shaped monotonically decreasing	0 m–15 km	0.071	0.052
Distance from built-up areas	Linear monotonically decreasing	0 m–30 km	0.287	0.153
Distance from attractive areas	Linear monotonically decreasing	0 m–30 km	–	0.311
Consistency ratio			**0.06**	**0.06**

Source: own work.

2.7. CA_Markov

CA_Markov refers to the integration of Cellular Automation and Markov Chain. The simulation maps of 2019, 2031, and 2049 were created by defining the basis land cover/use image. As the basis land cover/use image, the land cover/use map of 2007 was used for the simulation of 2019, and the land cover/use map of 2019 was used for the 2031 and 2049 simulations.

2.8. Validation

Validation, which aims to test the reliability of the modelling, measures the level of conformity between the simulation and the actual result. The validation analysis of this study was conducted by comparing the simulation map of 2019 with the actual land cover/use map of 2019. Model validation contains agreement, disagreement, and Kappa variations defined by a number of mathematical formulas. The mathematical formulas in Table 6 show the two maps are similar in terms of location and quantity (Pontius Jr and Suedmeyer, 2004; Pontius, 2002). After the validation process in this study, we have reached 11 different variation results.

Table 6. Definition of validation variations and results

	Variations	Formula definition	Results (%)
Components	Disagreement due to quantity	P(p)-P(m)	0.0178 = 1%
	Disagreement at stratum level	P(m)-K(m)	0.0000 = 0%
	Disagreement at grid cell level	K(m)-M(m)	0.1200 = 12%
	Agreement at grid cell level	MAX[M(m)-H(m),0]	0.1667 = 16%
	Agreement at stratum level	If MIN[N(m),H(m),M(m)] = N(m), then MIN [H(m)-N(m),M(m)-N(m)], else 0	0.0000 = 0%
	Agreement due to quantity	If MIN[N(n),N(m),H(m),M(m)] = N(n), then MIN [N(m)-N(n),H(m)-N(n),M(m)-N(n)], else 0	0.1920 = 19%
	Agreement due to chance	MIN [N(n),N(m),H(m),M(m)]	0.1667 = 16%
Kappa	Standard Kappa (Kstandard)	((M(m)-N(m)))/((P(p)-N(m)))	0.7851 = 78%
	Kappa for no information (Kno)	((M(m)-N(n)))/((P(p)-N(n)))	0.8346 = 83%
	Kappa for grid-cell level location (Klocation)	((M(m)-N(m)))/((P(m)-N(m)))	0.8075 = 80%
	Kappa for stratum-level location (KlocationStrata)	((M(m)-H(m)))/((K(m)-H(m)))	0.8075 = 80%

Source: own work.

Pontius Jr and Millones (2011) have indicated that agreement or disagreement values provide much simpler and more useful information than the Kappa indicators. The components of quantity disagreement and allocation disagreement are the basic parameters indicating model validation. According to the validation results of the 2019 simulation, the overall accuracy value, which refers to the conformity rate between the simulation map and the actual land cover/use map, is 86%. The quantity disagreement is 1%, and the allocation disagreement is 12%. The number of cells in each class on the 2019 simulation map corresponds to 99% in quantity and 88% in allocation, compared to the actual map. All these validation values have proven that the model is valid and reliable. The fact that Kappa's statistics also provide an average of 80% is a significant result of the validation process.

3. RESULTS AND DISCUSSION

3.1. Spatial development process

The study's analysis of urban growth in the Mersin-Tarsus-Adana corridor from 1989 to 2019 reveals a clear pattern of linear expansion, primarily along major transportation routes. The data indicates that this linear growth pattern is closely tied to the region's infrastructure, particularly highways and railways, which have acted as conduits for urban expansion. Over the 30-year period analysed, the urbanised areas expanded from 1.6% in 1989 to 3.8% in 2019, with simulations predicting further increases to 5.2% by 2031 and 7.4% by 2049. This expansion is predominantly at the expense of agricultural and semi-natural areas, with the latter showing a significant decline from 22.4% in 1989 to 7.9% in 2019. This shift represents a substantial transformation in land use, driven by both population growth and economic development pressures.

The urban growth during this period had some important spatial impacts which could be observed through the changes in the land cover/use classes (Yildiz Gorentas and Sargin, 2021). The agricultural areas consisted of the largest area in the region, with an area of 3,286 sq. km in 1989, and 3,898 sq. km in 2019. The main reason for this increase in agricultural areas was that three wetlands in the south part of the region were drained and converted into agricultural land during this period. The agricultural areas occupy more than half of the study area (52.3%), mainly due to the presence of the Cukurova plain in the region (Fig. 5). This is also related to the fact that most of the commercial and industrial activities in the region are related to agriculture, including the production, storage, transportation, and the processing of agricultural products.

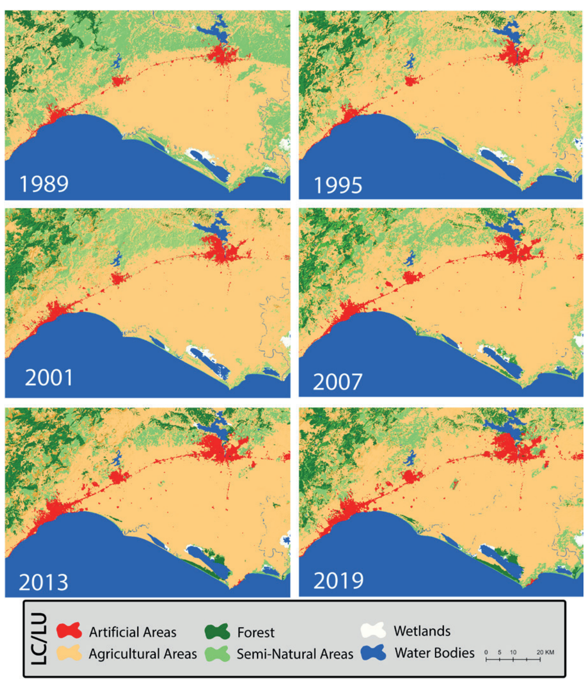

Fig. 5. Land cover/use maps from 1989 to 2019

Source: own work.

One of the most critical findings of this study is the extensive conversion of agricultural lands into urban areas. The region's fertile agricultural lands, particularly in the Cukurova plain, historically were the backbone of local food production and agro-industrial activities. However, the results indicate that these lands are increasingly being encroached upon by urban development. The artificial areas, which represent the urban sprawl, increased from 1.6% in 1989 to 3.8% in 2019. Compared to the other land-use classes, the artificial area is the only land cover/use class that has shown a steady increase spatially in the region during this period. The cities of Mersin, Tarsus, and Adana extend from the southwest to the northeast. The results show that the urban growth took place on the line between these three cities from 1989 to 2019.

Table 7. The fields of land cover/use classes between 1989 and 2019 (sq. km, %)

LULC	1989		1995		2001		2007		2013		2019	
	sq. km	**%**	**sq. km**	**%**	**sq. km**	**%**	**sq. km**	**%**	**sq. km**	**%**	**sq. km**	**%**
Artificial Surfaces	116	1.6	127	1.7	182	2.4	203	2.7	272	3.7	284	3.8
Agricultural Areas	3,286	44.1	3,992	53.5	3,928	52.7	4,045	54.3	3,965	53.2	3,899	52.3
Forest	265	3.6	412	5.5	387	5.2	480	6.4	560	7.5	562	7.6
Semi-Natural Areas	1,670	22.4	819	11	849	11.4	631	8.5	552	7.4	590	7.9
Wetlands	63	0.8	42	0.6	51	0.7	33	0.4	31	0.4	28	0.4
Water Bodies	2,053	27.5	2,061	27.7	2,056	27.6	2,061	27.7	2,073	27.8	2,090	28.0
Total	7,453	100	7,453	100	7,453	100	7,453	100	7,453	100	7,453	100

Source: own work.

It is crucial to assess the urban growth and spatial changes that have occurred in the region within the context of planning decisions. The large-scale regional investments made in the region, particularly on agricultural areas, imply that planning measures may not impose strict constraints on urban expansion. According to Environmental Impact Assessment reports by the Ministry of Environment, Urbanization, and Climate Change, planning decisions have been modified, and the status of lands has been altered, citing the absence of alternative sites for investment and prioritising the public interest. Notable examples include the Çukurova International Airport, the Tarsus Food Specialization Organized Industrial Zone, and the Toros Tarim Special Industrial Zone (ÇED, 2009; ÇŞB, 2017, 2020). The development of these structures on fertile agricultural lands suggests that their operational areas may expand further in the future, potentially leading to industrial pollutants impacting the region ecologically.

3.2. Transition probabilities of land cover/use classes

The transition probability matrix provides a more granular view of the conversion processes. The probability matrix of the movement of each land cover/use class to itself and to the other land cover/use classes were produced for the periods 1995–2007, 2007–2019, and 1989–2019. The cross-product of the matrix in which each land cover/use class intersects in row and column gives the value of conversion of a land-use class into itself in the future (Table 8). The likelihood of the artificial surface conversion to itself is similar in each of the three periods (79%, 78%, 75%). The transition probability matrix shows that a proportion of the agricultural areas and semi-natural areas turned into artificial areas. For example, 2% of the agricultural areas and 4% of the semi-natural areas became artificial areas during the period between 1995 and 2007. The matrix also indicates that the probability of conversion from any other land-use class to the artificial land-use class is relatively low in rate. However, since agricultural and the semi-natural areas cover a large area in the region, even the slightest change in rate will correspond to large areas spatially. For instance, 5,000 ha of the agricultural areas and 3,300 ha of the semi-natural areas were converted into artificial areas during the period between 1995 and 2007. The conversion of the agricultural and the semi-natural areas into the artificial area in the study area in each of the three periods is an indication that the urban growth will continue to occur on these land-use classes in the future.

Table 8. Transition probability matrix of LULC classes for three periods (%)

LULC	Period	Artificial surfaces	Agricultural areas	Forest	Semi-natural areas	Wetlands	Water bodies
Artificial surfaces	*1995–2007*	0.7954	0.1683	0.0005	0.0236	0.0000	0.0123
	2007–2019	0.7821	0.1947	0.0040	0.0168	0.0000	0.0025
	1989–2019	0.7522	0.2124	0.0088	0.0134	0.0000	0.0133
Agricultural areas	*1995–2007*	0.0291	0.7619	0.0691	0.1321	0.0009	0.0069
	2007–2019	0.0425	0.7382	0.0713	0.1354	0.0017	0.0109
	1989–2019	0.0488	0.7185	0.1610	0.0633	0.0006	0.0078
Forest	*1995–2007*	0.0006	0.2359	0.7192	0.0439	0.0000	0.0004
	2007–2019	0.0003	0.2176	0.7170	0.0563	0.0023	0.0066
	1989–2019	0.0000	0.2330	0.6878	0.0756	0.0001	0.0035

LULC	Period	Artificial surfaces	Agricultural areas	Forest	Semi-natural areas	Wetlands	Water bodies
Semi-natural areas	*1995–2007*	0.0459	0.5359	0.0055	0.4000	0.0057	0.0069
	2007–2019	0.0174	0.5582	0.0166	0.3957	0.0041	0.0079
	1989–2019	0.0584	0.6700	0.0289	0.2284	0.0026	0.0117
Wetlands	*1995–2007*	0.0001	0.1972	0.2004	0.0880	0.4647	0.0497
	2007–2019	0.0000	0.0472	0.0996	0.1519	0.5289	0.1724
	1989–2019	0.0000	0.0874	0.1803	0.2072	0.2957	0.2294
Water bodies	*1995–2007*	0.0039	0.0976	0.0079	0.0168	0.0319	0.8419
	2007–2019	0.0187	0.0283	0.0071	0.0396	0.0578	0.8485
	1989–2019	0.0082	0.0978	0.0032	0.0282	0.0168	0.8459

Source: own work.

3.3. Simulation

The first simulation map was created to predict the land cover/use classes in 2019. The simulation map was then compared with the actual one. The results show that the two maps overlap in terms of both the quantity and the allocation. The artificial area covers an area of 284 sq. km in the actual map of 2019, and 287 sq. km in the simulation map (Table 9). The spatial expansions of the artificial areas in both maps are the same; they constitute 3.8% of the total area in both maps (Fig. 6). The area ratios of the other land cover/use classes on the actual map and the simulation map were 52.3–50.9% agricultural areas, 7.6–8.7% forest, 7.9–8.5% semi-natural areas, 0.4–0.4% wetlands, and 28.7%–28.7% water bodies, respectively. The results show that there is a high degree of similarity between the two maps, both in quantity and allocation. All these results indicate that the modelling is accurate and reliable.

Table 9. Area statistics of the land cover/use classes through simulations

LULC	Actual map (2019)		Simulated map (2019)		Simulated map (2031)		Simulated map (2049)	
	sq. km	**%**	**sq. km**	**%**	**sq. km**	**%**	**sq. km**	**%**
Artificial surfaces	284	3.8	287	3.8	391	5.2	554	7.4
Agricultural areas	3,899	52.3	3,796	50.9	3,459	46.4	3,592	48.2
Forest	562	7.6	647	8.7	711	9.5	592	7.9
Semi-natural areas	590	7.9	630	8.5	774	10.4	598	8
Wetlands	28	0.4	33	0.4	28	0.4	28	0.4
Water bodies	2,090	28	2,060	27.7	2,090	29.1	2,089	28.1
Total	**7,453**	**100**	**7,453**	**100**	**7,453**	**100**	**7,453**	**100**

Source: own work.

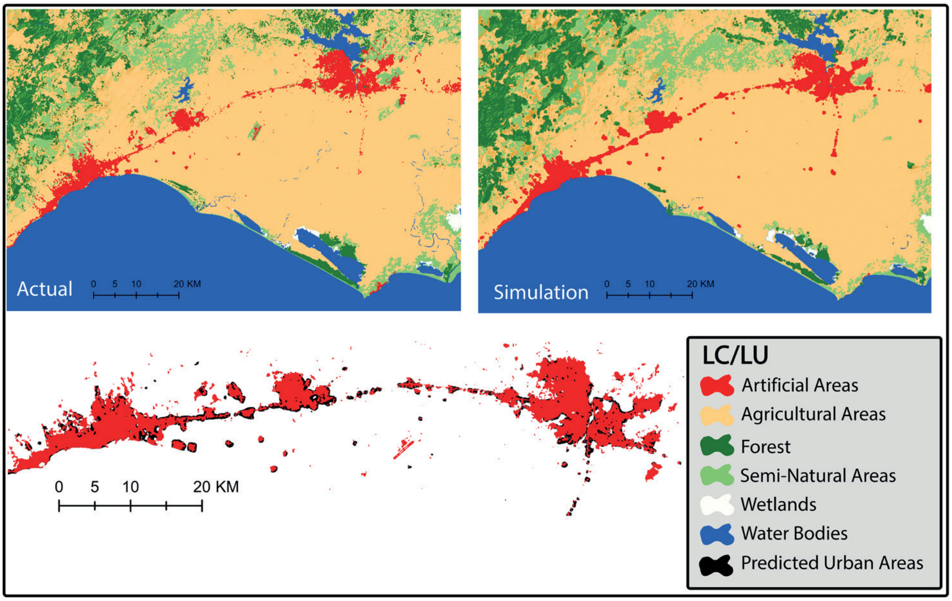

Fig. 6. Actual-simulated maps in 2019 and comparison of urban areas

Source: own work.

The simulations for 2031 and 2049 suggest that urban growth will continue to be driven by economic and infrastructural factors, with the most intense growth expected along the Mersin-Tarsus-Adana axis. This region, already characterised by high levels of industrial and commercial activity, is likely to see further densification, which will place additional strain on local resources and infrastructure. The results indicate that the artificial areas will increase to an area of 391 sq. km in 2031 and 554 sq. km in 2049. The urban sprawl is estimated to occur in the undeveloped lands and in the northern parts of the cities (Fig. 7). The urban expansion will occur more intensely around the attraction centres, due to economic, social, and cultural life exists in these areas. The main road between these three cities is one of the most important economic lines of the country and being intensely used for commercial and industrial purposes. This is the main reason why urban growth occurs horizontally along a linear line. The predicted northward expansion, facilitated by the Adana-Erdemli highway, underscores the role of transportation infrastructure in shaping urban growth patterns. The highway has a great impact on the direction of the urban expansion, due to its feature that allows relatively faster and easier interactions with other important economic and cultural centres outside of the region.

The simulation results have shown a significant change in land use occurred in the artificial areas class. The simulation maps of 2031 and 2049 predict a decrease in the agricultural areas, and an increase in the artificial areas. The simulations predict that the urbanised areas will further increase to 5.2% by 2031 and 7.4% by 2049. Since the modelling process is conducted by the experience of land cover/use changes in the past, such scenarios will inevitably occur in the future predictions. The current situation clearly confirms the degradation of the agricultural areas in the past, especially in the urban fringe. The simulations of 2031 and 2049 show that the three cities will grow towards their peripheries, and along a linear line towards each other (Fig. 8). The urban growth is predicted to encroach partly on the agricultural and semi-natural areas in the region. The artificial areas are estimated to expand on 8,772 ha of the agricultural areas and on 179 ha of the semi-natural areas in 2031; and the expansion will continue on 22,207 ha of the agricultural areas and on 4,888 ha of the semi-natural areas in 2049.

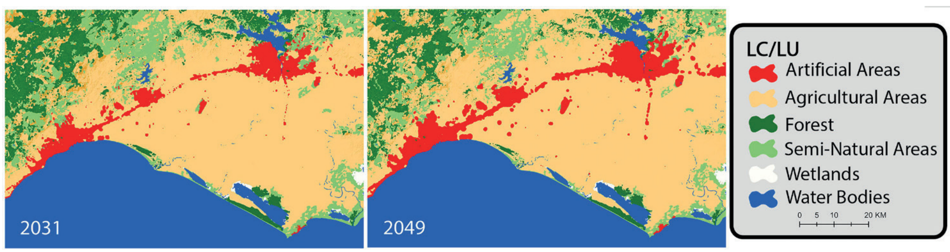

Fig. 7. Simulated maps of 2031 and 2049

Source: own work.

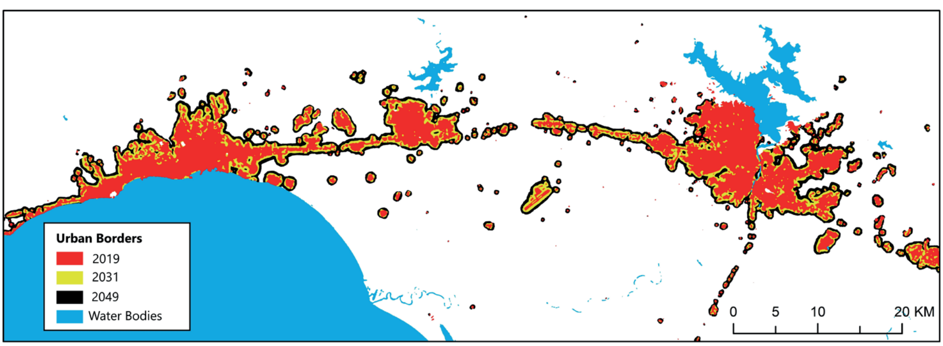

Fig. 8. Borders of simulated urban areas

Source: own work.

The study's findings also highlight a critical sustainability challenge: the current trajectory of urban growth is significantly unsustainable. The expansion of urban areas into fertile agricultural land not only threatens food security but also undermines efforts to promote sustainable land use practices. The continued encroachment into agricultural areas is a clear indication that current land-use planning and governance frameworks are inadequate to manage the pressures of urbanisation. To mitigate these challenges, the study suggests that urban growth should be redirected towards less productive areas, such as semi-natural lands, which could serve as a buffer zone for urban expansion. The northward urban expansion will be more beneficial for environmental sustainability. However, this approach must be carefully managed to avoid the complete loss of these semi-natural areas, which also play a vital role in maintaining ecological balance.

Everest *et al.* (2011) have argued that I., II., and III. classes of agricultural lands should not be used for non-agricultural purposes, even for the public interest. Yet, this study clearly showed that this advice has not been followed in this study area. The simulation maps of 2031 and 2049 predict that the artificial areas will expand on grade I, II, and III agricultural lands in the region. The simulation of 2031 estimates that the artificial areas will occur on the grade I agricultural areas of 44 sq. km, grade II of 9 sq. km, and grade III of 15 sq. km. The situation might be even worse in 2049, as the urban growth will continue the grade I agricultural areas of 94 sq. km, grade II of 24 sq. km, and grade III of 36 sq. km (Table 10). Thus, 17% of the artificial areas in 2031 and 28% of the artificial areas in 2049 will grow on arable agricultural areas.

Table 10. Area of artificial surfaces on land cover/use capability classes (sq. km)

Land Use Capability Classes	**Actual map (2019)**	**2031**	**2049**
I	16	44	94
II	4	9	24
III	5	15	36
Total	25	68	154

Source: own work.

According to the simulation maps, the northern part of Mersin, the western and eastern parts of Adana and the western and eastern parts Tarsus are the areas where the urban growth will occur on the agricultural areas, especially in 2049 (Fig. 9).

The broader implications of this study extend beyond the immediate region of Mersin, Tarsus and Adana. The findings provide valuable insights for other rapidly urbanising regions in developing countries facing similar challenges. The integration of CA and MC models offers a robust framework for predicting urban growth patterns and assessing the potential impacts on land use. Policymakers and urban planners can use these models to develop more effective land-use strategies that balance the needs of urban development with the imperative of environmental sustainability. The study also underscores the need for a more integrated approach to urban planning, one that considers the complex interactions between economic, social, and environmental factors. For instance, the ongoing investments in large-scale investment projects, such as the new airport and logistics centres, must be aligned with sustainable land-use practices. This requires not only stricter enforcement of existing regulations but also the development of new policies that promote vertical growth and the densification of urban areas, rather than unchecked horizontal sprawl.

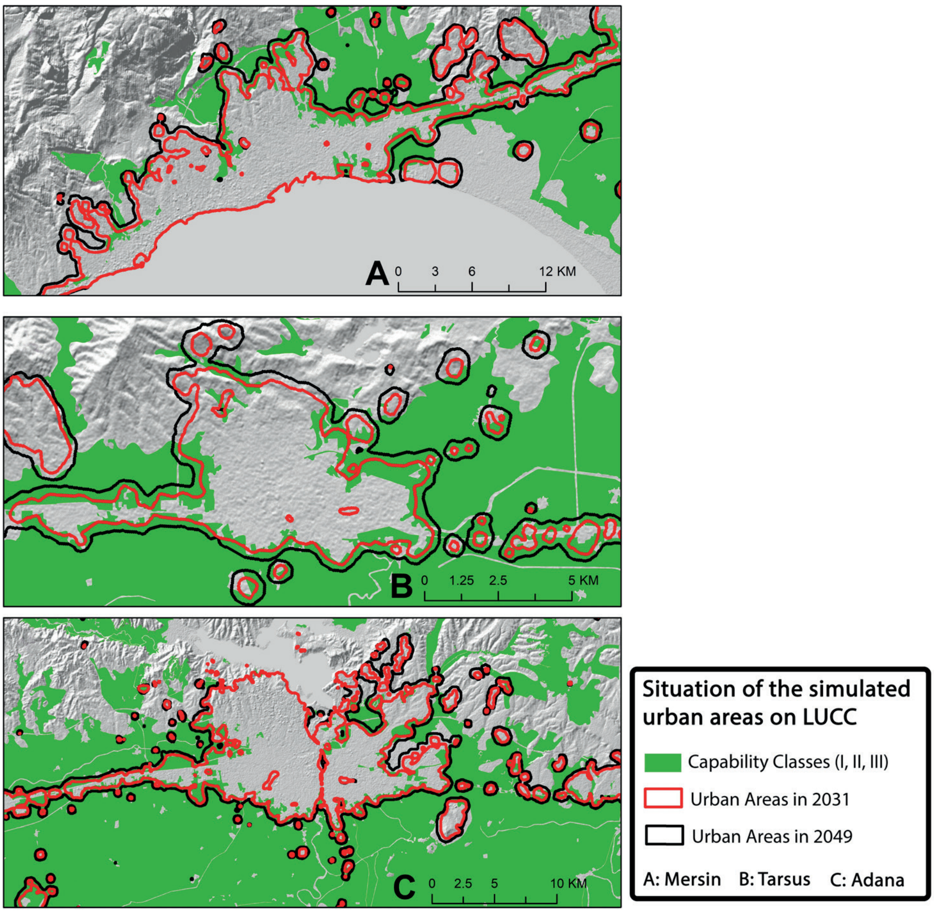

Fig. 9. Situation of simulated urban areas on land cover/use capability classes

Source: own work.

Finally, the study highlights the potential socio-economic impacts of urban growth on local communities. The conversion of agricultural land to urban areas can lead to the displacement of rural populations, changes in land ownership patterns, and increased socio-economic inequality. These issues are often overlooked in urban planning processes, but they are crucial for ensuring that urban growth benefits all segments of the population. Future research should focus on these socio-economic dimensions, exploring how urbanisation affects local communities and identifying strategies to mitigate negative impacts. Additionally, further studies could investigate the potential for alternative land-use scenarios that prioritise environmental sustainability and social equity. This could include exploring the role of green infrastructure, community-based land management practices, and innovative urban design approaches that promote sustainable development.

4. CONCLUSIONS

This study utilised Cellular Automata (CA) and Markov Chain (MC) modelling techniques to analyse urban growth in the Mersin, Tarsus and Adana corridor, revealing significant trends and future projections. Over the past three decades, the region has experienced substantial urban expansion, driven by infrastructural developments and economic activities. This growth, predominantly linear along major transportation routes, has resulted in the conversion of extensive areas of fertile agricultural land and semi-natural areas into urban spaces.

From 1989 to 2019, artificial areas in the region expanded from 1.6% to 3.8%, with the simulations predicting a further increase to 7.4% by 2049. This expansion is largely at the expense of agricultural and semi-natural areas, with agricultural areas being increasingly encroached upon. The Cukurova plain, one of Türkiye's most productive agricultural zones, is under significant threat as urban sprawl continues. The study emphasises that this trajectory of urban growth is unsustainable, posing severe risks to the economic viability of agriculture and the environmental sustainability in the area.

The projected urban expansion for 2031 and 2049 indicates that the cities of Mersin, Tarsus, and Adana will continue to grow towards each other, leading to a densely populated corridor characterised by significant infrastructure development. The simulations suggest that the most intense urban growth will occur in the northern peripheries of these cities, with a notable trend of horizontal expansion along the linear axis connecting them. This pattern of growth is expected to further exacerbate the loss of agricultural and semi-natural areas, with the artificial areas predicted to occupy 68 sq. km of fertile agricultural land by 2031 and 154 sq. km by 2049.

These findings highlight the urgent need for integrated, sustainable urban planning. The study advocates for stricter development plans and land-use legislation to protect agricultural lands from further encroachment. Redirecting urban growth towards less productive areas, such as semi-natural areas, and promoting vertical development within existing urban centres are crucial strategies for mitigating the adverse effects of urbanisation. By focusing on densification rather than horizontal sprawl, policymakers can help to preserve fertile agricultural areas.

Furthermore, the study highlights the importance of carefully managing future investment projects to avoid further degradation of natural resources. The ongoing and planned projects, such as new industrial zones and transportation hubs, should be aligned with sustainable land-use practices to ensure that they do not contribute to the unsustainable expansion of urban areas into fertile agricultural land. A planned and controllable governance approach is essential, balancing economic development with environmental protection to achieve sustainable urban growth.

The implications of this study extend beyond the Mersin, Tarsus and Adana corridor, offering valuable insights into other rapidly urbanizing regions in developing countries. The integration of CA and MC models provides a robust framework for predicting urban growth patterns and assessing their potential impacts on land use. These models can serve as critical tools for policymakers and urban planners, helping to develop more effective land-use strategies that address the complex interactions between economic, social, and environmental factors.

In conclusion, the study of urban growth in the Mersin, Tarsus and Adana corridor provides a compelling case for the need to rethink current urban planning practices. The findings clearly demonstrate the risks associated with rapid urban expansion, particularly the loss of valuable agricultural land and the degradation of natural areas. As urbanisation continues to accelerate, it is imperative that policymakers, urban planners, and researchers work together to develop more sustainable and resilient approaches to urban growth. By integrating the lessons learned from this study into future urban planning initiatives, there is an opportunity to create more liveable and sustainable urban environments. Through such collaborative efforts, it is possible to achieve a balance between urban development and environmental protection.

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REVIEW ARTICLE

Lidia GROEGER *

SENIOR HOUSING POLICY IN POLAND: DETERMINANTS AND DESIDERATA

Abstract. This paper aims to determine the comprehensive actions (which require interdisciplinary cooperation) to optimally prepare a high-quality housing environment for the growing population of seniors in Poland in the context of the current housing situation and the need to foster sustainable development. The paper outlines the determinants and specific actions to be taken to implement an effective senior housing policy in Poland. The study is based on the analysis of data obtained from the CSO on the senior housing environment, publications which study the expectations of the growing senior population and on the author's own research conducted in 2024 among seniors residing in urban and rural areas. The results are a set of recommendations to facilitate the implementation of a rational housing policy targeted at the needs of seniors.

Key words: seniors, housing policy, senior housing, housing environment, housing space, sustainable development, Poland.

1. INTRODUCTION

Given the challenges in the fields of urban planning and architectural design to satisfy the requirements of the ageing population in Poland[1], it is important

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[1] According to the CSO report entitled *Situation of Older Persons in Poland* [*Sytuacja osób starszych w Polsce*], the population of people aged 65+ could range from 9 to almost 11 million in 2050 depending on the scenario; at present, this population in Poland amounts to 7.5 million (CSO 2023).

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to understand the current determinants and directions of the housing policy[2] in order to satisfy the needs of seniors while complying with the guidelines of sustainable development. On the macro scale, housing policy is partly convergent with social and economic policies, especially as regards the operation of housing, financial and capital markets. However, on the meso and microscale, any housing policy is an integral part of urban policies (Lis, 2019). While the programmes to date do support housing development, it is mostly for first-time buyers and the current housing policy in Poland is primarily aimed at the needs of young people. Given the changes in age demographics, greater attention should be devoted to identifying the housing needs and preferences of older persons. They are a diverse social group with very different needs that incorporates both professionally active seniors and those who are no longer self-sufficient and require constant specialised care.

The implications that arise from the ageing society have become a pressing issue, which is being widely debated within the public sphere (Szatur-Jaworska, Błędowski, 2017; Szweda-Lewandowska, 2023). This debate focuses primarily on the issues of low birth rates and higher life expectancy (Szukalski, 2017; Błędowski *et al*., 2012). Jerzy Krzyszkowski (2018) has stressed that while the family in Poland has been traditionally seen as playing the leading role in the structure of senior care, in most cases it proves insufficient (Krzyszkowski, 2018). The long-held belief that the care of ageing parents rests with their children appears quite unrealistic in practice. Demographic changes, the migration of younger generations to major cities, and evolving family patterns all contribute to a decline in traditional family support. As a result, the caring capacity of the family for the safety and support of seniors in their place of residence is eroding. The elderly must increasingly rely on their own financial and organisational resources, which is not always feasible. Thus, the burden on local authority support for senior citizens in adapting their homes to their needs and to provide access to care and nursing services is growing. The decline in the caring potential of the Polish society will also require new, systemic solutions for a sustainable housing environment[3] that considers the needs and abilities of seniors.

[2] Housing policy is defined as key directions and approaches taken by the state and by other public, political or social organisations that affect the housing sector and the provision of housing needs (Adam Andrzejewski, *Polityka mieszkaniowa*, Warsaw, 1987).

[3] Jan Turowski (1979) studied the impact of the housing environment on shaping favourable living conditions for residents, distinguishing three main tiers of this environment. The first is the micro-environment, i.e., the space of the flat or house and its immediate vicinity. The second is a wider housing environment, i.e., the residential structure within the housing estate and the district, with its particular type of housing. The final, macro-environmental tier, encompasses extended urban systems, including roads, transport routes and networks, and any other urban infrastructure which affect the quality of life throughout the city.

An analysis of local spatial development plans at a municipal level reveals that they only contain rudimentary provisions on the adaptation of public space to the needs of an ageing population and on the changes to planning policies to meet demographic trends (Solarek, 2017). It seems imperative, however, to implement standards for the design of the housing environment that consider the needs of the changing demographics.

While senior citizens accounted for 17.2% of Poland's population in 2005, this figure rose to 26% by 2023. With the decline in the total population of the country and the rise in the share of seniors within the population, there will be an increase in the dependency ratio, which reached 29.9% in 2022. These demographic changes call for systemic solutions for senior policy. A problem that is recognised as evidenced by the establishment of a new ministry for senior policy. Despite this there is still a lack of well-developed and effective tools that could be employed to improve the senior housing policy in Poland.

A number of studies show (Bojanowska, 2021; Magdziak, 2017; Niezabitowski, 2014; Zrałek, 2012) that the home is the most important place for older persons and a focal point of their life, providing shelter, and a sense of security, enabling their most basic needs to be met. As they get older and become less physically and mentally capable, senior citizens spend more time at home or in its vicinity. If they are to remain in their own housing environment, solutions must be implemented to make their everyday life easier.

The relevance of the home stems, inter alia, from its role in public policy. Article 75 of the Constitution of the Republic of Poland obliges public authorities to pursue policies conducive to satisfying the housing needs of citizens. This issue is also among the tasks assigned to local (municipal) governments, which are obliged to take measures to improve access to housing.

With this in mind, this paper aims to raise awareness of the need for action on senior housing policy in Poland; to establish the necessary standards and quality of senior housing; the housing needs of this social group and to identify desirable instruments for senior housing policy while commenting on their current performance.

2. LEGAL CONDITIONS

In 1991, the United Nations General Assembly adopted Resolution no. 46/91 called *United Nations Principles for Older Persons*, which provided recommendations on senior housing, stressing that older persons had the right to dwell in conditions adapted to their individual requirements and suited to their deteriorating health and capacities. The need for them to remain in their current place of residence for as long as possible was also stressed.

Article 23 of the (Revised) European Social Charter adopted by the Council of Europe in 1996 explicitly states that every older person has the right to social protection. This right aims to enable seniors to remain active members of society for as long as possible by providing means for a dignified life and active participation in public, social, and cultural life; supplying information on available services for seniors, guidance on how to use them and enabling them to continue their lifestyle, and remain independent in a familiar environment for as long as desirable and possible. This includes, inter alia, adapting housing to their needs and health requirements or assisting them in doing so; providing necessary medical care; and respecting their privacy and promoting their involvement in decisions about moving to more suitable accommodation (e.g., care homes).

The Act on Social Care of 2004 only stipulates that "a person who – due to age, illness or other reasons – requires assistance from others but does not receive such assistance, is entitled to custodial or skilled care." The arrangement and provision of such care at the person's place of residence is an obligatory task assigned to local authorities.

In 2014, the Council of Europe compiled a document on the protection of the rights of older persons, entitled *Recommendation CM/Rec(2014)2 of the Committee of Ministers to Member States on the Promotion of Human Rights of Older Persons*, which proposed a social policy structure divided into three key sectors. The first is public institutions in charge of planning and implementing state policies financed by public funds, the second sector, known as the market sector, is composed of a variety of for-profit entities and often relying on public support to meet social needs, while the third sector, often referred to as the non-government or civic sector, comprises a wide range of organisations that have different objectives and legal forms and are independent of the public sector. These not-for-profit institutions often rely on volunteers and are autonomous from public administration.

In Poland, senior policy only emerged as a separate field of public policy in 2012, following the initiative of *The European Year for Active Ageing and Solidarity between Generations* (Szatur-Jaworska, 2015). However, the Act on Older Persons of 2015 contains no regulations on the housing environment, except for a single recommendation to monitor housing conditions.

Similarly, the 2018 governmental publication *Social Policy Towards Older Persons 2030: SAFETY – PARTICIPATION – SOLIDARITY* [*Polityka społeczna wobec osób starszych 2030. BEZPIECZEŃSTWO – UCZESTNICTWO – SOLIDARNOŚĆ*] only provides recommendations on what ought to be done in social policy, without detailing who is responsible and within what timeframe the different actions need to be taken. As for senior housing policy, this publication, which is over one hundred pages long, contains only the following recommendations:

– "Reducing dependency on others by facilitating access to services that enhance independence and adapting the housing environment to the functional capabilities of dependent older persons."

– "Promotion of activities aimed at the eradication of functional barriers within the housing environment of dependent older persons shall be pursued through implementing projects and raising public awareness of partners from all sectors within the field of universal design. Besides the measures aimed at providing direct services to dependent older persons, it is also imperative to adapt the housing environment to their needs and capabilities so as to enable them to remain in their own home for as long as possible."

The manner in which these postulates are formulated and the little attention generally paid to senior housing policy in the said document indicate a lack of state policy on the senior housing environment in Poland.

3. HOUSING CONDITIONS FOR SENIORS

As of 2022, the majority of elderly persons resided in urban areas. At that time, the level of urbanisation among the 60+ population amounted to 64.1%, representing 27.9% and 23.0% of the total urban and rural populations, respectively (CSO, *Situation of Older Persons in Poland* [*Sytuacja osób starszych w Polsce w 2022 roku*]).

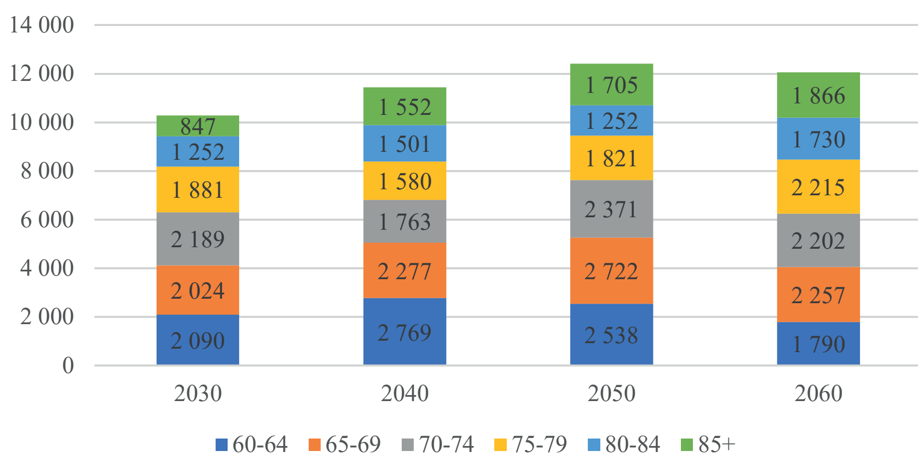

Fig. 1. Projected age structure of the senior population in Poland

Source: CSO, *Situation of Older Persons in Poland in 2022* [*Sytuacja osób starszych w Polsce w 2022 roku*].

According to CSO projections, the 60+ population will reach 10.3 million in 2030 (an increase of 5.0% compared to 2022), 11.4 million in 2040 (+16.8%), and 12.4 million in 2050 (+26.6%). The projected age structure reveals that over the next fifteen years there will be a significant rise in the senior population aged both

60–70 and 80+. The peak is predicted in 2060, at which time the senior population is predicted to reach 11.9 million (+21.0% compared to 2022), accounting for 38.3% of the total population in Poland (Fig. 1).[4]

In 2022, households containing only people aged 60+ had an average monthly disposable income of 2,623 zlotys per person. However, their expenditure per capita was, on average, 26.3% higher than in households with no senior members.

As shown by the CSO data for 2022, the percentage of seniors taking out mortgages was 3.4%, with the average debt amounting to ca. 88,000 zlotys. In contrast, data from the Credit Reference Agency in Poland reveals that older persons have long primarily resorted to consumer loans, which are the most common type of debt among this age group. Data obtained from two Polish banks – PKO BP and mBank – indicates that this is virtually the only type of credit product available to seniors, and also that the interest rates on these loans are among the highest. Given the age restrictions imposed by banks, a mortgage is practically unattainable for seniors should they desire to purchase a new property that is better suited to their needs, and then sell the one they currently reside in, for instance.

The CSO data for 2022 also shows that the average usable floor space in senior-only household was 71.2 sq. m, with significant disparities between urban and rural areas. In cities, the average floor area of properties occupied by seniors was 64.7 sq. m, rising to 93.2 sq. m in rural areas. The average floor area of homes occupied by single seniors was slightly smaller, averaging 60.8 sq. m, while this figure amounted to 82.3 sq. m for two-person senior-only households.

Table 1. Facilities within seniors' households in: Poland, urban areas, and rural areas in 2022

Details	Total	Urban areas	Rural areas
	percentage of seniors' homes		
Running water from water mains	99.8	100.0	99.4
Flushable toilet	98.8	99.4	96.8
Bathroom	98.6	99.1	96.7
Hot running water	99.0	99.5	97.3
Gas	91.5	91.5	91.5
from mains network	67.8	79.6	27.7
from gas tanks	23.7	11.9	63.8
Air-conditioning	1.9	2.2	1.1
Central heating	86.4	88.3	80.0
Boiler	13.5	11.6	19.7

Source: CSO, *Situation of Older Persons in Poland in 2022* [*Sytuacja osób starszych w Polsce w 2022 roku*].

[4] CSO, *Situation of Older Persons in Poland in 2022* [*Sytuacja osób starszych w Polsce w 2022 roku*].

Analysis of access to basic home facilities (Table 1) reveals that – save for air-conditioning or occasionally central heating – the situation for seniors is quite favourable, with elderly residents of rural areas only experiencing slightly worse housing conditions. Indeed, compared to data for all Polish citizens, it does not differ significantly from the national average. The exceptions here are the aforesaid air-conditioning, to which very few seniors have access, and the floor space per capita, which for seniors is considerably larger than the national average.

Table 2. Subjective opinion of housing currently occupied by seniors as of 2022

Details	**% of a given type of household within all households**			
	with no over-60s	**over-60s only**		
		total	**including**	
			single-person households	**two-person households**
adequate technical and sanitary conditions	96,7	93,4	89,9	97
located in a noisy or polluted area	5,5	6,1	5,4	6,8
located in an area at significant risk of crime, violence, vandalism, etc.	0,4	0,4	0,3	0,5
located in an area with poor infrastructure	7	8,1	9,4	6,8
located in a particularly sought after area	5,2	5,4	5,2	6
has a balcony (patio), garden	94,6	91	87,5	94,5
sufficiently warm in winter	98	96	93,8	98,2
sufficiently cool in summer	97,7	96,7	95,7	97,8
located in a building with reduced access due to architectural impediments	15,5	16,8	16,2	17,7

Source: CSO, *Situation of Older Persons in Poland in 2022* [*Sytuacja osób starszych w Polsce w 2022 roku*].

Based on the subjective opinions provided by the surveyed senior citizens, it can be stated that the majority of homes meet adequate technical and sanitary standards (Table 2). In 2022, 96.0% of all households containing only people aged 60+ considered their housing conditions as adequate when it came to technical and sanitary standards. In urban areas, this was stated by 96.8% households, while in rural areas: 93.4%. The majority of homes provided adequate thermal comfort in winter (96.4%) and summer (96.0%). Finally, 78.9% of seniors stated that they had access to a balcony or garden at home.

However, research conducted by the CSO on the subjective opinions on housing quality also revealed that people aged 60+ considered access to a balcony or garden in their home to be worse than among younger age groups. The same applied to living in a building with architectural barriers that make access to the home difficult (28% of respondents). Senior citizens also consider the noise and pollution in their neighbourhood to be slightly worse than other age groups. However, they report the technical and sanitary conditions, as well as thermal comfort in winter and summer as acceptable.

The self-assessment of their financial situation and housing conditions by older persons shows a strong dependence on the number of members of the household. When compared to those in two-person households, seniors living alone are less likely to describe their financial situation as good or quite good (29.4% versus 49.2%) and more inclined to perceive it as bad or quite bad (12.7% versus 3.4%). Seniors living alone in rural areas are particularly negative in the assessment of their economic situation. In 2022, 17.0% of seniors in single-person rural households considered their situation as quite bad or bad. As in previous years, the highest financial contentment was stated by seniors living in two-person households in urban areas, where 52.7% considered their economic situation as good or quite good in 2022.

In late 2022, there were 31,600 patients aged 60+ in residential health care facilities, nursing homes, hospices, and terminal wards. The largest group were people aged 80+, amounting to 16,700 people. At that time, there were 2,082 full-time social care facilities, an increase of 67 units compared to 2021, including 902 social care homes and 632 centres providing 24/7 care for the disabled, chronically ill, and seniors.

When one considers that older persons account for a staggering 50% of the homeless population and ca. 40% of the residents of night shelters, it shows what serious problems they face in accessing permanent accommodation and effective support, a fact that demands tailored measures to resolve this travesty.[5]

The data above reveals how very different and difficult the housing and financial situation of Polish seniors can be. For this reason alone, it is essential to perform an in-depth analysis of the availability of financial instruments to support independent housing for seniors.

In 2015, an international survey (98 countries) of the living conditions among older persons was conducted, in which Poland ranked 32[nd]. The results showed that the homes of the Polish elderly are often unsuitable for their specific needs and limitations. The most common issues include high maintenance costs, limited accessibility due to reduced mobility, and poor access to public transport.

[5] *National Survey on the Homeless Population* by the Ministry of Family and Social Policy (2024); https://www.gov.pl/web/rodzina/ogolnopolskie-badanie-liczby-osob-bezdomnych [accessed on: 9.10.2024].

In addition, research conducted as part of the Pol Senior2 Project confirms that a large number of Polish high rise residential areas fail to meet the requirements of seniors, who, paradoxically, are the largest group residing there at this time (Niezabitowski, 2014). On the one hand, this stems from the fact that when they were erected (between the 1960s and 1980s), they were mainly populated by young parents who have now turned into elderly residents of limited mobility. On the other hand, this also results from the political transformation of 1989, and more specifically, from the changes in the real estate sector after 1990 (Szafrańska, 2010), which had led to pensioners today account for a significant percentage of property owners in Poland. According to a pilot census study conducted in the municipality of Połaniec on the housing and economic situation of seniors (Tomasz Duda, *Housing policy and ageing* [*Polityka mieszkaniowa a proces starzenia*], 2014), approximately 70% of people aged 60+ lived independently (without children) in their own flats or houses, with an average floor area of 90 sq. m.

The 2022 study by the Public Opinion Research Centre in Poland found that the average floor area per citizen aged 65+ amounted to 47 sq. m, which was ca. 12 sq. m more than for younger age groups. These figures imply that the floor areas of homes occupied by older persons often exceed what is considered the optimum size for them to live comfortably with low maintenance costs. Oversized homes burden their budgets, especially in winter, thereby further exacerbating their financial situation.

The monograph entitled *Medical, Psychological, and Sociological Aspects of Aging in Poland* [*Aspekty medyczne, psychologiczne, socjologiczne starzenia się ludzi w Polsce*] (2012) also addressed the issues related to the conditions of senior housing, showing that over 55% of respondents aged 80+ lived in single-family homes; 41% in multi-family residential units, and 0.6% in retirement homes. Among people aged 90+, retirement homes were home to 1.1% of respondents. In addition, architectural barriers pose a particular challenge for the oldest seniors, for instance, 22.8% of people aged 80+ state they are a major problem when attempting to leave home. The study further revealed that seniors rarely engage in refurbishment of their homes, exhibiting a passivity in this regard (Bartoszek *et al*., 2012).

Regardless of the current condition of their housing, seniors are often reluctant to change their present home for a smaller, more cost-effective and modern one. This age group displays a strong attachment to their home, which sometimes makes the decision to move house difficult, even if it were to result in financial benefits and improved comfort (Fig. 3). 80% of seniors would rather stay in their present home while benefitting from various forms of support provided by relatives and/or caregivers, even if they were unable to lead a fully independent life.

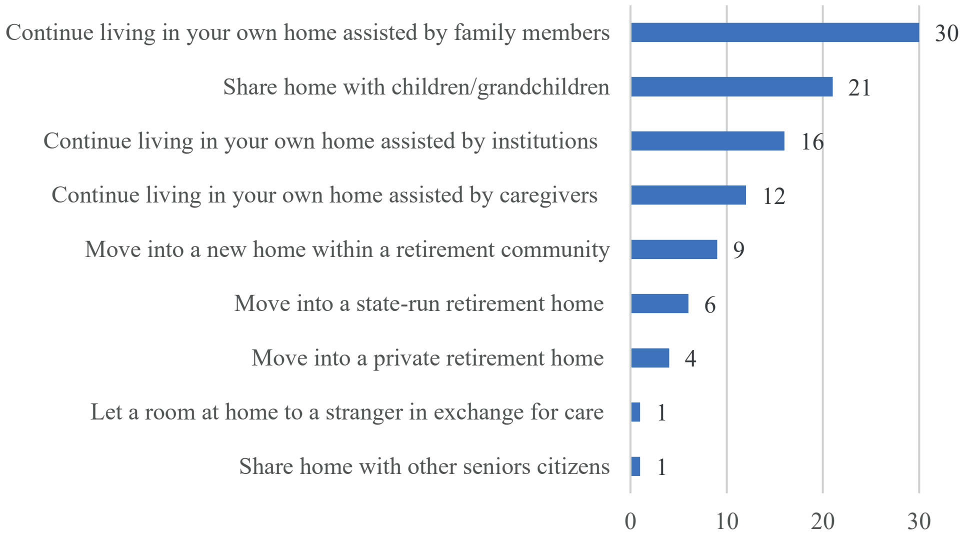

Fig. 2. Stated preferences of seniors on housing options when a problem (e.g., health-related) arises and there is a need for assistance

Source: Łukasz Strączkowski, Marcin Boruta (2018), 'Housing Conditions and Senior's Decisions on the Local Housing Market' ['Warunki i decyzje mieszkaniowe seniorów na lokalnym rynku nieruchomości'], *Krakow Review of Economics and Management*, 3 (975), pp. 69–81.

Since there is still a dearth of comprehensive studies of the conditions of senior housing that consider: the spatial distribution, age structure, household size, and financial situation of senior households in Poland, research conducted for individual municipalities remains the main source of information (Duda, 2014; Mossakowska *et al*., 2012). This research indicates that the housing situation in rural municipalities for seniors shows they reside in homes that are larger but worse equipped and furnished than those in cities. The latter are smaller (mainly 36 to 60 sq. m) but primarily located in blocks of flats built between the 1960s and 1980s by housing co-operatives, which means the location is usually quite favourable, as are the technical conditions and access to green areas, services, and public transport. However, the ever growing utility bills coupled with general property maintenance costs in the city can put a financial strain on senior citizens. This burden is currently estimated at ca. 30% of the average retirement pension for seniors in urban areas (this type of data is unobtainable at present for those residing in rural areas).

A 2023 study of the housing situation in Poland conducted by the Habitat for Humanity Poland Foundation[6] showed that the cost of maintaining homes has

[6] This CAWI survey was conducted on a representative sample of Polish men and women aged 18–65 via the ePanel.pl research panel.

grown noticeably, while residents' ability to improve housing conditions has remained limited. The concern most often reported among those surveyed was the inability to perform the necessary renovations, and an increasing number of respondents also mentioned difficulties in maintaining thermal comfort in their homes throughout the year – a problem that has exacerbated in recent years, becoming the second most commonly cited housing-related challenge in Poland. Given the low disposable income of seniors compared to the overall average income among Polish residents, one may presume that this is the reason older persons are impacted even more.

4. SENIORS' HOUSING PREFERENCES, CONSTRAINTS, AND NEEDS

Currently, there are neither comprehensive nor representative studies on seniors' housing preferences and needs in Poland. However, this research subject has been addressed through surveys and interviews conducted primarily in urban areas and in relation to preferences on the housing market (Magdziak, 2017; Strączkowski and Boruta, 2018; Tanaś *et al.*, 2019; Jancz and Trojanek, 2020). A broader picture was provided in a 2015 social cohesion study conducted by the CSO, which revealed that Polish seniors feel a strong attachment to their place of residence.[7] Namely, as many as 96% of respondents aged 65+ declared a strong bond with their homes, while 85% felt a connection with their neighbours and the local community. This attachment to the home was also observed to be more important than relations with neighbours, indicating the fundamental significance of home in their everyday life (Dudek-Mańkowska, 2017).

Trzpiot and Szołtysek (2015) reported that seniors attached great importance to a number of factors that supported health, mobility, quality of public space, safety, and daily life when assessing their place of residence. Accessibility of health centres and the quality of services they provide was a priority. As for mobility, they highly valued the possibility to travel easily, especially using mass transit. What mattered were comfort while waiting for a bus or tram, priority seats, the ease of transfer and the overall quality of public transport. The immediate surroundings of the home also played a major role. Seniors had a negative perception of

[7] Graham D. Rowles (1983) identified three key aspects of older people's attachment to their place of residence: (1) social insideness, which refers to the level of integration with the social environment: the local community, social groups, neighbours, etc. (the so-called significant others); (2) autobiographical insideness, which is emotional attachment to places associated with significant life events and memories that evoke different stages of life; and (3) physical insideness, i.e., attachment arising from a sense of comfort and spatial orientation, based on familiarity with the physical features of the housing environment, formed through everyday experience (after: Bojanowska, 2021).

neighbourhoods that were noisy, run-down or considered a poor neighbourhood with black market activity. High-quality public space was also of importance, especially places that fostered social interaction, e.g., parks, culture venues, community centres, etc., U3As, outdoor gyms, and health centres. Seniors particularly appreciated the proximity and easy access to such facilities. Top priorities for safety were safe pedestrian crossings, safe surroundings of bus and tram stops, streets, neighbourhoods and public spaces, as well as quick response times of rescue services in an emergency. As regards everyday life, support for vulnerable individuals, including the elderly and the disabled, was essential since it translates into sense of security and good quality of life.

Paweł Kubicki (2016) has identified three major obstacles that impede the social integration of older persons and affect how user-friendly cities and towns are for them. These are architectural barriers, difficulties in accessing health care, and financial constraints. For many senior citizens, the latter is a major obstacle to being active outside the home. Participation in activities also depends on health, which is often a prerequisite for an active life. This is where architectural barriers come into play as they may greatly limit the possibilities for seniors experiencing reduced mobility. Another issue is poorly adapted homes and buildings (lacking lifts and ramps, etc.), which further restricts mobility. A feature of public infrastructure that is crucial for the comfort and well-being of older persons are benches, ideally placed at distances from one another so that seniors can rest on their way to the shops or while out walking. Equally relevant is easy access to public toilets, which are still uncommon in many cities.

Strączkowski and Boruta (2018) have confirmed that the elderly generally wish to reside in their homes for as long as possible, using the assistance of official (caseworkers, etc.) or unofficial (relatives) caregivers. Younger seniors are more open to alternatives to staying in their current home, including senior housing communities or co-living with other persons in exchange for care, and seniors living alone are more likely to consider living in a retirement home, be it private or state-run (Strączkowski and Boruta, 2018).

Feedback collected in the project *Seniors Decide – Senior Citizens' Dialogue in Kraków* [*Seniorzy decydują – dialog obywatelski seniorów w Krakowie*] (Spasiewicz-Bulas, 2013) has revealed that factors like financial independence, access to quality health care, regular contact with relatives, and the ability to remain as independent as possible are vital for seniors. The last element largely depends on the removal of architectural barriers in urban space, as confirmed by studies into the activity of the elderly and the disabled (Bujacz *et al*., 2012), which indicate that the needs of the elderly are poorly addressed in new urban developments. For instance, there are often no clear markings separating pavements from cycle paths and too few benches (only 10% of the 102 streets under study in Kraków have them).

Senior citizens also report a number of issues inside their homes and within the buildings where these are located, especially in blocks of flats that have no lift, which greatly impedes their mobility, resulting in reduced social contact and impaired health. They mention difficulties within their flats, e.g., the non-ergonomic positioning of bathroom fittings that render it difficult to maintain personal hygiene and increase the risk of a fall and injury, which for an elderly person can have grave health consequences. Another issue are cupboards and cabinets that are often positioned too high or too low, thus making it hard to reach the items stored there. These factors often cause seniors to become isolated, contributing to social exclusion and deteriorating well-being. If their homes were adapted to their needs, it would be fundamental to improving their quality of life and independence.

As part of her own research aimed at expanding the knowledge on how seniors in rural and urban communities of Łódź and its vicinity assess their home and what preferences they have in this regard, in 2024 the author conducted twenty in-depth interviews with people aged 65–90. Given the complete lack of such data on seniors in rural areas, it was deemed imperative to include them into the study alongside elderly residents in urban areas. During the interviews, common opinions of home and specific needs were revealed, although these depended on the place of residence, the household size, and the age of the respondent.

Besides the opinions and preferences indicated above, the interviewed seniors reported a strong attachment to their homes, where they have had often lived for many years, further strengthened by good rapport with neighbours (often the only form of social interaction). Seniors spend their time mainly in the private space of their flat, allotment or garden (if any), and these factors determine the level of satisfaction with their current home. While members of two-person households considered their living conditions the best, those aged 80+ would often like to be assisted by and reside with relatives under the same roof, but in separate living quarters. Although they are generally reluctant to use day care centres, they still consider the possibility of moving, motivated by easier access to health care, better relationships with new neighbours, and the possibility to remain reasonably independent. They favour living in smaller towns with good access to health care and shops, believing that the public space in such places (e.g., Koluszki or Łęczyca, both ca. 13,000 residents; CSO, 2023) is better adapted to their needs than in large cities like Łódź. In their place of residence, they value peace and quiet, e.g., they are easily disturbed by loud church bells, heavy traffic, etc. Other issues that may deter them are uneven pavements, potholes, dogs running loose and making them feel unsafe, and "too few benches, not enough green spaces, as these are blocks of flats made for dwelling, not leisure."

In rural areas seniors mostly would like a decent road with a separate pavement for pedestrians but, if there is one, they would still complain, this time about the traffic. They also complain about the long distances to bus stops and shops ("everywhere is far from here"), which translates into poor mobility, especially among those who have no driving licence (mainly elderly women). Thus, demand for a mobile grocery van or a mobile hairdresser is reported. Although seniors are aware that they can shop online, they do not often use this option. And since they rarely use the Internet, they also have limited knowledge of help dedicated to seniors or cultural events promoted online. Although affected by the rising cost of home maintenance, seniors still claim that it is paying for medication that poses a greater financial burden on them.

Seniors who reside in urban areas consider flats of ca. 40 sq. m to be the optimal size for their needs and in terms of maintenance costs. They greatly appreciate it if their flat has a large balcony. The most commonly reported problem with the building itself is the absence of lifts and stair handrails, while for the immediate vicinity it is places to sit and rest. Seniors also would like air-conditioning, dedicated parking spaces for the residents of the building, and push-button activated pedestrian crossings. If assistance is needed, they rely on family or friends, and use taxis if mobility is impaired. Younger seniors would like to have a café in the vicinity of their home, a graduation tower, and a venue for events dedicated to seniors that would enhance their well-being without having to travel longer distances.

Although older persons often choose to remain in their current housing environments for as long as possible, even if their independence is reduced (Fig. 3), the aforesaid survey among seniors in Połaniec revealed that this decision was by no means absolute. When given the opportunity to move to a home adapted to their needs and allowing them to maintain independence, over 70% stated they would be willing to do so, which indicates a potentially high demand for such solutions (Duda, 2014).

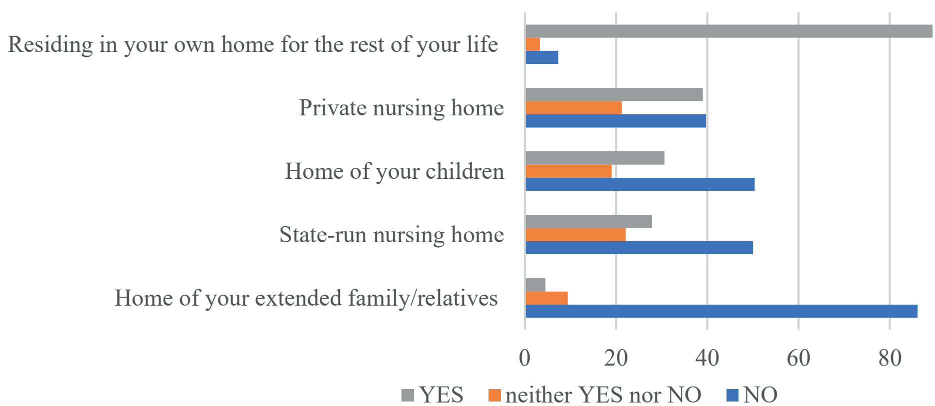

Fig. 3. Respondents' preferred housing option when faced by loss of independence (%)

Source: a survey by Elżbieta Bojanowska, Martyna Karwińska (2018) entitled *Attitudes of Senior Citizens towards Old Age and the Social Determinants of Ageing, on a Sample of 453 Respondents Aged 60+, Residents of the Warmian-Masurian Province* [*Postawy seniorów wobec starości i społecznych uwarunkowań starzenia się, na próbie 453 respondentów w wieku 60 lat i więcej, mieszkańców woj. warmińsko-mazurskiego*].

In order to allow seniors to benefit from living at their home for as long as possible, thereby reducing the costs of social care and supporting intergenerational relationships in their place of residence, the housing stock should be adapted to meet the specific needs and requirements of older persons. This requires a number of measures to be taken at the national level, namely the launch of support schemes that would make it possible to fund renovations and adaptations so that current housing could meet seniors' needs. A legal obligation for property developers to build a certain percentage of homes adapted to the needs of the ageing population is also an option worth considering. However, the greatest room for action remains with local authorities and could be pursued under the slogan: "one day you will also be a senior," for example.

5. INSTRUMENTS OF THE HOUSING POLICY AIMED AT SENIOR CITIZENS

A housing policy that focusses on older persons and is implemented on national and municipal scales by both public-private partnerships and private entities should consider a variety of aspects so as to provide senior citizens with safe, comfortable and tailored housing. The key components of the policy proposed are as follows.

5.1. Financial availability

Nearly all activities require financing, and thus, financial assistance for low-income seniors should be made available, including subsidies, tax exemptions, and dedicated banking products to enable them to sell their present properties in order to buy, or rent long-term, homes better suited to their needs.

The only instrument currently available to seniors is the **housing benefit** disbursed by municipalities. In 2022, 2,648,000 households in the country reportedly benefitted from this support, with an average allowance of 276 zlotys (CSO, 2023). However, there is no detailed data on the number of seniors that received this benefit. Although the benefit itself and the criteria for its acquisition[8] are positives, the list of documents required (property information sheet certified by the housing co-operative or community, pension statement for the three months preceding the application, extract from the land and mortgage register confirming ownership of the property, forms that need to be downloaded from the office's website and then filled out), the difficulty in understanding the information on calculating the

[8] Income in a single-person household; costs converted to a floor area of 35 sq. m; allowance applicable irrespective of the legal title to the home occupied.

benefit amount, and then the need to repeat the whole procedure every six months, render the entire process rather problematic to seniors.

Another instrument, **tax deductible renovation costs**, was in force in the 1990s, resulting in the refurbishment of a large number of homes and reducing the grey market of contractors, as invoices were required to obtain the tax deduction. As a result, it also generated revenue for the budget (Groeger, 2016). Currently, only subsidies for boiler replacement and thermal modernisation of the building are available, but there are no schemes to support the renovation of bathrooms, their adaptation to seniors' needs, or the installation of lifts or balconies. Even when an elderly person has the financial means, they would still find it immensely difficult to single-handedly manage an investment project of this scale. Thus, it would seem sensible to offer a "documentation to finished state" renovation of their bathroom or installation of a lift, especially given the fact that there is a wide range of similar services on the market, e.g., from renovation companies that replace windows and doors. As regards the installation of a lift, a further hindrance is the legal requirement to obtain the consent of all tenants within the building, which often renders the investment unfeasible.

As stated above, a **home mortgage loan** is virtually unattainable for seniors, even if they own another property that could act as collateral (based on information from PKO BP and mBank) for agents operating on the property market who would like to recommend this product to their senior customers (Strączkowski and Celka, 2012). Older persons are usually only able to take out a high-interest commercial loan of up to 250,000 zlotys, which frequently prevents them from replacing their current home with one better suited to their needs.

Since 2014, a **reverse mortgage** has been available for seniors who own a property that fulfils the requirements. This equity release allows the house owners to improve their current financial situation. The loan amount depends on the market evaluation of the property in question, and generally ranges from 30% to 60% of its estimated value. The funds can be paid out either for the rest of the senior's life or over a contractually stipulated period. Upon the death of the loan recipient, either the financial institution acquires the property or the senior's heirs keep it upon repaying the loan with any interest accrued. Despite the transparent legal regulations for this solution, it remains rather an unpopular option and, so far, no bank in Poland has decided to offer this product.

There is also a product called **life annuity** provided by mortgage funds, which are entities unregulated by banking law, making this instrument quite risky. According to the Bankier.pl website and based on data from the Association of Financial Enterprises, between 2010 and 2022, mortgage funds paid out only 30 million zlotys, with an average monthly benefit of ca. 1,000 zlotys, despite managing properties worth 150 million zlotys at the time. These figures testify to the low coverage and the still perceived high risk of participating in this scheme.

5.2. Housing availability

A well-designed senior housing policy should accommodate **a variety of housing options** for older persons, considering their family situation and level of independence.

The most desirable accommodation type amongst seniors today in Poland is independent living and, if affected by disability, it is care homes known as Social Care Homes (SCH) or nursing homes known as Residential Health Care Facilities (RHCF). However, the number of beds in these units is limited and the standard of service varies. In 2024, the monthly fee to stay in a state-run SCH ranged from 6,000 to 9,000 zlotys, depending on the location. The cost must be borne by the senior citizen, their relatives and/or the municipality. Other accommodation options include assisted living, sheltered housing, supported living, intergenerational homes, and retirement homes (Dudek-Mańkowska, 2017).

A more appropriate housing policy and greater commitment to its development would extend the period of independence for seniors and allow them to be supported more effectively in the place where they live, often for decades. The demographic projections noted previously reveal the importance of this action, which means the problem will escalate over time and a number of housing policy measures should be taken with no further delay.

One such desirable measure would be to promote or even mandate **housing adapted to seniors' needs**, i.e., free from architectural barriers. There are architectural design studies that focus on the needs of seniors at different ages, e.g., a study by Maria Bielak-Zasadzka and Dominika Szweda (2022) which has considered a broad spectrum of factors, i.e., the need for housing that is easily accessible by public transport, has proximity to green areas, easy access by road, is within a safe neighbourhood, and has no serious nuisance factors in the vicinity. The body of the building itself should have a maximum of three floors, use natural finishing materials, shared spaces suitable for its residents (wide corridors, staircases, etc.), a clearly marked and easily accessible main entrance, and no architectural barriers. The building should contain single or two-person housing units, and be well lit by daylight. The housing development itself should allow convenient access to the building (incl. facilities for the disabled), have a sufficient number of parking spaces, be favourably orientated to make the most of the daylight, and have no architectural barriers. Designing buildings and their immediate surroundings to suit the needs of seniors of all ages should be fostered through architectural competitions and be widely promoted among municipal authorities and property developers.

Assisted living is a solution addressing the housing needs of seniors who, while in need of some support, still wish to live independently and be part of the local community. This housing option can be a major component of the long-term care system for older persons. For instance, in the USA it is enjoyed by over a million residents across ca. 36,000 facilities (Andrews, 2010). Assisted living aims to support seniors to live independently outside the relatives' home or care centre, through providing professional assistance from caregivers, wardens and volunteers.

In Poland, assisted living projects are implemented by municipalities, but their scope remains very limited.[9] Private property developers have considered the introduction of senior apartments,[10] but this product has so far been aimed at wealthy citizens who do not require permanent care. Gradzik (2017) has argued that only 3% of Polish seniors can afford this type of accommodation, making assisted living an option available to a tiny fraction of the senior population and thus a marginal housing option on the national scale.

In Poland, there are very few social or council housing units adapted to senior's needs. Priority is given to families with children and those at risk of eviction. Many municipalities do not provide social or communal housing at all, as it is perceived too heavy a burden given the obligation to maintain the housing infrastructure. And in cities that offer this type of housing, there is a long waiting list, which is a major challenge for senior citizens.[11]

5.3. Safety

Safety at home should include the categories of **physical, economic, welfare, and social safety**. Based on the results of the surveys cited above on the preferences and nuisances reported by seniors, it should suffice to introduce renovation programmes (e.g., applying the tried and tested rules governing the thermal modernisation of buildings) and to impose mandatory regulations for lifts, ramps, and widened entrances to staircases and flats to be implemented in the existing buildings. A recommended conduct for interiors would involve offering affordable refurbishment of bathrooms (replacing bathtubs with showers, installing bath and shower grab bars, etc.), smoke and water leak detectors, and periodic inspections by relevant experts. With consent, visual monitoring and an easily accessible alarm button could also be installed inside the flat. Given how great the uptake for replacement windows and

[9] Measures to support seniors in retaining their independence include, inter alia, the *Nie Sami* Programme in Stargard Szczeciński and the Workers' Initiative Programme called *Mieszkanie na Winogradach* in Poznań. As part of the former, a building with twenty-four flats for let to people aged 55+ was built in 2009. As for the latter, an old flat in Poznań was renovated to create sheltered housing. It comprises four bedrooms, a kitchen with a dining area, a bathroom and a toilet (Dudek-Mańkowska, 2017).

[10] Poland's first housing complex for seniors, called Senior Apartments, was built in the municipality of Wiązowna near Warsaw (https://seniorapartments). The complex consists of eighteen detached houses and offers a wide range of support services, including catering based on customised diets, nursing care, 24/7 medical care, consultations with a GP and a physiotherapist, 24/7 supervision for emergencies, private assistance (concierge), housekeeping assistance (e.g., cleaning), to-door grocery deliveries, and Internet access. As of 2024, the monthly long-term rent for a single room was 2,790 zlotys and for a whole apartment: 5,790 zlotys; the prices did not include fees for the extra services offered.

[11] In Poland, 126,425 households are on waiting lists for social or council housing (CSO, as of 31 December 2022).

doors to improve thermal and acoustic comfort has been among seniors, it is quite likely that a programme to enhance safety at home, which would not require direct, physical involvement on their side, would be equally popular with seniors and they may be more than willing to fund it. A balcony clearly adds to the comfort at home. Alas, a number of factors, including the procedure to obtain a planning permission, the legal obligation to get the consent of all other tenants, and the necessity to co-ordinate the entire investment, render it unfeasible for most individuals in Poland. The same applies to the addition of lifts in blocks of flats that were not originally equipped with these facilities. Thus, appropriate legislative measures to simplify the procedural requirements behind such investments would be advisable in this regard.

Physical safety near home is determined by well-lit streets, smooth pavements, not too steep ramps and, of course, regular benches (which seniors mention repeatedly), which should be provided as standard along footpaths and within residential areas. Another factor to be considered is to construct public toilets in grocery discount chains and local shops in exchange for incentives for the owner, e.g., reduced taxes or rent.

The sense of safety among seniors is also strongly impacted by home delivery services, e.g., the delivery of shopping or meals. Although available on the market (e.g., boxed diets), these solutions are often difficult for seniors as they may lack the necessary online skills or experience financial or health constraints. In Poland, the implementation of long-term care insurance, which has long been available abroad (e.g., in Germany since 1995, in Japan since 2000, and in France since 2007), should also be considered (Zych, 2019).

5.4. Health care and nursing services

All surveys conducted to uncover seniors' attitudes show the paramount importance of easily accessible health care and nursing to their place of residence. For this reason they have been placed in a separate section of this paper, even though they are unquestionably related to the safety at home discussed above. Since seniors state that medical costs are the greatest burden to their budget, this issue should be entrusted to relevant institutions. To counteract loneliness and the feeling of helplessness at home, psychological and social support programmes as well as group therapy for seniors should be implemented using support groups, voluntary work or social activation schemes. These initiatives, however, require suitable and publicly accessible space within residential areas.

5.5. Community and integration

In any housing development it is important to promote **intergenerational communities**, in which seniors can live close to younger people and benefit from mutual support. One worthy approach is the concept of **time banking**, an informal barter network where time replaces money. Participants provide services, be it child or pet care, tuition, cooking lessons, doing shopping, cleaning, etc. The key principle is all services are valued equally, regardless of their actual market price elsewhere, and the unit of account is time, i.e., a single hour. Time spent by one participant helping another can be reclaimed when yet another participant assists them in a different matter. To launch a time banking scheme, one needs a group of people willing to exchange services, and this should include senior citizens. While service exchange are easier managed online, such schemes can still operate without access to the Internet. However, it is always mutual trust between participants that is a prerequisite to launch them (Pędziwiatr, 2015).

There should also be **communal spaces** where seniors could meet and participate in activities near their homes. In 2014, the state-run Senior-WIGOR programme was launched, which, from 2016, ran under the name Senior+ and covered the years 2015–2020 as part of *Premises of the Long-Term Senior Policy in Poland of 2014–2020* [*Założenia Długofalowej Polityki Senioralnej w Polsce na lata 2014–2020*]. The programme allowed local authorities to decide which of the two types of day-care facilities for the elderly they would like to establish: a Senior-WIGOR day-care home or a Senior-WIGOR club, differing in the range of services offered. The choice depended on the actual needs, and the financial support from the state budget that was earmarked for local authorities (often under budget pressure) with high proportions of the elderly within the population and insufficient infrastructure to provide social care and nursing services outside of seniors' place of residence.

Having analysed the implementation of the programme, Grzegorz Gawron reported that over a five-year period 7,070 seniors benefited from day care centres and 12,134 seniors from senior clubs (Gawron, 2023). The predominant beneficiaries were residents of rural municipalities (367 municipalities) and urban-rural municipalities (226). In contrast, only 117 urban municipalities and 62 cities with powiat rights participated in the programme. All senior participants claimed to have been very satisfied with the initiative, and between 80% and 90% reported that almost all important aspects of their lives had improved (Gawron, 2023).

The said initiatives should be assessed positively and be promoted accordingly. The only concern is the poor recipient reach, which may be evidence of limited publicity and insufficient public awareness.

5.6. Education and communication

In Poland, only 0.6% of the 60+ population participate in courses, lectures or educational programmes, compared to 5% in other EU Member States (Zych, 2019). The inclusion of seniors in the process of shaping the living space could be achieved through the involvement of local leaders who are knowledgeable about the administrative processes and regulations that shape local land use laws (Bujacz *et al.*, 2012). For this reason, it is essential to educate seniors on how local governments operate, how municipal policies and local regulations are developed, and what local initiatives that support seniors on legal, social and economic issues are available.[12] This issue could be addressed by help and advisory desks for seniors, providing information on support programmes and opportunities to solve housing issues, available online and on-site. Another effective way of reaching seniors would be traditional letters containing guidelines on the available support instruments, services, institutions, voluntary organisations, time banking schemes, etc., sent to their home address. Fortunately, younger seniors in years to come will most likely be able to make use of the information posted online more effectively.

5.7. Transport

Providing **easy access to public transport** adapted to senior's needs (low-floor vehicles, priority seats, raised stop platforms, etc.) has been partially achieved in large cities. Other improvements should include more legible timetables (large font, more conveniently placed signboards), seats at stops, and more push-button pedestrian crossings. As for rural areas, the organisation and performance of public transport is still quite a challenge. As is often the case, solutions should incorporate a number of complementary activities: communication, social integration, and coordination of actions within a given area. Once up and running, local senior citizens' associations prove to be very successful, especially when acting on their own behalf. Seniors become more active and willing to help each other, and they no longer feel alienated in their housing environment (Gawron, 2018).

5.8. Assistive technologies

In technologically developed countries like Poland, support should be given to the promotion and subsidisation of home assistive technologies for seniors, including telecare systems, smart home devices, and health monitoring applications, which

[12] One measure to support older persons in legal matters is free legal aid, which is available at senior day centres and as part of the government programme called Free legal Aid and Citizens Advice [Darmowa pomoc prawna i poradnictwo obywatelskie] (darmowapomocprawna.ms.gov.pl). Another worthy initiative, modelled on solutions employed in the West, is the "sliver haired legislature," – a panel of deputies elected by seniors to identify and promote legislative priorities relevant to seniors and to exert pressure on legislative bodies to implement these regulations on the local and national scales. There is also a number of local initiatives in Poland to support seniors in legal and economic matters, e.g., the economic security and debtor support programme implemented in Gdańsk, the Academy of Law for Seniors project [Akademia Prawa dla Seniorów] run by the Warsaw Bar Association, and the research projects of the Warsaw Legal Education Foundation: On Law for Seniors [O prawie dla seniorów] and Survey of Seniors' Needs [Badanie potrzeb seniorów], which delve into legal and economic needs among the group in question (Zych, 2019).

are all relatively easy to implement. While email communication and the use of dedicated patient service applications should be standard in health clinics today, practice shows that in primary health centres the simple renewal of a prescription for regularly taken medication still requires seniors or their caregivers to appear there in person and present a prescription. Equally desirable would be the application of AI in contacting seniors for early identification of their needs. Clearly, the comprehensive and efficient implementation of the software should be preceded by training on how to use this modern technology, constantly available online for seniors or carers.

5.9. Long-term policy

Measures for senior housing policy should shift away from short-term, small-scale programmes to the long-term operation of proven support instruments that produce the most desirable results (e.g., Senior+ programme). Developing a long-term housing strategy that considers the ageing population and the growing housing needs of seniors would reduce the population waiting for a place in nursing homes and the associated exorbitant costs for families and municipalities. Harnessing the potential of senior citizens and activating them would also facilitate the development of the so-called silver economy, thus responding to market demands in a number of fields and sectors. It would also be necessary to constantly monitor and assess how effective the implemented programmes are, a task that should be performed by the Supreme Audit Office.

5.10. Intersectoral collaboration

All the constituents of the senior housing policy advocated above require intersectoral collaboration of government agencies, NGOs, experts, and private businesses in order to create comprehensive solutions for the senior housing environment. One sign that this need has been recognised is a brand new addition to the government – a minister for senior policy. The inclusion of the said constituents can foster an effective senior housing policy that provides older, and often less able persons, with decent housing and support in their daily life.

6. CONCLUSIONS

The applied model for a senior housing policy is not only a direct product of the adopted social policy, but it is also determined by the current economic and political situation, and the cultural and demographic circumstances, which are subject to dynamic changes over time.

Since senior citizens differ substantially in needs and incomes, it is imperative to recognise both the needs of those facing poverty and social exclusion, and those who can easily afford to rent or buy a property that meets their changing needs. In all cases, improving housing means improving seniors' lives, thus helping them to remain independent and self-reliant in their preferred place of residence, highlighting how important it is for the state to develop an effective housing policy. The economic, social, and societal safety of senior housing is affected not only by the aforementioned instruments, but also by housing options and efficient social care which helps to secure the fundamental requirements of seniors in their current place of residence. Although there are a number of measures to support older persons, they are only implemented to a limited extent. The most favourable climate for organisations that support seniors is found in large cities, which – due to the advanced demographic structure and greater needs among seniors – boast a well-developed social infrastructure and ample financial resources. In mid-sized towns, the situation is heterogeneous: some offer a variety of initiatives to benefit seniors, while others only provide basic care services. The most formidable challenge, however, is in rural areas, which lack well-structured and tailored support for the elderly in their place of residence. One source of hope for improving local initiatives aimed at seniors can be the fact that they are an active electoral group, which may motivate local decision-makers to take action on their behalf.

Despite the growing awareness of the unfavourable demographic trends, the local housing policy in Poland still focuses on economic development, competitiveness, and attracting new residents, while ignoring the potential of seniors and the silver economy. At the central government level, priority is given to constructing new housing, while the need to renovate existing homes is neglected, even though they could be adapted to the requirements of the expanding senior population. The current housing policy, centred on newly built but increasingly more expensive housing from property developers, is not particularly suited to seniors. An alternative could be the revival of communist-era type housing developments made up of large-panel-system blocks of flats, where – at a relatively low cost – a comfortable housing environment can be created for seniors and younger residents, offering them an optimum floor space of 40–60 sq. m in green surroundings and a familiar social space that promotes safety and comfort of living.

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BOOK REVIEW

Helen KOPNINA, Rory PADFIELD and Josephine MYLAN, *Sustainable Business. Key Issues*, Abingdon and New York, Routledge, 2023, 302 pages

First published in 2015, this book is now in its third edition, which proves its continued usefulness for successive generations of readers. And no wonder as it builds on the problem of economic activity intertwining with sustainable development, which has not yet lost its relevance in any way. News about human-led disruptions that affect local communities and their natural environment are spreading in an instant, reaching masses of recipients all over the globe. Some of those events are misunderstood, some are ignored, while others may be reacted upon with exaggeration and some even fuel conspiracy theories. People become confused faced with a difficult and increasingly uncertain future. In this context, business has become a key player. On the one hand, companies are one of the main sources of disrupting activities, and, on the other, they themselves experience negative externalities generated by other economic entities. Therefore, nowadays more than ever, a thriving business world depends on profound knowledge about sustainable development. There is a pressing need for responsible and reliable explanations of the motives, mindsets, and possible consequences of unsustainable business practices. More importantly, both societal and business actors must be informed how such effects might be avoided or at least mitigated. An excellent field to promote such deep understanding and expand specialist implementation-ready knowledge is the higher level of education, where future professionals working in the business community and natural environment are trained. This is exactly the idea Helen Kopnina, Rory Padfield and Josephine Mylan had as they offered an introductory-level textbook for business, management, and sustainability courses.

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Obviously, *Sustainable Business* is not the first or the only voice in the discussion on the possibilities and limitations for business in the context of environmental challenges. Yet it does offer many fresh insights. However, its main value lies in a systematic, extensive, solid, balanced and reliable approach. For students, and all other readers just starting their adventure with sustainability within an economic context, such a concept is indisputably accurate.

The book is refined in terms of both content and form. Consisting of four main sections (‘Key concepts,’ ‘Critical evaluation: Key challenges,’ ‘Globalization, technology, and new trends in business,’ and ‘Solutions’), it is further divided into chapters and subchapters. Despite this seemingly complex structure, getting familiar with the content and navigation through the publication does not pose any difficulty.

Naturally, the publication begins with a comprehensive introduction to sustainable business with the key terms clearly explained (e.g., eco-efficiency, green growth, and degrowth) and exemplified, while the following chapters elaborate in detail on business ethics. They discuss the corporate environment from the perspective of its social responsibility, PR and governance practices, employment, and poverty. Again, multiple examples showcase how this topic intertwines with sustainable development. Actually, that is one of the most valuable features of the book. There is no doubt that for academic textbooks scientific theory is essential. However, it is real life cases that make it more appealing to the readers. In section one, such examples enhance exploring the essence of business ethics and visualise the consequences of stretching or breaking the rules. At the same time, the examples also reveal feasible remedial actions (that is just a foretaste of what yet is to come in the final section).

The second part of the textbook is devoted to a critical assessment of environmental, and social and economic challenges for business activity. Among those challenges, biodiversity, climate change, ecological justice, and ecocentrism (just to name few) are discussed. Much attention is paid to the commodification of nature, as well as to economic inequalities – their causes, ways to measure poverty, and their ethical dimension.

As expected, the following section elaborates on globalisation, technology, and new trends in business activity. The authors explore divergent perspectives on increasing connectedness and the interdependence of national economies, reflecting on them in a neo-liberal context. Moreover, the reader finds here a concise review of theories which tackle development and innovation (the EKC hypothesis, the ecological modernisation theory, and the post-material value theory). Also, competitive advantage issues in relation to sustainable business practices, as well as the role of employment practices and eco-entrepreneurship are discussed.

One third of the publication is devoted to sustainable solutions. They are discussed in the final part of the book. The presented solutions obviously have a great application value, while being extremely captivating (even despite the fact that the section almost completely devoid of graphics). Not only can readers become familiar with an array of tools, possible actions, and frameworks, but they also learn that these are just some of the necessary means and actions as there might be a need to adapt them to a particular context, account, medium of communication, etc. Environmental management systems, audit schemes, eco-labels, collaborative consumption, consumer choice editing, biomimicry, and blue economy are investigated among many more tools and frameworks. The last two chapters of this section scrutinise the cradle to cradle and circular economy concepts. The final pages of the book contain an extensive glossary, references, and an index.

I find the range of issues covered and the selection of the related examples impressive, especially since an edition of around 300 pages (A5 format) cannot possibly contain all the useful knowledge in the field of sustainable business. Nevertheless, the authors have skilfully balanced the number of issues covered with the level of detail in which they are discussed. For those to whom sustainable business is a secondary point of interest, this single textbook offers sufficiently solid and reliable knowledge. For students eager to specialise in this field the book offers an excellent foundation, as well as a rich source of reference that can be explored further.

Another feature of this book is that its authors were not afraid to ask tough questions (leaving some of them unanswered), and reveal paradoxes. *Sustainable Business* presents a great variety of contrasting opinions and explanations. Some might fear that this approach makes the textbook difficult to comprehend for less experienced readers, but that is not the case. The authors' reasoning (or questioning) is logical and their subtle guidance ensures that no one gets lost along the way.

The book is not captivating as far as its visual form is concerned, but, after all, this is a compendium of sustainability and economics. You would not expect it to contain a myriad of colourful graphics on a glossy paper. In fact, some grayscale photographs appear here and they keep the reader intrigued. Also, key text content is framed (not in a fancy way, but legibly enough). Despite the visual purity, the book's arrangement is apparently student-friendly, being perfectly tailored for the requirements of academic teachers as well. The content is reasonably structured, enabling quick navigation. As the scope is so wide, some readers might want to go back and forth to explore a selected issue or retrieve the meaning of the abbreviation (there are plenty of them). However, the fact that the book is provided with an extensive contents' lists at its beginning makes that task less burdensome. What the teacher will probably appreciate the most (apart from the rich content, of course) is the clear emphasis in the book on key issues, the summary of each chapter with questions for discussion, and excellent proposals for additional activities for the course participants. Those include role playing exercises, debates, watching recommended films, preparing a marketing strategy, and other tasks requiring the use of additional material available on the publishers' website.

On a final note, the reader might find the book both disturbing and reassuring. It exposes a whole array of business malfunction and failures (Volkswagen's emissions scandal, Coca-Cola's overall 'split personality,' Patagonia's 'good intentions' vs actual outcome, etc.), weaknesses, and adverse effects. At the same time, it showcases numerous 'green' and responsible ways of doing business, being a handy tool for increasing social, economic, and environmental awareness. In any case, *Sustainable Business* stimulates critical thinking. Therefore, I would broaden the target audience to include at least students of urban studies, spatial planning, and geography. Actually, this is a valuable textbook for anyone interested in sustainable business, regardless of whether they are involved in business and natural environment professionally or not. It might seem less captivating for non-professionals. However, if one aspires to become a more aware citizen, parent, businessperson or consumer, digesting Kopnina, Padfield and Mylan's publication is definitely worth the effort.

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