urban science

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The Inter-Relationships of Territorial Quality of Life with Residential Expansion and Densification: A Case Study of Regions in EU Member Countries

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Abstract: High-density urban development is promoted by both global and local policies in response to socio-economic and environmental challenges since it increases mobility of different land uses, decreases the need for traveling, encourages the use of more energy-efficient buildings and modes of transportation, and permits the sharing of scarce urban amenities. It is therefore argued that increased density and mixed-use development are expected to deliver positive outcomes in terms of contributing to three pillars (social, economic, and environmental domains) of sustainability in the subject themes. Territorial quality of life (TQL)—initially proposed by the ESPON Programme—is a composite indicator of the socio-economic and environmental well-being and life satisfaction of individuals living in an area. Understanding the role of urban density in TQL can provide an important input for urban planning debates addressing whether compact development can be promoted by referring to potential efficiencies in high-density, mixed land use and sustainable transport provisions. Alternatively, low-density suburban development is preferable due to its benefits of high per capita land use consumption (larger houses) for individual households given lower land prices. There is little empirical evidence on how TQL is shaped by high-density versus low-density urban forms. This paper investigates this topic through providing an approach to spatially map and examine the relationship between TQL, residential expansion, and densification processes in the so-called NUTS2 (nomenclature of terrestrial units for statistics) regions of European Union (EU) member countries. The relative importance of each TQL indicator was determined through the entropy weight method, where these indicators were aggregated through using the subject weights to obtain the overall TQL indicator. The spatial dynamics of TQL were examined and its relationship with residential expansion and densification processes was analysed to uncover whether the former or the latter process is positively associated with the TQL indicator within our study area. From our regression models, the residential expansion index is negatively related to the TQL indicator, implying that high levels of residential expansion can result in a reduction in overall quality of life in the regions if they are not supported by associated infrastructure and facility investments.

Keywords: high- and low-density development; territorial quality of life (TQL); entropy weight method; urban sustainability; EU member countries

Citation: Ustaoglu, E.; Williams, B. The Inter-Relationships of Territorial Quality of Life with Residential Expansion and Densification: A Case Study of Regions in EU Member Countries. *Urban Sci.* **2024**, *8*, 22. https://doi.org/10.3390/urbansci8010022

Academic Editor: Thomas W. Sanchez

Received: 15 February 2024
Revised: 11 March 2024
Accepted: 13 March 2024
Published: 19 March 2024

1. Introduction

Europe is one of the most urbanised regions in the world with more than 70% of the population living in cities, and it is projected that this figure will reach 83% by 2050 [1,2]. The expansion of built-up areas has continued in multiple regions of Europe even in regions in which the population has declined or stagnated [3,4]. Artificial areas such as built-up areas and roads showed an increase of over 6% during the 2000–2018 period [5]. This rapid development has brought many urban problems such as environmental pollution, traffic congestion, high energy consumption, the degradation of natural resources, shrinking public services, and social segregation [6,7]. As cities and urban regions continue to grow, not only do artificial uses accumulate but natural resources also indicate a corresponding decline [8]. This accumulation in artificial assets is related to economic and social development [9]. Artificial surfaces and their potential adverse impacts have led to sustainable development being identified as a priority that is aligned with three fundamental pillars as follows: social, economic, and environmental.

Research gaps were identified by Wolff and Haase [10] in finding the optimal compromise between high and low densities and liveability and sustainability [11]. As indicated in Figure 1, on the left side of the turning point (Figure 1), there are low-density developments associated with higher liveability, and on the right side, there are high densities associated with higher sustainability A combination of the difficulties in addressing housing needs and meeting sustainability goals have led to an increased role for increased residential densities and apartment developments as a preferred policy approach. This is backed by several factors that are related to sustainable urban form, such as the preservation of rural landscapes; reductions in fuel emissions from car travel, the encouragement of using public transportation, walking, and bicycling; the improvement of utility and infrastructure provisions; and the rejuvenation and regeneration of inner-city areas [6,12,13].

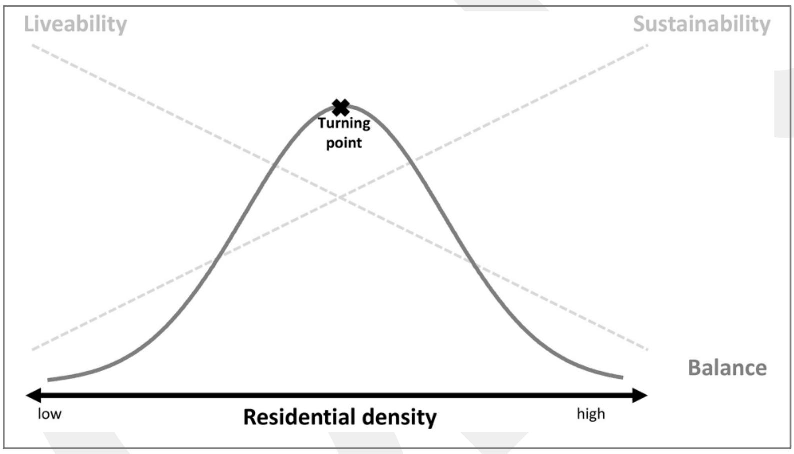

Figure 1. Balance of sustainability and liveability based on residential densities. **Source:** published in Wolff and Haase [10].

In this context, the compact city approach has been widely investigated and employed in practice as it can theoretically lead to increased sustainability [14]. This theoretical sustainability of compact cities and the impact of such policies as seen in practice remains a contested debate that requires empirical evidence to validate [15]. High-density urban development may not offer the desired urban quality of life and may even work against a sustainable future. Despite the considerable interest in the topic, there is no consensus in the literature on the impact of high- and low-density development on quality of life (QoL). This stems from the existence of various methods, definitions, and variables used for explaining the existence of spatial factors which have an influence on QoL [16–18]. A further reason is that the analysis has been conducted for different case study areas characterised by different socio-economic and spatial development patterns, and it is questionable whether a spatial pattern of an urban system in one urban area has a similar effect in determining QoL in a different urban area [19–21].

Thomas and Cousins [22] contend that people living in low-density areas experience higher urban QoL because of the higher availability of amenities like urban green spaces. However, QoL derived from green spaces is directly related to its quality and accessibility. According to Haaland and van den Bosch [23], the process of urban densification such as consolidation and infill development can endanger urban green spaces, and this may result in a loss of private urban green spaces which is hardly offset by introducing more public green spaces in an urban area. Breheny [24] and Williams et al. [25] represent examples of authors who are not certain of the link between higher densities and reduced car trips. They found that short trips in local areas may decrease; however, travelling for specialised employment, specific shopping, and leisure can be independent of urban density. Shim et al. [26] found an inverse relationship between population and transportation energy consumption given that an increase in the degree of a city's concentration decreases the energy efficiency regarding Korean cities. Fang et al. [27] represent another example of authors who showed a negative correlation between urban continuity and CO_2 emissions, and the authors asserted that increased irregularity with respect to urban form may increase CO_2 emissions. A study by Yigitcanlar and Kamruzzaman [28] examined the changes in CO_2 emissions in UK cities and found that the impact of city smartness on CO_2 emissions does not change over time.

This study develops an innovative approach for understanding the relationship between quality of life and urban expansion and densification in the pan-European area. The examples mainly focus on small study areas and cities in Europe [20,29,30]. The study has the objective of creating a scientific approach to examining quality of life issues in the context of ongoing urban development trends. The research provided original research on a high number of indicators that were classified under economic, socio-cultural, and ecological capitals, applied indicator reduction analysis to construct composite indicators of QoL in the pan-European area, and constructed the relationship between QoL and residential expansion and densification to understand whether QoL improves by being on the left side of the turning point or whether it is the right side which leads to a higher QoL (Figure 1). Here, we presume that the decline in residential density is associated with liveability and that an increase in density is related to sustainability. The QoL indicator comprises sub-indicators that are both related to liveability (green infrastructure in a region, land, climate, air quality) and sustainability (circular economy, living environment, governance, etc.). Most studies that constructed the urban liveability index did not consider searching relationships between quality of life and urban densities [31–34]. A small number of studies published in recent periods examine the relationship between compact urban forms and QoL, for example, in the city of Kolkota, India [17]; in Oslo, Norway [29]; in Jakarta, Indonesia [35]; and in US cities [36]. However, in these applications, the regions or the neighbourhoods at the local scale are assumed to be spatially independent despite the existence of spatial dependence and spillover effects.

This paper's original contribution is first in constructing the territorial quality of life (TQL) index in the EU member countries using the NUTS2 regional level indicators and then computing indicators for residential land expansion and densification. This is followed by research on the relationship between the quality of life index and land expansion and densification indicators. A TQL index is constructed based on the sub-indicators which were classified under socio-cultural, economic, and ecological capitals as defined by Zoeteman et al. [37]. Principal component analysis (PCA) was used to construct an uncorrelated set of sub-indicators. For the weighting of sub-indicators, entropy weight method was applied. Similar approaches were undertaken for the development of indicators including by Arifwidodo [38], Zoeteman et al. [37], Xiao et al. [39], Bovkır et al. [34], and Ustaoglu et al. [21]. Residential expansion and densification indicators were constructed based on residential land use, economic output, and population data (for the review of urban expansion and densification indicators, refer to Ma and Xu [40], Xu and Min [41], and Chen et al. [42]). Statistical models can reveal the relationship between quality of life and urban expansion and densification and provide an improved approach for quantifying the principal factors in comparison to qualitative analysis. This research indicates geographical clusters based on QoL and urban densities in European regions which will provide evidence for future research and policy decisions.

2. Literature Review

Understanding the relationship between the European policy context, regional planning approaches to land use, and resulting spatial and environmental trends observed is essential for this research. The European Green Deal sets a package of policy initiatives that aim to set the EU on the path to a green transition, with the ultimate goal of reaching climate neutrality by 2050. Target 15.3 of the Sustainable Development Goals for 2030 (SDGs) of the United Nations (UN) focuses on indicators of land degradation at the global level. Land use and socio-economic data support many other targets and we therefore aimed to use land use and socio-economic data in the study. Examples include SDG target 15.1 on the conservation, restoration, and sustainable use of ecosystems; SDG target 8 on sustainable economic growth; and SDG target 11 on sustainable cities and communities. To address the priorities for socio-economic and environmental sustainability set forth in the European Green Deal and other EU policies, land cover/use and land use change data must be integrated into data and policy analysis aiming to provide the sustainable development of the cities and urban regions.

As land is a limited natural resource, the continued conversion of natural and agricultural land into artificial surfaces primarily to provide for urbanisation, infrastructure, and property development processes, called "land take", is often a permanent process. While facilitating further economic development in the short term, this often has significant environmental and economic consequences over both the longer and shorter terms [43]. The concept of land take involves agricultural, forest, and other semi-natural land being taken and used instead for urban and other artificial land development [44].

The European Commission [45] called for "No Net Land Take" by 2050, and the European Commission's Roadmap to a Resource Efficient Europe aims to preserve land as a resource by reducing the pressures of urban development on the natural and managed landscapes. The concept of "No Net Land Take" combines reductions in land take with policies which will encourage land return to non-artificial land categories through re-cultivation or rewilding to provide the ecosystem services of unsealed and natural environments and soils once again. The EU Soil Strategy for 2030, published in November 2021, requires member states to set land take targets with the aim of reaching land take neutrality by 2050.

The continued political difficulties in the adoption and implementation of such measures were seen with the adoption of the Nature Restoration Law in 2023 following a contentious debate in the EU Parliament. This law is intended to be a key step in avoiding ecosystem collapse and preventing the worst impacts of climate change and biodiversity loss. A majority of MEPs (Members of European Parliament) supported the Commission's proposal to put restoration measures in place by 2030 covering at least 20% of all land and sea areas in the EU. To address the sustainable development of cities and urban regions, the European Commission promotes the compact city growth model which supports high-density mixed-use growth [46]. Density is considered as a crucial factor in defining sustainable and high-quality urban structures [47]. This is supported by a substantial body of literature suggesting that "significant and ecologically relevant services require scale and density" (Newman, [48]: 278). Compact and mixed land use patterns of development are associated with less car dependence, shorter journeys to work, more use of public transport, encouraged social interaction, and less consumption of greenfield land compared to low-density suburban developments [49]. Neumann [50] illustrates the diverging views where high levels of compactness are preferred by policy, yet excessive density can have negative effects on quality of life, health, and urban well-being.

For this research, an understanding of the planning policy approach in individual regions and their potential role in development outcomes is necessary. Drawing on recent ESPON Compass research [51], the planning systems of European regions can be identified as evolving from the differing approaches in European planning traditions. The categories were based on the scope of planning, the extent of planning at the regional and national levels, the locus of power, the relative roles of public and private sectors, the legal system, constitutional provision and administrative traditions, the maturity or completeness of the system, and the distance between objectives and outcomes [52]. The four planning traditions were as follows: regional economic planning, comprehensive integrated planning, urbanism, and land use management. This results in broad grouping into discretionary and regulatory systems, confirming high diversity as well as the existence of hybrid categories [53].

The modern housing development typologies proposed with increased scale and density promoted by key figures such as the architect Le Corbusier are regarded as seminal influences on later forms of urban development [54]. The approach to increased densities as it subsequently evolved has been criticised as being one-dimensional in that many of the supporting ideas of transit provision and ancillary facility provision are omitted with a focus only on increased density and higher buildings. Curtis ([55]: 293) critiqued that "To reduce the matter to high density when no due attention was given to communal facilities was to court disaster; to create open space without greenery was to devalue the idea of the community living in nature. The imitations of the Unité usually involved such drastic omissions. Does this mean that the prototype should be blamed for the later disastrous variations?" Smętkowski et al. [56] in their paper discuss development in a market-led system as sometimes being an organic or evolutionary processes with planning and their governance consistently trying to play catch-up. Developments are created with a site-specific mindset as private developers aim to achieve the functional transformation of lands into newer, marketable uses in line with the needs and transformations of the broader metropolitan economy.

This ties in with international debates on how liberal economic philosophies have strongly influenced policy discourses over recent decades globally. Harvey [57] has consistently argued that economic liberalisation, including the increasing role of financialisation and globalisation in housing markets, has transformed both the means and the purpose of local governance and policy approaches towards the facilitation of capital interests. Thus, numerous initiatives aimed at developing compact cities have focused on increased residential density, as well as addressing development difficulties, such as market needs and social concerns [58,59].

The compact city is therefore becoming one of the most promoted concepts in planning, with many planners and politicians advancing the compact city with high densities as the preferred urban form for sustainable development [60]. Sustainability of compact cities is linked to urban form, as illustrated in the case of Oslo [58]. However, the extent to which compact city policies can realise pre-defined policy objectives when implemented is also of concern, particularly in countries where housing development is industry- or market-driven [61–63].

3. Methods

3.1. Data

The growing density of people, activities, and amenities is related to the overuse of infrastructure, increasing land prices, privatisation of urban spaces, traffic congestion, and environmental pollution. On the one hand, artificial land and its expansion into open land and brownfields put urban green areas and open spaces under pressure [64]. On the other hand, low densities provide other different benefits such as clean air, closeness to nature, and habitats for plant and animal species. The three sustainability pillars—the ecological, sociocultural, and economic domains—as well as the subsystems that make up each of them are used in the sustainability balancing measure. A development process known as "sustainable development" strives to promote balanced growth in the robustness and quality of the environment (also known as "ecological capital"), in human physical and spiritual wellness (also known as "socio-cultural capital"), and in sound economic growth (also known as "economic capital"). For monitoring the evolution of each capital and its relative positions, they are divided down into subsystems called "stocks" utilising soft system modelling [65]. These stocks are vital for the state and growth of each capital as well as the overall system. The system of the subdivision of indicators under economic, socio-cultural, and ecological capitals is well defined by Zoeteman et al. [37]. The indicators in the current study were chosen to encompass the sustainability components that were just described of (1) ecological capital, (2) socio-cultural capital, and (3) economic capital (see Zoeteman et al. [37] where they are used in order to track the advancement of urban and regional sustainability in the EU countries). The indicators included in the study and their data sources are given in Table 1. It can be noted that the databases that we obtained from the European Environment Agency (EEA), ESPON, and Eurostat serve as our primary data sources. Additional information on the data sources used in the study is also provided in Table 1. The information is offered at the national (NUTS0), regional (NUTS1 or NUTS2), and local (NUTS3) levels. The data are cross-section data covering the post-2015 period. To create the composite indicators for our analysis, we thus aggregated or disaggregated all the data at the NUTS2 level, which is the statistical unit of our study. The disaggregation of data into smaller units means that it is assumed that the values that were calculated at a coarser scale also hold true for a smaller scale. Because there are no data calculated at the NUTS2 scale regarding some of the indicators, we had to disaggregate the NUTS0 or NUTS1 level to the NUTS2 level. Based on the availability of data for the subject indicators, we can re-conduct composite indicator analysis in the future and compare the findings from that research with the current findings. A further issue with the data is that of the absence of indicator data on a time series basis. We could not compute the composite indicators on a yearly basis and compare the indicators based on their yearly value, rather, we had to use the cross-section data and compute the composite indicators at a point in time. Depending on the existence of time series data in the future regarding our selected indicators from PCA, we can analyse the changes in quality of life in a time series context.

To compute residential densification and expansion indicators, we used high-resolution remote sensing data that represent the spatial information for various land uses, making them useful for studying the spatial pattern and analysing changes in land use. In this context, the Corine land cover/use (CLC) data that have a resolution of 100 m were obtained from the European Environment Agency [66]. To compute land use change, we used the residential land use data for the period between 2000 and 2018. There are 44 land cover classes listed in the CLC data. Among these, continuous and discontinuous urban fabric were lumped into a single land use to analyse the dynamics of residential land use within the 2000–2018 period. Population and economic output data were obtained from Eurostat's regional databases for the subject period [67]. The use of residential land use and population data for the construction of residential expansion and densification indicators is elaborated in the next section.

Table 1. Capitals, stocks, and indicators to assess quality of life in the regions.

Capitals and Stocks	Indicators
Economic capital	(ECON_C)
Labour	Total employment, unemployment, share of full-time employment, involuntary part-time/temporary employment, non-employed persons (Eurostat)
Economic structure	GDP per capita, disposable income of households, job opportunities (Eurostat)
Circular economy	Total employment in material providers, total turnover generated by material providers' activities, total employment in technology providers' sectors, total turnover generated by technology providers' sectors, total employment in Circular Business Model (CBM) sectors, total turnover generated by CBM sectors (ESPON CIRCTER Project (2017–2019): Circular Economy and Territorial Consequences (https://database.espon.eu/project-archives/#/archives) Accessed: 15 September 2023)
Infrastructure and mobility	Internet at home; broadband at home; online interaction with public authorities; internet access (Eurostat); potential accessibility to rail, air, and multimodal transport (ESPON TIA- (https://database.espon.eu/project-archives/#/archives) Accessed: 15 September 2023); green infrastructure initiatives; share of areas in a region that have poor access to the following: (a) primary schools, (b) secondary schools, (c) hospitals, (d) closest doctors, I pharmacies, (f) bank office, (g) train station, (h) urban morphological zone, (i) cinemas, (j) shops, (k) regional centres (ESPON PROFECY Project (https://database.espon.eu/project-archives/#/archives) Accessed: 15 September 2023)

Table 1. *Cont.*

Capitals and Stocks	Indicators
Knowledge	Higher education attainment rate, lifelong learning, employment in high-tech sectors, employment in science and technology (Eurostat regional education statistics)
Research and Development	EU patent applications, EU trade mark applications, EU community design applications (Eurostat)
Social-cultural capital (SC_C)	
Education	Lower secondary education completion rate, early school leavers, employment and training, young people not in education and training (Eurostat regional education statistics)
Health	Life expectancy, unmet medical needs, insufficient food, cancer diseases death rate, hearth diseases death rate, suicide death rate, infant mortality rate, premature mortality rate, road accident fatalities (Eurostat regional health statistics)
Safety	Crime, safety at night, money stolen in the household, assaulted/mugged (Gallup World Poll Statistics)
Living environment	Burdensome cost of housing, housing quality, overcrowded housing, lack of adequate heating in the dwelling, lack of toilet in the dwelling (EU statistics on income and living conditions)
Governance	Control of corruption, government effectiveness, political stability and absence of violence/terrorism, regularity quality, rule of law, voice and accountability, public service quality, impartiality (all treated equally, with some receiving special advantages in education, health care, law), corruption in public service provision, trust in the national government, trust in the legal system, trust in the police (http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1682130 Accessed: 24 November 2023)
Ecological capital (ECOL_C)	
Air quality	Average NO2 concentration, average Ozone3 concentration, average PM2.5 concentration, average PM10 concentration, emissions of CO_2 per capita, electricity produced by renewable energy resources (European Environment Agency (EEA), ESPON TIA, Baranzelli et al. [68]
Climate	Change in annual mean number of days with heavy rainfall, change in annual mean number of days with snow cover, change in annual mean number of summer days, potential vulnerability to climate change, combined adaptive capacity to climate change, relative change in annual mean evaporation, relative change in annual mean precipitation in summer months, relative change in annual mean precipitation in winter months (ESPON CLIMATE Project (https://database.espon.eu/project-archives/#/archives) Accessed: 15 September 2023)
Waste	Total waste production, municipal solid waste recycling rate, uncollected sewage, sewage treatment (EEA; ESPON CIRCTER Project (https://database.espon.eu/project-archives/#/archives) Accessed: 15 September 2023)
Hazards	Number of hazards, number of vulnerability causes (EEA)
Water	Water Retention Index, satisfaction with water quality, freshwater consumption per capita (ESPON GRETA Project (https://database.espon.eu/project-archives/#/archives) Accessed: 15 September 2023)
Soil	Capacity of ecosystems to avoid soil erosion, soil retention (ESPON TIA Project)
Green infrastructure	Coverage percentage of green infrastructure (GI), forest area within a region, area of NATURA2000 sites relative to regional area (EEA)
Land	Soil sealing within a region, share of agricultural area in protected areas, share of urban area in protected areas, percentage share of urban use areas within a region, percentage share of agricultural use areas within a region, development of urban use per capita, amount of raw material extracted from natural environment (ESPON SUPER Project (https://database.espon.eu/project-archives/#/archives) Accessed: 15 September 2023)

3.2. *Territorial Quality of Life Index*

We computed four different composite indicators to represent the sustainability aspects aligned with economic capital (ECON_C), socio-cultural capital (SC_C), ecological capital

(ECOL_C), and the sum of them (TOTAL_SC). The stages of the composite indicator development methodology that is applied in the research are summarised below.

3.2.1. Normalisation of Indicators

Due to the wide and narrow range in the variation between the variables, normalisation of the variables is required in multivariate statistical analysis. Data transformation inside a particular range (0–1) is facilitated by parameter normalisation. In this study, four separate indices (SC_C, ECON_C, ECOL_C, and TOTAL_SC) were developed using the statistical data presented in Table 1. As a result, consistency must be achieved between the four indices throughout all European regions in order to compare them. All of the indicators were standardised to have values ranging from 0 to 1. We utilised Equation (1) to denote a positive indicator and Equation (2) to represent a negative indicator.

$$I_{ij} = \frac{\left(N_{ij} - \min\left(N_{ij}\right)\right)}{\left(\max\left(N_{ij}\right) - \min\left(N_{ij}\right)\right)} \quad (1)$$

$$I_{ij} = 1 - \frac{\left(N_{ij} - \min\left(N_{ij}\right)\right)}{\left(\max\left(N_{ij}\right) - \min\left(N_{ij}\right)\right)} \quad (2)$$

where I_{ij} is the normalised value of the parameters, N_{ij} denotes the actual value of the parameters of j of location i (i.e., NUTS2 region) for the study's time period (i.e., post-2015), and min and max represent the minimum and maximum value of the parameters in the given dataset.

3.2.2. Principal Component Analysis Used for the Selection of Indicators

It is crucial to highlight that the individual indicators, which are typically connected with one another, may produce information that is excessively repetitive even though the indicator system can provide comprehensive information on the territorial quality of life at the regional or municipal size. Rather than utilising every indicator available, from the perspective of decision makers and urban administrators, using a set of comprehensive indicators is more manageable and practical. Therefore, the goal should be to build an extensive set of indicators that indicate the quality of urban life in cities and regions in order to reduce the overlap of data among different indicators. For this goal, principal component analysis (PCA), which is an unsupervised technique, is frequently used for ranking and building composite indicators [69,70]. Reduced dimensionality and weighting of all data based on composite indicators are the goals of unsupervised techniques. In quantitative terms, it establishes an initial set of correlated indicators before generating uncorrelated components, each of which is a weighted linear composite of the original indicators [70]. The linear combination of the original indicators that makes up the examined uncorrelated components are called PCs. They are computed using the eigenvectors of the indicators' correlation or covariance matrices. This technique enables us to identify a number of comprehensive indicators that can better explain disparities in territorial quality of life. Factor analysis (FA) is an alternative technique used to describe variability among correlated indicators aiming to obtain a lower number of unobserved indicators called factors. This technique can also be used for indicator selection, as applied in Bovkır et al. [34], who found that the same results were obtained from the FA and PCA methods. Because two methods follow similar approaches in the determination of components and the same results were obtained as claimed by Bovkır et al. [34], we used the PCA approach that is commonly used in the literature for indicator selection within the current study.

PCA was used for the 109 indicators, which comprise the total number of regional sub-indicators available to EU member states (Table 1). The principal components (PCs) have been extracted using the eigenvalue criterion, with eigenvalues higher than 1.0 and in other cases 0.5 being explanatory. The proportion of variance attributed to the relevant PC among the original indicators was determined next. The PC matrix, commonly referred to as PC loadings, is then obtained, which shows the weight of each PC in respect to each original indicator. The resultant matrix was rotated using the Varimax criterion to obtain loadings for computing the final outcomes for each PC. Concerning the PC loadings, the PC score coefficients were analysed, and only a single indicator from each PC was chosen for having the highest PC score to represent the other correlated indicators pertaining to the same PC loading. As a result, we decreased the number of variables to 29 and developed a set of comprehensive indicators to analyse territorial quality of life in European regions. Different studies in the literature use PCA or alternative methods such as correlation analysis to eliminate highly correlated indicators and to construct a set of comprehensive indicators. Examples include Floridi et al. [71], Mascarenhas et al. [72], Annoni and Bolsi [73], and Bovkır et al. [34].

3.2.3. Weighting the Indicators

Weights used in composite indicator construction can have a big impact on the final composite indicator and its outcomes. A great deal of composite indicators uses equal weighting, which assigns the same weight to each component. In other instances, such as factor analysis, principal component analysis, the entropy method, or data envelopment analysis (DEA), the weights are derived directly from the data [21,34]. Other methods use the AHP (Analytical Hierarchy Process) [74,75], the best worst method [76], SMART (Simple Multi-Attribute Rating Technique) [77], and the delphi method [78] to estimate the weights external to the data. These methods are examples for the expert weight determination methods and include similarity-based methods such as TOPSIS [79], index-based methods [80], and cluster-based methods [81]. A full review of the expert-based methods can be found in Chen et al. [82]. There are also examples using hybrid approaches such as when Zhang et al. [83] integrated Grey Relational Analysis (GRA) with TOPSIS to find the final rank of each alternative for the selection of the optimal green material for sustainability. Rosic et al. [84] used composite indicators developed from DEA and TOPSIS and proposed PROMETHEE-RS to select a road safety composite index. The combination of data-driven and participatory weighting approaches is provided by Xu et al. [85] as well as by Lee and Chou [86]. Other examples can be found in El Gibari et al. [87] and Correa Machado et al. [88]. Although data-based weighting methods such as the entropy method have their problems, i.e., the method ignores the sub-indicators' relative importance in a multidimensional evaluation framework, we selected the data-based method in the study and excluded the expert-based approaches for two reasons as follows: The first is the high cost of organising stakeholders at the pan-European level. The second is the effectiveness of data-based methods at coarser scales as the expert-based methods reflect the local conditions and these are more powerful at local scales. A further reason for selecting the entropy method is that according to the findings of Ustaoglu et al. [21], it is the least sensitive method to a change in weights, and it can be considered as a robust and flexible method in the construction of composite indicators.

Entropy is a scientific notion that is approximately connected with a system's state of disorder, variability, or uncertainties; therefore, a minimum production of entropy might be that of the sustainability standard. Given the intrinsic difficulty of evaluating sustainability, which necessitates integrating all dimensions (ecological, economic, and socio-cultural capitals) and their associated indicators in a tangible form, the unbiased nature of the entropy weight method (EWM) allows it to be suitable for sustainability analysis by producing unbiased results. The EWM is an objective weighting method built on Shannon's [89] entropy coefficient. It is defined in several statistical steps to determine the weight of indicators based on the data they provide, avoiding the unfavourable effects of subjective factors and producing reliable results. "H", which satisfies some features for each p_i inside an estimated joint probability distribution P, was first used to measure entropy. It was demonstrated that the only function that meets these requirements is $H = -\sum_i^n p_i \log(p_i)$ [90]. If there is significant variation between the options, the criterion provide a wealth of information and is thus regarded as an essential factor. Assuming there are m objects to evaluate, each with n evaluation criteria, the decision matrix can be constructed as follows: X = {z_{ij}, i = 1, . . ., m; j = 1, . . ., n}. For each criterion C_j, the decision matrix "X" is normalised, with P_{ij} standing in for the normalised values.

$$P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{m} z_{ij}} \quad (3)$$

The entropy E_j of each criterion C_j is calculated as follows:

$$E_j = -g\sum_{i=1}^{m} p_{ij} \ln\left(p_{ij}\right) \quad (4)$$

where g is a constant, i.e., g = $(\ln(m))^{-1}$. The entropy weight w_j of each criterion C_j is calculated as follows:

$$w_j = \frac{D_j}{\sum_{j=1}^{n} D_j} \text{where } D_j = 1 - E_j \quad (5)$$

A drawback of the entropy weighting approach is that it assigns weights that may be incompatible with the conceptual importance of the sub-indicators [91]. Additionally, the discriminating power and the composite indicator's ability to encapsulate the concept of the multidimensional phenomena are adversely affected by the weighting of the entropy index sub-indicator [92]. Despite these drawbacks, the entropy weighting approach is one of the most widely used methods in the literature.

3.2.4. Development of TQL Indicators

The TQL indicator is composed of three different indices that are related to ecological capital, socio-cultural capital, and economic capital. These indices are ECOL_C, SC_C, and ECON_C. Then, the following equation was used to compute the quality of life index across European regions:

$$\begin{gathered} TQL = ECOL\_C + SC\_C + ECON\_C \text{ where} \\ ECOL\_C = \sum_{i=1}^{m} w_i X_i; SC\_C = \sum_{j=1}^{n} w_j X_j; ECON\_C = \sum_{k=1}^{l} w_k X_k \end{gathered} \quad (6)$$

Here we used an additive aggregation method that summed up the normalised values of sub-indicators to develop the TQL indicator. Given the identified relative measurement error of a group of indicators, the additive aggregation method's continuity characteristic suggests that the bound for the sustainability index can be determined with precision [93]. This characteristic can be applied to uncertainty quantification and sensitivity analysis. There are two issues to consider: First, all the indicators' contributions can be totalled together to produce a total value, suggesting that there is no conflict or synergy between them—an assumption that appears unlikely in many circumstances [94]. Second, because the basic character of additive procedures necessitates a compensating logic, the weights used in these approaches are substitute rates rather than importance coefficients. Therefore, when there are significant interactions between indicators, additive approaches should not be used [93]. When considering the viewpoint of strong sustainability, the use of compensatory methods to aggregate indicators is frequently controversial because these methods suggest that compensation among the sustainability sub-components is appropriate [95]. Non-compensatory aggregation approaches become significant when substituting one sub-component for another is regarded as inappropriate.

3.3. Residential Expansion and Densification Indicators

There are two indices that were used to measure residential land expansion from 2000 to 2018 as follows: the first one is the residential land expansion rate (RE) that measures the average land expansion rate in the subject time period and the second one is the residential land expansion intensity rate (RI) that quantifies the average expansion intensity in the subject period (Table 2) [41,96]. Both indices are essential for comparison purposes of the residential land use change in different time periods. The normalisation factor accounts for the difference between the two indices as follows: RI uses the total built area of the last year as opposed to RE, which uses the total built area of the initial year.

Table 2. The indices and their equation for the population, residential land expansion, and densification (adopted from Chen et al. [42]).

Index	Equation
Average annual residential land expansion rate (RE) (%)	$$RE = \frac{R_2 - R_1}{R_1} \times \frac{1}{T} \times 100$$ where R_1 is the total residential built area at the initial time period, R_2 is the total residential built area at the final time period, and T is the time period.
Average annual residential land expansion intensity rate (RI) (%)	$$RI = \frac{R_2 - R_1}{R_2} \times \frac{1}{T} \times 100$$ where the expressions are the same as those for the residential land expansion rate.
Average annual population growth rate (PR) (%)	$$PR = \frac{P_2 - P_1}{P_1} \times \frac{1}{T} \times 100$$ where P_1 is the total population at the initial time period, P_2 is the total population at the final time period, and T is the time period.
Population growth-to-residential land expansion ratio (PRL) (%)	$$PRL = \frac{PR}{RE}$$ where PR and RE are as defined previously.
Urban population density (PD) (persons per km^2)	$$PD = \frac{P_i}{R_i}$$ where P_i is the total population and R_i is the residential built-up area in year i.
Decoupling indicator (DI)	$$DI = \frac{\%\Delta R}{\%\Delta GDP}$$ where R is the percent change in the residential built-up area and percent change in total GDP.

The population growth rate (PR), a measure of the typical growth rate during a specified time period, was utilised in this study (Table 2). The study employed two indicators to look at the connection involved between residential land expansion and population increase as follows: (1) the ratio of population growth to urban expansion (PRL) is that of PR to RE and (2) by dividing the total population of cities by the total built-up area in a year, urban population density (PD) is determined. Higher-density constructions and the use of PRL as a measure of urban compactness have been proposed in earlier research as strategies to achieve sustainable urban expansion [97,98]. Lastly, to measure the impact of a built-up area on the economic output, the DI is defined as the ratio of the percentage change in a residential built-up area to the percentage change in the total GDP in the specified region.

3.4. The Relationship between TQL Indicators and Residential Land Expansion and Densification

3.4.1. Regression Analysis

Landscape metrics are used to calculate and evaluate changes in landscape patterns, which are a result of changes in land use. As examples of landscape metrics, indices of residential land expansion and densification were introduced in Table 2. It is of significance to understand how the direction and magnitude of land use changes relate to quality of life at the regional scale and to the aim of planning for sustainable land management.

The relationship between land use change and TQL was examined for this purpose using spatial econometric models. In contrast to the OLS model, the spatial econometric models can more accurately depict the spatial effects of various factors on the TQL variable by taking into consideration spatial correlation and spillover influences. The usual econometric models may not work if the geographical effects are not considered [99]. Spatial lag models (SLMs) and Spatial Error Models (SEMs) are the two common spatial economic models. By enabling outcomes from one area to be influenced by (a) outcomes of surrounding areas, (b) covariates from adjacent regions, and (c) errors from adjacent areas, spatial econometric models improve linear regression. In the case of the SLM given by the following formula, spatial correlation is mirrored in the dependent variable as follows:

$$Y = \alpha WY + X\beta + e; e \sim N\left(0, \delta^2 I_n\right) \quad (7)$$

where Y is the dependent variable, W is the normalised spatial weight matrix that describes how spaces are related to one another, α indicates the geographic impact of the nearby area observation value WY on the local observation value and is known as the spatial regression coefficient, X is the independent variables, β is the regression coefficient, and e is the error term. The Spatial Error Model (SEM) looks at the spatial dependency in the error term, which suggests that there are spatial spillover effects in the error term. The SEM is provided in the equation below.

$$Y = X\beta + \rho W\mu + e; e \sim N\left(0, \delta^2 I_n\right) \quad (8)$$

where ρ is the space error coefficient of the error term, μ is the normally distributed random error term, and the other parameters are as defined previously. The issues with spatial autocorrelations in the TQL index and the failure to explain variances that may potentially be caused by spatial relationships could be solved simultaneously by applying these spatial regression models while taking into account the spatial lagged responses of the dependent variable and other unexplained spatial errors.

3.4.2. Global and Local Spatial Correlation Analysis

Spatial autocorrelation is measured using both global and local rating systems. By representing the mean difference between a variety of geographical units and their neighbouring units, spatial statistical methods are used to show the spatial properties of a dataset [100]. The spatial weight matrix W is employed to represent the spatial–geospatial relationships among various data points. Explanatory spatial data analysis (ESDA), one of the methods for spatial statistical assessment, analyses spatial autocorrelation by determining spatial dependency and heterogeneity. One of the most commonly used ESDA indicators is that of global Moran's I. Moran's I technique seeks to quantify how dependent the data are on their geographic context and evaluates if their spatial pattern is clustered, random, or dispersed [100]. When using a spatial weight matrix, the degree of variance between two sets of data are determined by how similar and how far apart they are from one other. In this study, the I index as given in Equation (9) was used to calculate the spatial correlation of TQL and residential indicators across the NUTS2 regions.

$$I = \frac{n}{\sum_i (x_i - \bar{x})^2} \frac{\sum_i \sum_{j \neq i} w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_i \sum_{i \neq j} w_{ij}} \quad (9)$$

where n represents the number of regions in the study area, x_i and x_j are the values of tested variables, $\bar{x} = (\sum_i x_i)/n$ is the average value of the tested variable, w_{ij} is the value in the spatial weight matrix. The range of values accepted by the Moran's I statistic is that in [1,1]. The data are close to one another but do not share any properties, so if the estimated I statistical value is close to -1, there is negative spatial autocorrelation. If it is near to +1, then there is positive spatial autocorrelation, meaning that the data are clustered together and have similar features in specific regions. It is inferred that there are no clusters or dispersion and that the data are distributed randomly if the estimated I statistical value equals 0.

As a local correlation analysis, bivariate spatial correlation method was utilised in the study. The statistical correlations between several variables recorded at the same location are typically the subject of traditional statistical analysis methods. It is common that the

QoL measures can extend over a wider area. This problem can be solved by doing a spatial bivariate analysis to determine the spatial associations between QoL indices and residential expansion and densification data. This co-location analysis technique was first introduced by Anselin et al. [101] that designed BiLISA to examine the spatial correlation patterns between two geospatial variables. BiLISA can be used to evaluate the link between a variable in one region and a second variable in neighbouring regions. Bivariate analysis is based on the relationship between the dependent variable and explanatory variables that are isolated at a given time point. Bivariate local Moran's I (I^{local}) was used for the spatial analysis of the regional data that are provided at the NUTS 2 level.

$$I_i^{local} = X_i^a \sum\nolimits_{j=1, j \neq i}^{n} w_{ij} X_j^b \quad (10)$$

where I_i^{local} is the bivariate local Moran's I at location i, X_i^a and X_j^b are the values of variables a and b at locations i and j, respectively, and w_{ij} is the weight matrix representing the weighting between locations i and j. Variable a at location i is clearly associated with variable b in the nearby region when I_i^{local} is strongly positive or negative; otherwise, there is not a clearly apparent relationship between them. Four types of spatial relationships can be obtained from this statistic for our study, i.e., low-low (LL—spatial concentration of low values of the TQL index and low values of the independent variable from neighbouring regions), high-high (HH—spatial concentration of high values of the TQL index and high values of the independent variable from neighbouring regions), low-high (LH—spatial concentration of low values of the TQL index and high values of the independent variable from neighbouring regions), and high-low (HL—spatial concentration of high values of the TQL index and low values of the independent variable from neighbouring regions) types of spatial clustering of different values. The summary of the methodological framework is presented in Figure 2.

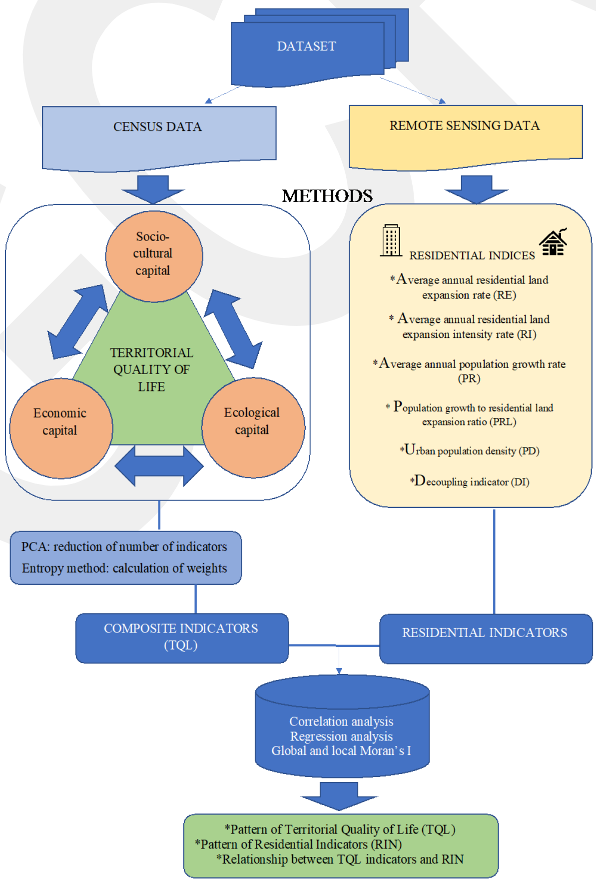

Figure 2. Methodological framework of the study.

4. Results

There are two key findings of the study as follows: First, residential expansion and densification affected TQL which is composed of economic, socio-cultural, and ecological capitals. Second, there is spatial variation explicated by spatial correlation analysis between TQL and residential indicators. From the spatial regression models, we found that residential land expansion rate and residential densification are correlated with socio-cultural capital. Socio-cultural capital has sub-components including education, health, safety, and living environment. Regarding the health sub-component, our finding supports Jackson [102] who argued that the healthiest architecture places occupants in close proximity to outside green spaces, vistas of the outdoors, ventilation, and sunlight, which are the common characteristics of low-density developed urban areas where there are an abundance of green spaces and low-rise buildings. From a different perspective, Berman [103] and Cervero [104] claimed that mixed land use and high densities increase pedestrian and bicycle activity. This supports the health benefits of the residents while protecting open spaces by consolidating development. In contrast, the proximity of shopping centres, dwellings, and transportation hubs causes noise pollution that may have a negative impact on local health outcomes [105].

Residential land expansion was found to be negatively related to economic capital and ecological capital while the relationship was positive for residential densification. Economic capital has sub-components that are related to labour, economic structure, circular economy, infrastructure and mobility, knowledge, and research and development. It was shown that these sub-components are positively related to densification, which explains the importance of agglomeration economies, accessibility to different land uses, the sharing of a common labour pool, and knowledge spillovers. This is also verified by Angel and Blei [106] who showed that densification, relocation, and improved accessibility increased the productivity of US metropolitan labour markets. Another piece of research in the US and Europe implies higher productivity in locations with a higher economic density [60].

Ecological capital has sub-components including air quality, climate, waste, hazards, water, soil, green infrastructure, and land. Some of these sub-components were verified to have a positive relationship with residential densification. Transport-related air quality was found to be more improved for the densification scenario than achieving progress in addressing urban sprawl in Quito, Ecuador [107]. A report by the OECD [108] highlights the importance of densification as it saves farmland and natural areas. Another report by the European Commission in 2016, namely "FUTURE BRIEF: No net land take by 2050?", mentions land take as one of the key trends for climate change, biodiversity, landscape fragmentation, flood risk, and urban heat island effects. This literature points to the benefits of urban densification as it improves benefits specified under ecological capital.

4.1. Selection of Indicators from PCA and Their Weighting

Table 3 presents the findings from PCA concerning the indicators selected from each PC based on their high score coefficients. The total number of selected indicators from each PC adds up to twenty-nine because this is the number of PCs that were retained. The details on the selected indicators from each PC and the variance explained by the subject PC are provided in Supplementary Materials (see Table S1). The potential impacts of the indicators on the TQL index are shown in Table 3 with plus and minus signs. For instance, employment in science and technology positively contributes to quality of life within regions, whereas the share of regions that have poor access to primary schools has a negative impact. The weights calculated from the entropy weight method are shown in the last column of Table 3, with the cancer diseases death rate having the highest weight and freshwater consumption per capita having the lowest weight.

Table 3. Selected indicators from PCA and their weights from the entropy method.

Capitals and Stocks	Indicators (Impact)	Weights
Economic capital (ECON_C)	1. Employment in science and technology (+)	0.0355
	2. Total employment in Circular Business Model (CBM) sectors (+)	0.0093
	3. Higher education attainment rate (+)	0.0437
	4. Lifelong learning (+)	0.0437
	5. Share of areas in a region that have poor access to primary schools (−)	0.0364
	6. Share of areas in a region that have poor access to closest doctors (−)	0.0365
	7. Share of areas in a region that have poor access to urban morphological centre (−)	0.0285
	8. Share of areas in a region that have poor access to cinemas (−)	0.0181
Social-cultural capital (SC_C)	9. Control of corruption (+)	0.0345
	10. Crime (−)	0.0361
	11. Assaulted/mugged (−)	0.0364
	12. Housing quality (+)	0.0439
	13. Early school leavers (−)	0.0424
	14. Cancer diseases death rate (−)	0.0552
	15. Life expectancy (+)	0.0428
	16. Unmet medical meets (−)	0.0151
	17. Insufficient food (−)	0.0228
Ecological capital (ECOL_C)	18. Average Ozone3 concentration (−)	0.0492
	19. Emissions of CO_2 per capita (−)	0.0101
	20. Electricity produced by renewable energy resources (+)	0.0479
	21. Municipal solid waste recycling rate (+)	0.0456
	22. Water Retention Index (+)	0.0472
	23. Freshwater consumption per capita (−)	0.0022
	24. Soil retention (+)	0.0170
	25. Forest area within a region (+)	0.0409
	26. Area of NATURA2000 sites relative to regional area (+)	0.0504
	27. Share of urban area in protected areas (−)	0.0052
	28. Development of urban use per capita (−)	0.0593
	29. Change in annual mean number of days with snow cover (−)	0.0329
	Bartlett's test Chi-square: 2876.339 Degrees of freedom: 406 *p*-value: 0.000 Kaiser–Meyer–Olkin measure of sampling adequacy KMO = 0.609	

Note: impacts on territorial quality of life are in parentheses, and weights are given in the last column that were obtained from the entropy method.

4.2. Spatial Variation in TQL Index in Europe

The findings showed that there was a significant variation in TQL indices between the regions in Europe (Figure 3). Socio-cultural capital was the highest in Ireland, the Netherlands, Austria, Belgium, Scandinavian countries, and some other regions in Central Europe.

Analysing the different regional approaches to social protection and investment in this sector can assist in understanding such trends. The European Commission reported that the ratio of social protection expenditure to GDP is at least 20% of GDP for the countries including Finland, France, Denmark, and Austria, and it is less than 10% in Ireland and the Netherlands [109]. With shares less than 10% of GDP in 2018, Denmark, Austria, and France recorded the highest ratios to GDP regarding health expenditures [109]. For education, the highest shares were registered in Sweden (6.9%), Denmark (6.4%), and Belgium (6.2%) [109]. These expenditures recorded under socio-cultural capital to verify our findings on the distribution of socio-cultural values in Europe.

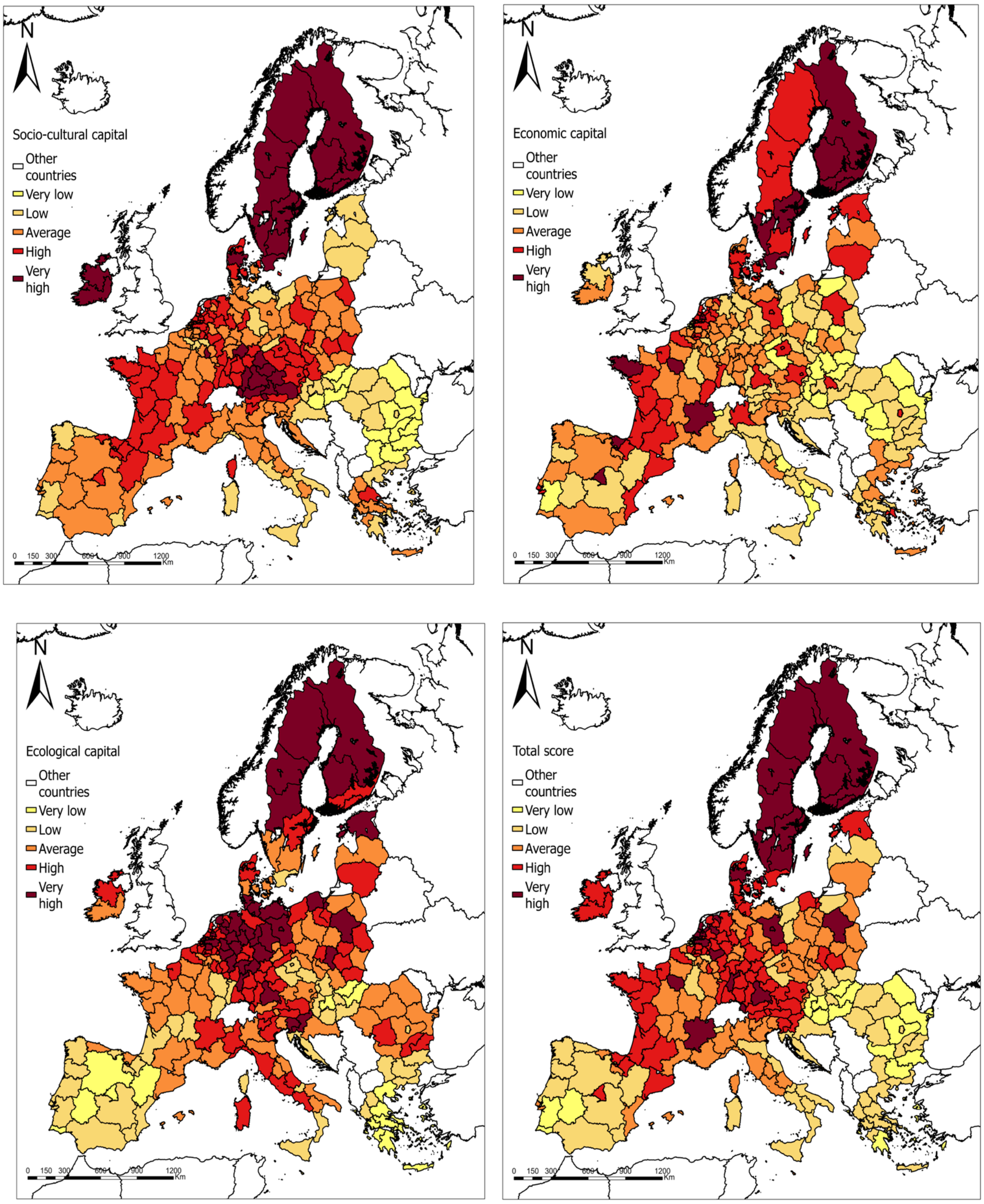

Figure 3. Territorial quality of life indicators measuring total sustainability, as well as the ecological, socio-cultural, and economic sustainability capitals at the NUTS2 level in Europe.

The details of the top five regions in each category from very high to very low scores are given in Table A1 in the Appendix A. For instance, the top five regions that have the highest scores regarding socio-cultural capital are Helsinki; West Finland; Border, Midland, and Western Ireland; Aland (Finland); and Upper Noorland (Sweden). Regarding economic capital, the highest values were computed for Belgium, Netherlands, Scandinavian countries, some regions in northern and western France, as well as central Spain and Portugal. Among these, France, central Spain, and the Scandinavian countries have recorded the highest GDPs in 2021 [110]. And gross domestic expenditure on research and development (R&D) is highest in France, Belgium, the Netherlands, and Scandinavian countries [110]. In particular, Belgium, France, the Netherlands, and Portugal have been identified as having two circular economy networks [111]. In the case of ecological capital, the highest values were observed for Northern and Central Europe, Scandinavian countries, and some regions in Eastern Europe. Except for the Scandinavian countries, these regions have been recorded as having the highest livestock and cereal production [110]. Scandinavian countries and some Eastern European countries have the highest number of heating degree days and the lowest number of cooling degree days [110]. These characteristics of the subject countries verify their being selected as having the highest ecological capital values. From the overall analysis, when the total score was computed, it was found that the total score was the highest for the Netherlands, Belgium, Scandinavian countries, and some regions in Central and Eastern Europe. The total score was lowest in Greece, Bulgaria, Romania, Slovakia, regions in southern Spain and Portugal. There are also some low values recorded for Central and Eastern European regions as well as for Southern Italy. The findings from socio-cultural capital, economic capital, and ecological capital, as well as the overall score computed at the country level are provided in Figure A1 in the Appendix A.

4.3. Spatial Distribution of RINs

The residential land expansion rate (RE) and residential land expansion intensity rate (RI) indices are not homogeneously distributed in Europe. It was identified that the highest values were in Spain, Poland, Latvia, Greece, southern and western France, regions in Central Italy, Ireland, Portugal, and Central Europe (Figure 4). These are the regions with already higher residential densities and economic growth (e.g., Netherlands, Belgium, southern and western Germany, Central and Northern Italy, western France) or regions that experienced rapid economic development (e.g., Ireland and central Spain and Portugal) [112]. The lowest values were observed for Eastern Europe, Central Europe, and northern regions in Scandinavian countries. These regions are mainly characterised by their declining population, with there being a negative change in population in many of these regions during the study period. The population growth rate (PR index) is highest in the regions where economic activity is concentrated, and these regions achieve population growth through natural processes and migration from less developed regions. The lowest values for the population growth rate (PR) and population growth-to-residential land expansion ratio (PRL index) can be found in Eastern Europe, Greece, Southern Italy, northern Spain, and Baltic countries. Among these regions, the Baltic states, Croatia, Romania, Bulgaria, and eastern Germany lost more than 7% of their population in the 2000s [113]. The distribution of the PD_00 index is more clustered than that of others, and the highest value clusters are in Spain, Italy, Greece, and Northern Portugal. Differently, the DI is distributed in such a way that the highest values can be found in any region in Europe. The lowest values are distributed with clusters that are observed for Romania, Finland, and Northern Ireland.

4.4. Results from Regression Analysis

In relation to the aims of the study, it is presumed that residential expansion and densification have an impact on the territorial quality of life. To understand their impacts on quality of life, we regressed each of the TOTAL_SC, SC_C, ECON_C, and ECOL_C on residential indicators (RINs) to represent the intensity of the effect as well as the negative and positive signs, thereby indicating whether residential indicators are negatively related to TQL or there is a positive relationship between these indicators. The results from the SLM and the SEM estimates are presented in Tables 4 and 5, respectively. It is important to note that there is no heterogeneity issue of the variances in these latter models and all the models were verified for the existence of spatial dependence of the dependent variable (Table 4) and the error terms (Table 5).

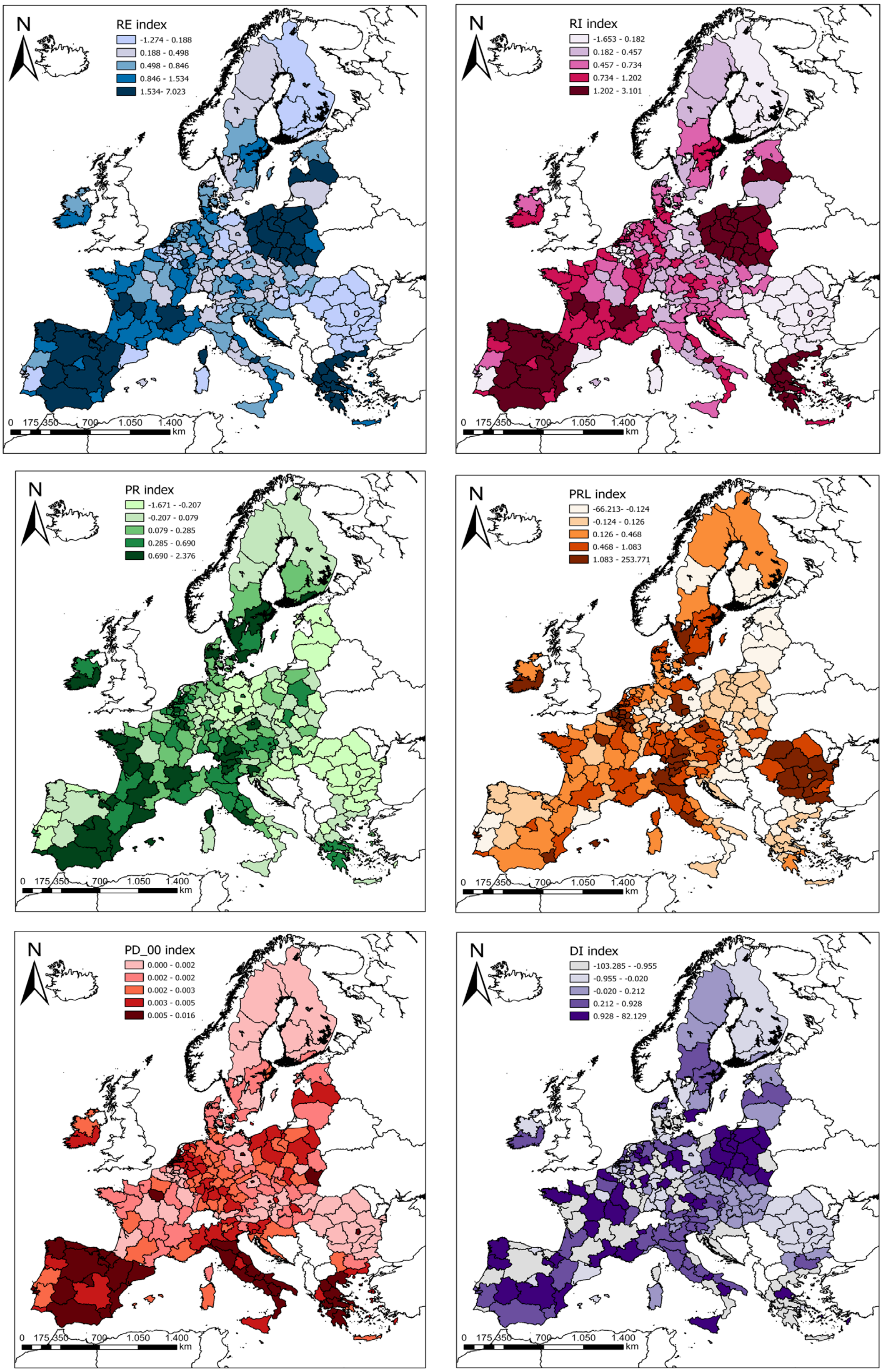

Figure 4. The sub-indices for residential indicators (RINs) including RE, RI, PR, PRL, PD_00, and DI (source: the analysis is based on the indices given in Table 2).

Table 4. The results from the SLM.

Dependent Variable	MODEL 1 TOTAL_SC	MODEL 2 SC_C	MODEL 3 ECON_C	MODEL 4 ECOL_C
Independent variables [1]				
W_dependent variable	0.256 ** (0.02) [2]	0.216 **[4] (0.03)	0.169 ** (0.04)	0.461 ** (0.03)
RE	−0.004 * (0.01)	0.008 ** (0.01)	−0.007 * (0.01)	−0.009 ** (0.01)
PR	0.047 ** (0.01)	0.085 ** (0.01)	0.072 ** (0.01)	0.007 (0.001)
PRL	−0.001 (0.01)	−0.001 (0.01)	0.001 (0.01)	0.001 (0.01)
PD_00	−2.581 * (1.56)	−6.708 ** (2.18)	1.882 * (0.78)	1.471 * (0.691)
DI	−0.001 (0.01)	−0.001 (0.01)	−0.001 (0.01)	−0.001 (0.01)
Constant	0.382 ** (0.02)	0.508 ** (0.02)	0.423 ** (0.02)	0.226 ** (0.02)
Number of observations	226	226	226	226
R-square	0.46	0.49	0.28	0.54
Adjusted R-square	0.45	0.48	0.27	0.53
Breusch–Pagan test	2.273 [0.811] [3]	8.399 [0.135]	6.694 [0.244]	1.262 [0.938]
LR test for spatial lag dependence	82.853 [0.000]	56.409 [0.000]	17.111 [0.000]	135.76 [0.000]
Root MSE	0.046	0.065	0.083	0.051

Note: (1) RI and PD-18 were omitted from regressions due to multicollinearity issues. (2) Standard errors are in parentheses. (3) Significance levels are in brackets. (4) * Significant at 0.10 level ** Significant at 0.05 level.

Table 5. Results from the SEM.

Dependent Variable	MODEL 1 TOTAL_SC	MODEL 2 SC_C	MODEL 3 ECON_C	MODEL 4 ECOL_C
Independent variables [1]				
Lamda	0.832 ** (0.03) [2]	0.801 **[4] (0.04)	0.499 ** (0.07)	0.691 ** (0.02)
RE	−0.007 ** (0.01)	0.004 ** (0.01)	−0.012 ** (0.01)	−0.011 ** (0.01)
PR	0.034 ** (0.01)	0.049 ** (0.01)	0.064 ** (0.01)	0.007 (0.01)
PRL	0.001 (0.01)	0.001 (0.01)	0.001 (0.01)	0.001 (0.01)
PD_00	1.470 (1.37)	−3.087 * (1.824)	6.376 ** (2.88)	0.758 * (0.69)
DI	−0.001 (0.01)	−0.001 (0.01)	−0.001 (0.01)	−0.001 (0.01)
Constant	0.451 ** (0.01)	0.618 ** (0.02)	0.494 ** (0.01)	0.291 ** (0.01)
Number of observations	226	226	226	226
R-square	0.69	0.74	0.42	0.65
Adjusted R-square	0.68	0.73	0.41	0.64
Breusch–Pagan test	0.632 [0.986] [3]	1.560 [0.541]	4.594 [0.467]	3.317 [0.651]
LR test for spatial lag dependence	159.54 [0.000]	160.32 [0.000]	44.755 [0.000]	144.986 [0.00]
Root MSE	0.035	0.046	0.076	0.043

Note: (1) RI and PD-18 were omitted from regressions due to multicollinearity issues. (2) Standard errors are in parentheses. (3) Standard errors are in brackets. (4) * Significant at 0.10 level ** Significant at 0.05 level.

From Model 1 estimations, it can be followed that RE has a significant coefficient and is negatively related to the TQL indicator, thereby implying that residential expansion results in a reduction in overall QoL in the regions. Population growth (PR) is positively related to TQL in both SLM and SEM regressions, whereas the population growth-to-residential expansion ratio is insignificant with varying signs. Though significant in the

SLM, population density, i.e., PD_00, is insignificant in the SEM and its coefficient is negative in the former regression model while it is positive in the latter model, thereby implying that the subject variable may not be robust in Model 1 estimations. Regarding Model 2, RE has a significant positive sign in both SLM and SEM estimations, and PD_00 has a significant negative sign. This indicates that the residential expansion that is associated with lower density development and the consumption of more green spaces can result in a higher socio-cultural capital value. In contrast, high-density residential development correlated with higher congestion costs, less green space per capita, and pollution impacts lead to a lower value of socio-cultural index. The population growth rate (PR) is significant and positively correlated with the QoL indicators in all models except for Model 4. The coefficient of PR is positive in Model 4, but it is insignificant in both SLM and SEM estimations. In Model 3 and Model 4, the coefficients of RE and PD_00 are both significant, and the former has a negative sign while the latter has a positive sign. Because urban services and activities are easily accessible in high-density neighbourhoods which are proxied by the PD_00 variable, it makes sense for people to live in close proximity to one another, which lowers land costs per person and improves quality of life (i.e., ECON_C and ECOL_C).

Given that the coefficient of RE is negative, this indicates that QoL has a lower association with an increase in residential expansion which has negative sustainability implications. Because this form of development is related to car-based mobility and there are few non-motorised activities, lower densities offer minimal possibility for interaction. This type of development is unsustainable on the grounds that it consumes high-value green land, which has various adverse impacts including negative impacts on energy use, health, the cost of public infrastructure provision, and the environment. In all the regressions, the population growth-to-residential expansion ratio (PRL) and the decoupling indicator (DI) were found to be insignificant, although these two variables had consistent signs throughout different model estimates in Tables 4 and 5. In general, we found that the residential density variable had the highest effect on QoL indicators in both SLM and SEM estimations, which is followed by PR and RE, and the smallest effect was estimated for the PRL index and DI, both of which were found to be insignificant in all the model estimations.

4.5. Results from Spatial Correlation Analysis

The inverse distance method was used to compute global Moran's I. The results showed that many of the TQL indicators and residential indicators (RINs) point to significant spatial agglomeration (Table 6). Except for the DI, which does not show any spatial autocorrelation, all the other indicators are assigned with a Moran's Index that is higher than zero. Therefore, it can be inferred that TQL or residential indicators exhibit positive agglomeration, which means high-index-value areas are surrounded by regions with high index values, with low-index areas being surrounded by regions with low index values. Because the OLS model does not account for spatial autocorrelation, we confirmed that the results from this model could not be reliable. Therefore, to measure the factors influencing TQL in Europe, spatial regression models were used and discussed in the previous section.

Table 6. Global Moran's I estimates for the parameters.

Variable	TOTAL_SC	RE	RI	PR	PU	PD_00	PD_18	DI
Moran's Index	0.3396	0.313	0.1938	0.1703	0.1699	0.1154	0.0379	−0.0062
Variance	0.0003	0.0003	0.0003	0.0003	0.0001	0.0004	0.0004	0.0002
Z-Score	18.121	15.944	10.461	9.221	16.1816	6.3757	2.251	−0.1091
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9131

The findings of the local bivariate correlation analysis are presented in Figure 5 which shows the five levels (high-high, low-low, low-high, high-low, and insignificant) for the spatial correlations between TOTAL_SC and residential indicators (RINs) across the NUTS

2 regions in Europe. The high-high and low-low clusters of TOTAL_SC and RE (or RI) are mainly located in Eastern Europe and only a few regions in Western Europe. This indicates a positive relationship between TOTAL_SC and RE (or RI), implying that residential expansion is positively associated with QoL in these regions. Regarding these regions, it was shown that liveability is more important than sustainability. Among these countries, Estonia reported that in Talinn between 2000 and 2008, more than 45% of new residential developments were established on agricultural land [114]. Other examples of cities that have experienced high land uptake include Bratislava, Prague, Warsaw, and countries such as Romania, which reported that urban expansion in eight cities was about 280% and that around 85% of 250 cities has reported concerns of urban sprawl [115]. The high-low and low-high clusters are in Eastern, Southern, and Northern Europe, thereby indicating a negative relationship between TOTAL_SC and RE (or RI). Sustainable development of these regions is more important than liveability given that residential expansion is negatively related to QoL in the subject regions. This implies that urban densification is positively associated with QoL in these regions among which large parts of Scandinavian countries had very low values of urban sprawl and very high values were observed for large parts of Western and Central Europe as computed by the European Environment Agency [116].

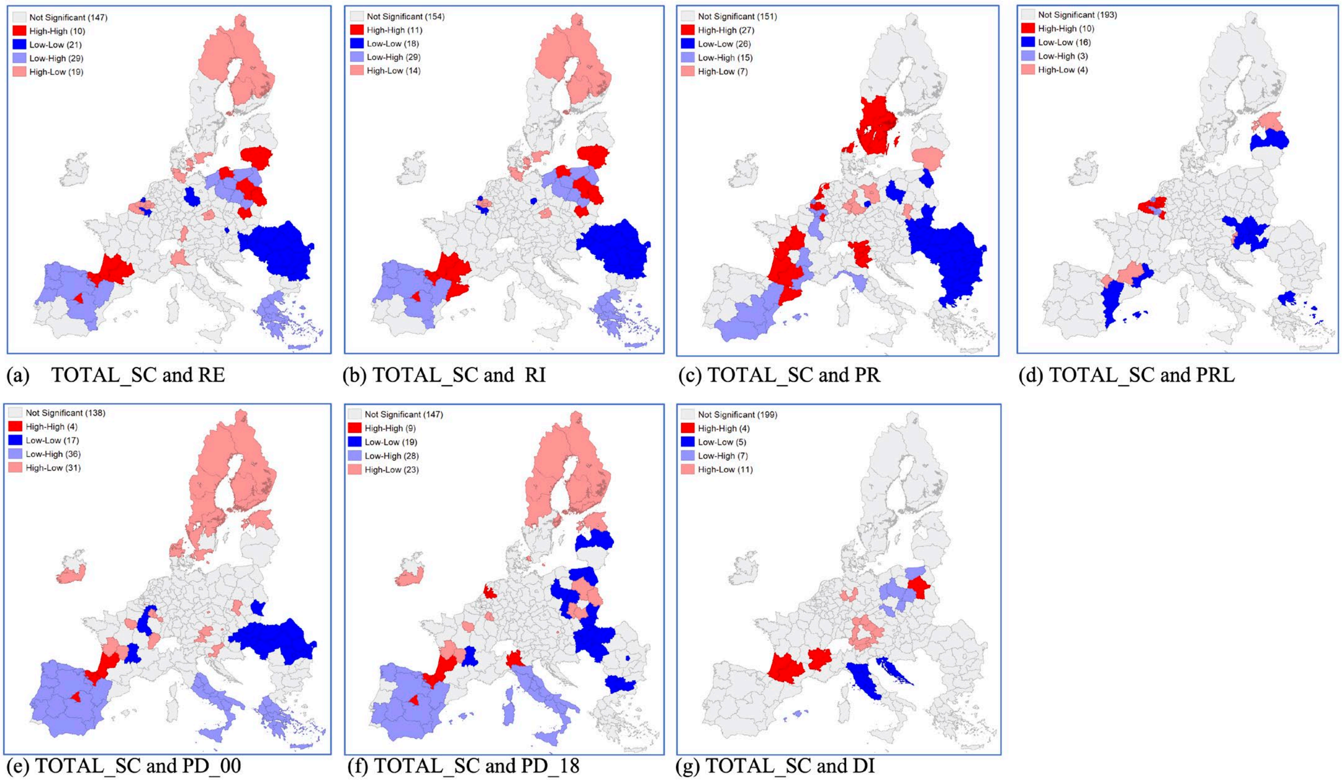

Figure 5. Bivariate local correlations between RE, RI, PR, PU, PD_00, PD_18, and TOTAL_SC indices across NUTS2 regions in Europe.

The high-high and low-low clusters of TOTAL_SC and PR are distributed in Eastern, Western, Northern, and some regions in Central Europe. For these regions, there is a positive association between QoL and population growth, whereas the relationship is negative for the high-low and low-high regions that are in Eastern, Central, and Southwestern Europe. The significant relationships between QoL and the population growth-to-residential expansion ratio generally cover high-high and low-low clusters which can be found in Eastern, Southern, and Western Europe and indicate a positive relationship between QoL and the PRL indicator. These are the regions which have experienced high numbers of population growth according to [110]. There are few high-low clusters that are in the Baltic states, southern France, and northern Spain. These high-low clusters point to a negative association between TQL and the PRL index; therefore, QoL declines when there is an increase in the population-to-residential expansion index. The population growth between 2021 and 2022 in these regions is slightly low, explaining the negative relationship between TQL and the PRL index [110]. Regarding QoL and density indicators, it can be observed that high-high and low-low clusters are in Western and Eastern Europe, which indicate a positive relationship between TQL and residential density in these regions. These high-high and low-low clusters are the regions where there are more compact urban developments, and these regions value compactness more than the others considering the covered benefits of a compact form of urban development. Low-high and high-low clusters can be seen in Southern and Northern Europe with some scattered regions in Central Europe, which highlight a negative relationship between TQL and residential density. Among these countries, the two largest clusters of urban sprawl values are located in northeastern France, Belgium, and the Netherlands, as well as part of western Germany and in the UK between London and the Midlands [116]. Finally, the TOTAL_SC and DI relationship was observed (Figure 5) with high-high and low-low clusters located in Southern Europe and low-high and high-low clusters in Central and Eastern Europe. In the first case, TOTAL_SC and the DI are positively associated, whereas the relationship is negative in the second case.

5. Discussion

It is frequently stated that urban form design can be a valuable tool to develop a sustainable urban environment, with major impacts on citizens' quality of life and wellness. The results of this paper suggest that urban expansion and densification contribute to TQL in several ways. From SEM findings, TOTAL_SC, ECON_C, and ECOL_C are negatively associated with residential expansion, whereas the relationship is positive with residential densification. Higher levels of QoL in high-density areas result from the high concentration of people allowing for easy access to different land uses and more socialising amenities, which allow for greater social networks and more active social lives. In European cities with a large aggregation of urban people, persistent pressure on infrastructure, and a limited supply of land use resources, it is obvious that creating a dense and compact urban form to accomplish service agglomerations becomes more significant. People's improved facility access allows them to engage in more socioeconomic activities by enhancing the spatial qualities of their neighbourhoods. This is often achieved by raising building heights, allowing for increasing housing and developing connecting street networks. Additionally, increased amenities and service alternatives in high-density neighbourhoods may help boost residents' sense of comfort and safety in these regions [102]. However, the extent and quantity of these amenities are often limited by financial and other practical constraints, which can result in an inadequate supply of communal facilities in less densely populated parts of the newly developed urban land.

The compact city approach's shortcomings in fulfilling the many characteristics of sustainability are evident through actual application and analysis of compact cities. After a certain level of environmental efficiency produced by a compact urban shape, certain negative effects may become more obvious [117]. This verifies the concept of the turning point mentioned by Wolff and Haase [10] who show the optimal compromise between high and low densities. For instance, some empirical data imply that the potential environmental advantages of compact cities, most notably decreased energy usage for transportation and associated emissions of greenhouse gases from less travel, are exaggerated and that the outcomes vary depending on the specific circumstances [118,119]. Furthermore, density alone may result in less desirable neighbourhoods and inferior public amenities, endangering social quality of life [120]. This is reflected in our estimated models where SC_C is positively related to residential expansion, and it is negatively related to densification both in the SLM and SEM. This implies that density negatively affects QoL, particularly the socio-cultural component, and residential expansion at lower densities, in contrast to high-density development, improves QoL through the provision of wider green spaces and a healthy and peaceful environment. While crowding can cause negative, anxious feelings, nature has significant perceived restorative qualities that can promote the pleasant emotions of calmness and relaxation [121].

Our finding on the negative relationship between SC_C and densification is also verified by Neuman [50], who indicated that high density is detrimental to liveability, and by Morrison [122], who suggested that high densities are related to unhappiness. Centred on the subject debate, critics are increasingly asking whether different styles of urban structure are more or less sustainable, particularly when linked to concepts of compactness. The study of the connection between urban form and social sustainability is therefore controversial [123,124]. The creation of a sustainable city and neighbourhood must consider not only the technical requirements but also the development's actual social-cultural, economic, and environmental implications [125]. To what extent the urban compact and dispersed developed cities have socio-economic and environmental implications is currently unclear from the literature and the supporting empirical case study evidence. Therefore, this study provides an empirical framework by focusing on European regions and searching the relationship between residential expansion/densification and three capitals (i.e., socio-cultural, economic, and ecological) of territorial quality of life.

In today's urban context, especially since the global experience of the COVID-19 pandemic, the concept of safety encompasses more than just crime or violence prevention and includes accessibility, public space, and socialising. The value of the built environment needed to be optimised by making the most efficient use of space to accommodate the increased "distance" needed during the COVID-19 pandemic. Kwon et al. [126] asserted that the scope of social distancing measures is limited in compact cities emphasising the compact city model's susceptibility to shocks by correlating the spread of diseases with high-density and mixed land use. To control disease outbreaks efficiently and sustainably in cities, a multifaceted urban planning strategy that considers polycentric and dispersed urban form is advised by the authors. This finding by Kwon et al. [126] explains the positive association between socio-cultural capital and residential expansion as well as the negative relationship between socio-cultural capital and densification in our model. The benefits of polycentric development include an improved economic performance through the realisation of economies of scale while minimising expenses related to congestion, increased economic inclusion, and more regionally balanced growth [127]. What is unexplained is the issue of dealing with violence and crime, which requires a mix of land uses that encourage continuous utilisation of space at various times of the day and an improvement in nighttime visibility using appropriate lighting, etc., which can be easily provided by a compact city model. This follows the generally believed but mostly untested argument that high-density neighbourhoods feel safer than low-density ones because they are more monitored with more people in the area [128]. A further implication of our findings supporting the positive association between socio-cultural capital and residential expansion is that of the education component. Higher quality school provision does not tend to be available in the lower quality inner-city areas which have both mixed-use and high-density developments [129].

Governance is the other component of socio-cultural capital that we found to be positively related to residential expansion. In a study by Ustaoglu and Williams [130], it was found that decentralisation and political fragmentation were positively related to urban land expansion and that the quality of regional government and governance was negatively associated. In their study, state-led and market-led spatial planning systems, as well as systems classified as being in-between, were linked to significant levels of agricultural land consumption. This was also confirmed by Dombi [131], who showed that the types of spatial governance and planning systems can impact urban form.

Land use change can be considered as a complex but self-organising series of synergetic market actions linked to individuals, businesses, and other agencies changing demand requirements, often within a regulatory context. Modern land use and development have evolved as a primarily economic market process in which major development interests along with policymakers and planners have a decisive influence. Development interests seek to standardise and provide various sector space requirements as a commodity and provide it at a profitable rental or sale price. The planning system in many regions operates as a legally based process with conflicting views contested at application and appeal stages by interested parties and regulators. Policy interests and regional planners, in turn, can seek to facilitate or direct the built environment process to achieve social, environmental, and economic aims. The development of the appropriate tools and evidence, such as urban modelling and analytics, which may assist in achieving the best utilisation of scarce public investment resources is an option which can benefit these processes.

This research and policy analysis can assist and balance effective urban and environmental management with investment strategies for regions and demonstrate them through evidence-based research. The research can inform choices regarding the optimal locations for residential development and investment in terms of broad infrastructure provision, employment capacities, demographic trends, and sustainable development patterns. This can be assisted by geospatial modelling and evidence analysis based on the data layers collated from regional and state agencies at the individual area/case study level. Further research on advanced environmental, urban, and regional modelling as well as analysis techniques can be used as part of research and policy analysis internationally. The context for the use of evidence-based indicators within regional planning decision making is the need for the evaluation of alternatives in decision making. Analysing policies within individual jurisdictions and development models would require further research to develop an understanding of the planning approach in each area. This would give context to the modelling and analysis which are developed in this project. For such further research, an analysis of the critical policy and planning practice would allow for unique individual regional circumstances to be considered.

In recent decades, researchers, policy, and industry interests have made considerable progress in improving the capabilities and usefulness of G.I.S., Spatial Decision Support Systems, and geospatial models for the evaluation of urban and regional environmental and development patterns as well as planning policy. Their rapid development is based on the need for evidence-based support for decision making in this area. Such tools are particularly valuable for agencies with environmental and ecological responsibilities, regional and city managers, planners, and policymakers, as well as for a wide range of economic and development institutions. Such evidence can be viewed as part of an integrated ecological approach to decision making with a strong scientific and quantitative basis. A concern with such approaches is that along with such specialised datasets and models, decision-making processes are dependent on the values and attitudes of the various socio-economic groups of city region residents and key decision makers. Earlier research on decision support tools for managing the urban environment in Ireland [132,133] provides an overview of research on the urban environment and integrates its use in the planning policy of data on air quality, urban transport, biodiversity, climate change, and urban sprawl. Examples of the key findings of this earlier related research using data analytics and the EU MOLAND model include how well-designed mixed-use developments can reduce transport-related emissions by reducing travel to employment and services and could enable an increased modal shift to public transport. For example, dispersed development in hinterland areas shows up to 15 times higher transport-related energy consumption. When compared with a business-as-usual scenario, a compact city scenario represents a saving of 18% in transport-related energy consumption. In addition, a compact urban form could provide a 16% decrease in energy demand for space heating under the evaluated climate change scenario.

A further important finding of the current study is that of the negative association between economic capital and residential expansion, and the relationship is just the reverse between economic capital and residential densification. This is supported by the study of Valenzuela et al. [134], which is an innovative study of residential densification that views residential density as an opportunity to implement circular economy cycles at the local level. Economic output is found to be higher in high-density built areas as shown by Li [135] who indicated that the urban structures that have evolved from low polycentricity and low dispersion to high polycentricity and low dispersion have undergone the highest per capita GDP growth. A further implication is that of the scaling effect represented by economies of scale and increasing returns, which was found to be stronger for regions with spatially compact GDP distribution, which has been confirmed by Meijers and Burger [136] and Kuno Pradipto [137]. In terms of infrastructure development, it can be asserted that high-density urban development is more effective and economical than lower density development when it comes to the provision of underground utilities (i.e., energy and transport networks, sanitation, etc.), which may reduce pollution [47]. It also encourages the development of a more effective public transportation system and an urban design that lessens the need for private automobile transportation. QoL in the built environment refers to the type and degree of accessibility to services and amenities in a particular location. Although accessibility is a broad word in and of itself, in this context, it can be defined as the quantity and variety of services and facilities, employment and educational opportunities, and adequate housing that are available in the neighbourhood. Accessibility also refers to how one can get to such services and facilities, including through local and distant networks of public transportation, walking paths, and bicycle lanes. Our study confirms the findings of research that indicated that accessibility to urban services is improved by high-density and compact development in contrast to the reduced accessibility of the dispersed urban form which leads to increased dependency on private modes [120,138,139]. A final component of economic capital is that of research and development which has a positive association with high-density development, confirming the study of Hamidi and Zandiatashbar [140] which found that urban compaction positively and significantly affects the number of innovative firms through providing spatial proximity to firms in related business sectors (see also Bereitschaft [141]).

This research found ecological capital to be negatively related to residential expansion and positively related to residential densification, which confirm the study of Kang et al. [142], thereby indicating that the degree of the land use mix, clustering, and concentration of development results in better air quality in comparison to dispersed urban development, which is associated with poorer air quality. This is in line with the findings of Fan et al. [143] who showed that fragmented and complex urban forms generally result in higher emissions of CO, NO_x, and $PM_{2.5}$ where the compact form of northern China reduced emissions more effectively than southern China, which had a more fragmented urban form. Energy consumption was also influenced by the urban form where more compact and less peripheral urban developments are associated with reduced residential electricity consumption as confirmed by Wilson [144] and Chen et al. [145]. The relation is just the reverse concerning the provision of urban green spaces and ecosystem services. Woldesemayat and Genovese [146] showed that high-density mixed residence use provided less urban green spaces compared to low-density mixed residential development. Urban green areas compete with other uses of urban space, such as housing or commerce, and are frequently seen as a land reserve for housing and other urban development projects [147]. Thus, urban densification may be associated with a loss of green space or a decrease in per capita green land provision. This is a counter argument and does not support our findings of the positive relationship between residential densification and ecological capital.

6. Conclusions

In conclusion, our results showed that residential expansion is favourable for the residents concerning their socio-cultural capital values and that residential densification provides the residents with higher values of economic and ecological capital. This finding verifies the "compact city paradox" that refers to the conflict between increasing environmental quality and lowering social disadvantages (such as a lack of green spaces) through densification on the one hand and decreasing negative effects brought on by urban expansion (such as longer commute times, loss of fertile soils, reduction or loss of ecosystem services) on the other hand [148]. Studies that link urban spatial structure to socio-economic and environmental values typically concentrate on just one factor, such as energy consumption, urban green space, transport system, air pollution, health, education, or poverty [102,103,129,136,138,142,146]. Some incorporate various indicators or combine these indicators to construct a QoL index [20].

This research dealt with several facets of the quality of life both separately concerning the three different capitals of QoL including socio-cultural, economic, and ecological capitals, as well as collectively. We also specify some limitations to these findings. In our analysis, we included residential expansion and densification indicators to explicate the relationship between these indicators and TQL indices. We note that the process of urban expansion, which is fuelled by factors such as population growth, motorization rates, and increased income capacity, emerges as an inevitable aspect of economic development. Urban growth processes can take on various spatial forms, such as clustering, fragmentation, and sprawl, and it is important to highlight that urban expansion is not equal to sprawl. Future research is needed to identify the land use patterns of individual regions to understand whether there is urban sprawl, spatial clustering, or fragmentation.

Urban expansion is a physical process that results from repeated changes in the urban structure as a fundamental part of urban development. Sprawl, on the other hand, corresponds to a certain expansion pattern that is mostly described as scattered development. In future work, more detailed urban structure indicators measuring compact and sprawled developments can be developed and their association with TQL can be quantified. By including a comprehensive set of indicators, we aimed to consider all the aspects of TQL, and the inclusion of these indicators are limited based on the availability of data. The data on our sub-indicators are available for the post-2015 period and time series data regarding these indicators are not available at present. Based on the future availability of data, new indicators measuring different aspects of TQL can be considered and time series comparisons of QoL indicators can be conducted. A further issue is that of the spatial resolution of the images that were used for the calculation of residential expansion and densification indicators. We used a high-resolution (100 m) image from the Corine land cover programme for the years 2000 and 2018. With the given resolution and spatial details, there is not any other consistent spatial dataset covering the whole European region. Depending on the future availability of a spatial dataset with a higher resolution, our analysis can be repeated to see the impact of image resolution on the urban expansion and densification indicators and their relationship with the TQL indices.

This research highlights that the promotion of higher densities and compact cities in isolation may fail to recognise the complex impacts these changes can have on residents quality of life and the long-term sustainability of urban growth patterns. For planners and policy makers, the findings suggest that a more nuanced approach is needed for individual regions. The more localised regional approaches should include discussions on the benefits of more compact and dense residential developments but should be directly linked to existing area capacities, resources, and levels of supporting investment involved. The use of evidence-based models and the analysis of indicators are an integral part of obtaining a deeper insight into the changes in land use in an urban and regional context and how their interactions change over time. Such indicators enable analysis and synthesis of large datasets into clear information on important land use trends. That information can then be used to facilitate the interpretation of these datasets and support policy makers, planners, and decision makers to use such evidence, thereby allowing for a shift to evidence-based environmental policy and urban management. Major policy or paradigm shifts are necessary to move societies to more sustainable development paths, but this clearly presents political, economic, and social challenges. A more balanced type of development may be that of polycentric urban regions which point to regions characterised by the existence of multiple proximate centres where there is balanced development among these centres [149]. For the planning of such regions, the integration of land use planning, urban and regional planning, and the planning of transport and other infrastructure have been highlighted to be important and should be considered in the planning and policy-making actions of authorities. The EU's 7EAP highlights the significance of resource efficiency, the fact that land is a limited resource, and the need to take the urban environment into account.

Planning tools and practices are crucial in influencing changes in land use, especially that of urban sprawl.

Regional planners and policy makers should already possess a solid understanding of the elements that cause urban sprawl in their own areas as well as the policies and tools that would reduce any negative impacts. To help public agencies better manage urban sprawl, regional planning capacities and resources will need to be strengthened, especially in the regions with higher rates of residential expansion. These regions were identified in Figure 4 which shows the residential indicators pointing to residential expansion and densification. The planning tools may need to also be strengthened in regions which have existing high densities. These regions may struggle with air pollution, congestion in infrastructure use, high land prices, and other negative impacts of high-density development. These adverse impacts of high-density development are identified in the literature [122,150] along with contrasting studies suggesting that compact development may not be detrimental to well-being [151]. Therefore, more local case studies are essential for the relationship between QoL and the varying degrees of densification, which can be set as a future research goal. This in turn will inform more region-specific planning and policy responses to issues arising rather than a uniform policy response.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/urbansci8010022/s1, Table S1. Variance explained by principal components and selected indicators.

Author Contributions: Conceptualization, E.U. and B.W.; methodology, E.U. and B.W.; software, E.U.; validation, E.U. and B.W.; formal analysis, E.U.; investigation, E.U. and B.W.; resources, E.U. and B.W.; data curation, E.U.; writing—original draft preparation, E.U. and B.W.; writing—review and editing, E.U. and B.W.; visualization, E.U.; supervision, B.W.; project administration, E.U. and B.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data will be available upon request.

Acknowledgments: We would like to thank to three anonymous reviewers who contributed to the earlier versions of this manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

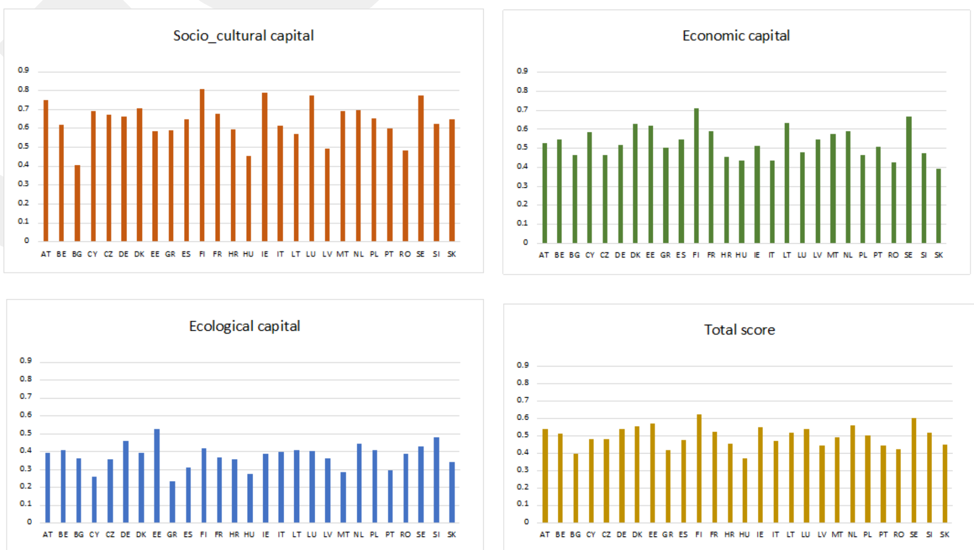

Figure A1. Territorial quality of life (TQL) indicators measuring total sustainability, and the ecological, socio-cultural and economic sustainability capitals, country average scores.

Table A1. Classification of regions based on TQL indices.

		Top Five Scored Regions						
Category	**Value Ranges**	**SC_C**	**Value Ranges**	**ECON_C**	**Value Ranges**	**ECOL_C**	**Value Ranges**	**TOTAL_SC**
Very high	>0.71	Helsinki-Uusimaa (FI1B); West Finland (FI19); Border, Midland, and Western Ireland (IE01); Aland (FI20); Upper Norrland (SE33)	>0.61	Ile de France (FR10), Helsinki-Uusimaa(FI1B), Utrecht(NL31), Madrid(ES30), South Finland (FI1C)	>0.44	Brandenburg (DE40), Berlin (DE30), Arnsberg (DEA5), Estonia (EE00), North and East Finland (FI1D)	>0.55	North and East Finland (FI1D), Helsinki-Uusimaa (FI1B), West Finland (FI19), Upper Norrland (SE33), Utrecht (NL31)
High	0.67–0.71	Trentino-Alto (ITH2), Detmold (DEA4), Oberfranken (DE24), FR61, Karlsruhe (DE12)	0.54–0.61	Southern Denmark (DK03), Catalonia (ES51), Brandenburg (DE40), Berlin (DE30), Aquitaine (FR61)	0.41–0.44	East Middle Sweden (SE12), Groningen (NL11), Oberpfalz (DE23), Gelderland (NL22), Oberfranken (DE24)	0.52–0.55	Oberpfalz (DE23), Malopolskie (PL21), Bretagne (FR52), Tübingen (DE14), Pays de la Loire (FR51)
Average	0.63–0.67	Rheinhessen-Pfalz(DEB3), Münster (DEA3), Opolskie (PL52), Aragon(ES24), Limburg(BE22)	0.49–0.54	Saarland (DEC0), Auvergne (FR72), Latvia (LV00), Namur (BE35), Bourgogne (FR26)	0.37–0.41	Niederbayern (DE22), BG32, Kujawsko-Pomorskie (PL61), Veneto (ITH3), Nordjylland (DK05)	0.49–0.52	Trentino-Alto (ITH1), Southern Denmark (DK03), Freiburg (DE13), East Flanders (BE23), Limburg (BE22)
Low	0.58–0.63	Castile-Leon (ES41), Lombardia (ITC4), Nord Pas-de-Calais (FR30), Eastern Slovakia (SK04), Norte (PT11)	0.44–0.49	Münster (DEA3), Kriti (GR43), Veneto (ITH3), Friuli-Venezia Giulia (ITH4), Hainaut (BE32)	0.32–0.37	Crotia (HR04), AT31, Marche (ITI3), Bremen (DE50), West Sweden (SE23)	0.44–0.49	Cantabria (ES13), Podkarpackie (PL32), Auvergne (FR72), Lorraine (FR41), Lisbon (PT17)
Very Low	<0.58	Kentriki Makedonia (GR12), Puglia (ITF4), Namur (BE35), Estonia (EE00), Leipzig (DED5)	<0.44	Sterea Ellada (GR24), Moravian Silesian (CZ08), Molise (ITF2), Kujawsko-Pomorskie (PL61), Puglia (ITF4)	<0.32	Navarre (ES22), FR42, Bucuresti-lifov (RO32), Yuzhen tsentralen (BG42), Western Transdanubia (HU22)	<0.44	Aragon (ES24), Latvia (LV00), Region of Murcia (ES62), Budapest (HU10), Severozapad (CZ04)

Note: In parenthesis are the NUTS2 codes of the region.

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