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THE CHANGING ROLE OF FUNCTIONAL URBAN AREAS IN REGIONAL POLICY: NEW CHALLENGES FOR PLACE-BASED POLICY

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ABSTRACT: The place-based approach in regional policy draws attention to the need for tailoring regional interventions to the specificity of local contexts and their spatial connections. In this context, functional urban areas (FUA) are significant, reflecting the spatial ranges of functional relations and linkages generated between nodal cities and the surrounding areas. The article points to the need to change the meaning of the FUA in the cohesion policy system under the current paradigm. We believe that FUAs are much more suitable for identifying spatial differences, allowing for much more effective and tailor-made regional interventions. We present a new methodology of typology of FUAs in Poland, on the basis of own FUAs' classification, aimed the scale of spatial differences of socio-economic development, and placing them in the range of the inner peripheries as areas with special development needs. A precise mapping of areas characterized by developed functional relationships and thus constituting a coherent functional whole makes it possible to more rationally plan interventions tailored to the specificity of a given area. The applied research methodology may be a high value of universality and applicability; therefore, it can be replicated in other countries (while taking into account all limitations).

KEY WORDS: functional urban areas (FUA), urban region, delimitation, functional linkages, place-based approach, Poland.

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1. Introduction

Developmental inequalities are a permanent feature of the reality that surrounds us. Regardless of the interpretation of the conditions and progress of the development process, the presence of its large spatial differences is commonly considered to be a negative phenomenon, limiting the effectiveness of the functioning of socio-economic systems (Amin, 2014; Harvey, 2016).

Striving to reduce spatial development inequalities is one of the main tasks of regional policy. When in search of optimal methods of programming and implementing development interventions undertaken within its framework, it is currently widely believed that effective regional policy requires reorientation towards an integrated place-based policy approach, effectively and consistently operationalizing the assumptions of regional policy reforms proposed by Barca (2009; European Union, … 2022).

A place-based policy approach in regional policy highlights the need for contextual planning and policy delivery by considering diverse local needs and spatially-diverse territorial resources (Churski et al., 2021a; De Toni et al., 2021; Moodie et al., 2022). This requires strengthening preferences for bottom-up activities and limiting activities carried out with the assumption of 'one size fit all' (Morgan, 2016). In this context, Functional Urban Areas (FUAs), which reflect the spatial ranges of functional relations and linkages generated between nodal cities and surrounding areas, are of particular importance (Dijkstra et al., 2019). It is emphasized that using them as the basis for identifying spatial development differences allows for better identification of differences and taking more effective actions in the relational areas of socio-economic links. The use of FUAs in determining spatial development differences is extremely useful for identifying areas with specific development features: suburban areas, commuting

zones, inner peripheries. Inner peripherality, in particular, is a more complex, multidimensional phenomenon, very important for identifying development differences and programming regional policy. Their characteristic feature is the degree of 'disconnection' (lack of linkages), not geographical location, in relation to the 'main areas' (Servillo et al., 2016).

Against this background, the aim of the paper is to present the possibility of using the delimitation of FUAs in the identification of inner peripheries. The analysis refers to the complete and separate delimitation and typology of FUAs in Poland, aimed at defining the scale of spatial differences of socio-economic development and distinguishing the inner peripheries from FUAs, as areas with special development needs, requiring properly programmed and implemented public development intervention. The spatial arrangement of the analysis is the municipal level (LAU1), and the research period covers the years 2011–2022.

The paper has been arranged as follows: after the introduction, new challenges in place-based approach in regional policy are presented. Attention is paid to the use of the concept of functional urban areas and its importance in the operationalization of an integrated territorial approach (place-based policy), as well as a new approach to defining inner peripheries in the system of functional urban areas. Then, the authors' concept of delimitation and typology of functional urban areas in Poland is presented, aiming at identifying areas with different development problems, including inner peripheries of various types. The obtained results are discussed with reference to the literature on the subject, emphasizing the most important advantages of the applied approach. Attention is also drawn to the similarities and differences in relation to the results of other studies. The paper ends with conclusions emphasizing the advantages of using functional urban areas in the practice of territorially-oriented regional policy.

2. New challenges for place-based policy

2.1. Functional urban areas in European regional policy and their importance in place-based policy

FUA is a term used to describe areas affected by the relational influence of cities. In the most general terms, they can be defined as areas of urban influence (spatial ranges) and functional relationships and linkages to a given city. This impact results from population movements related to migration and the functioning of the labour market, or for example, access to commercial and public services, including commuting to schools, health-care facilities, shops, etc. The consequence of these impacts are changes observed in areas affected by urban centres. They manifest themselves both in changes in the level of socio-economic development and in morphological transformations related to changes in the structure of land use and methods of spatial development. Consequently, around urban centres, their surrounding areas are identified, which in the literature are defined by different terms (agglomeration, metropolitan area/region, functional urban area/region, urban field, suburban zone, livestock zone, residuum, and others).

The theoretical foundation of a FUA is the concept of a node region, understood as a type of analytical region constituting a tool for spatial analysis (Whittlesey, 1957). This means homogeneity, hierarchy and region's closure. In this model, the city is the central centre and organizes the space around it, which becomes an area for the circulation of goods and services, commuting and other flows. These assumptions led to the creation of the concept of urban day systems (Berry, 1973) and urban functional regions (Hay and Hall, 1977). These two concepts are currently most often used as a definitional basis for understanding and determining FUA

(Antikainen, 2005; Dijkstra et al., 2019), including in Poland, (Korcelli, 1977; Bartosiewicz and Pielesiak, 2011; Śleszyński, 2014; Heffner and Gibas, 2016; Ilnicki and Janc, 2021), although the most frequently used term and research field are agglomerations and metropolitan areas, respectively (Czyż, 2012).

Along with the methodical and IT progress, and in particular the registration and collection of more and more detailed databases on spatial phenomena and mobility, the method of identifying and determining FUA is also evolving. These delimitations also affect the state of knowledge about the formation of urban impact zones. Earlier work focused mainly on the study of flows to work and other services (Sherrill, 1976). This is how the FUAs for OECD countries was determined (Dijkstra et al., 2019). However, due to the different measurement of commuting, the definition of a commuter, and the reference units (fields of analysis) analysed, this is not very comparable across countries. For example, in Poland, the quoted delimitation and previous similar studies turn out to be unsatisfactory, due to the incorrect estimation of the number of employees in communes (Śleszyński 2013). Nowadays, detailed data sets based on geodetic registers and remote sensing monitoring, including satellite data, data from mobile phones, tracking car routes, etc., are increasingly used (Ma and Long, 2020). In the case of data on the distribution of buildings, the course of streets and land use, the morphological understanding of the city's impact zone is considered. This means that the FUA is identified not on the basis of flows, relations and ties, but on the permanent (in the sense of spatial development) effects of the occurrence of these different types of relations. This is reminiscent of the earliest delimitation works, which used such indicators as, in particular, population density, the share of built-up area, features of buildings, and buildings and flats.

An example of the morphological understanding of FUA is the recent collection of papers edited by Duranton and Rosenthal (2021), which presents, among others, delimitation analyses

based on the brightness of city lights, concentration and topology of buildings, or land cover from satellite images (Arribas-Bel, 2021). The authors suggest there the use of the term delineation. In our study, we use the concept of delimitation, traditionally used for many decades, which seems to us to reflect better the territorial sense of FUA, including the range of the city's impact (Linge, 1965). The term delineation seems to be closer to the general idea of determining the impact of a city, e.g., taking into account gravitational methods and the structure of land use, as well as when the range of influences or impact zones of cities overlap or do not cover the entire geographical area. One of the most important problems to solve in FUA delimitation is determining what type of regions they are. The study by Garcilazo and Martins (2021) proposes three types of regions: (1) large metropolitan areas, (2) rural/intermediate regions near cities, and (3) remote rural regions. A classification of this type seems to be particularly useful from the point of view of research on peripherality and the conduct of regional policy. We propose a quite similar solution in this study. The novelty of the approach proposed in this paper consists of carrying out an exhaustive delimitation based on the concept of nodal region, grouping (inductive classification), exhaustive division and regional classification (Churski et al., 2023).

In the practice of regional policy, FUAs are defined as compact spatial systems consisting of functionally related areas, characterized by common conditions, and expected, uniform development goals. The reason for their designation is the need to create conditions for the use of their geographical potential for the development of the country and its regions. On the one hand, the delimitation of FUAs should be based on the results of objective diagnoses identifying the range of spatial relations; on the other hand, it should result from respecting the cooperation of its constituent entities, their partnership and effective cooperation - both vertically (e.g., from central level to local level) and horizontally (e.g., between the communes forming the FUA).

When creating conditions for the development of these areas, it is necessary to ensure their competence and financial empowerment, allowing them to program and implement development activities at the supra-local level (Churski et al., 2021b). The changing importance of FUAs in European regional policy results from the growing importance of cities in shaping contemporary development processes. Activities specifically dedicated to urban areas are directed in accordance with the assumptions of the implemented urban policy, which is programmed at the level of the EU and individual Member States (McCann, 2015).

FUAs have found application in place-based policy, and their operational use has materialized in the form of an Integrated Territorial Investment (ITI) instrument (Scenarios for…, 2015). As stated in the European Commission's report by Barca (2009), one of the basic operational distinguishing features of the place-based policy is the focus of activities in spatial terms, aimed at recognizing and taking fully into account the specificity of individual functionally-defined territories. Thus, the practice of European regional policy made an important recommendation indicating the need to territorialize intervention activities in the layout of functional areas, based on objectively recognized features of their territorial capital (Camagni, 2008, 2009). This draws attention to the role of the EU cohesion policy in rescaling subregional spatial policies and developing a functional understanding of the territory (Barca et al., 2012; Dąbrowski, 2014; Mendez et al., 2021). It is also an attempt to introduce fundamental changes in European regional policy and to depart from the primacy of a simple compensatory paradigm (Zaucha et al., 2015), preferring to support weaker regions, most often through direct transfers of funds for infrastructure development (Spilanis et al., 2013; Maynou et al., 2014; Rodríguez-Pose and Garcilazo, 2015, Garcilazo et al. 2010). Changing the way of programming and implementing regional policy measures will lead to the achievement of a critical mass for generating development impulses, which may have a lasting impact on the

development of a given area at the local and regional level, and as a result, at the national and European level. This leads to a common belief that, as Villaverde (2006, p. 131) writes, '*…space plays a significant role in the process of economic growth and convergence…*' and the recognition of territorial specifics determines the effective shaping of development factors that should not be unified and should also take into account the heterogeneity of endogenous resources (Rodrígues-Pose, 2013). The programming and implementation of effective interventions requires, on the one hand, full identification of the ongoing changes in development factors forming the relational territorial capital of each area (Camagni, 2008, 2009), and on the other, adapting their reinforcement and creation to territorial specifics (McCann and Ortega-Argiléz, 2012). The baseline report of the Polish EU Presidency (Böhme et al., 2011) and subsequent publications (Zaucha et al., 2014) recognized functional areas as one of the territorial keys allowing for the territorialization of development policies, including the Europe 2020 strategy then in force. In doing so, it was concluded that, in the context of territorial policy, it is possible to approach functional areas as: a) overlapping units filling the socio-economic space; or b) synonymous with the agglomeration factor in socio-economic development (Zaucha et al., 2015). In both cases, the basis is to undertake both the diagnosis and subsequent intervention independently of administrative boundaries.

However, the experience so far is not satisfactory. Even though the 2014–2020 financial perspective was programmed with the unequivocal recommendation to implement the place-based policy assumptions in the assumptions and implementation of cohesion policy activities, the operational implementation of these assumptions encountered very serious obstacles, casting doubts, despite the attempts made, on the possibility of their use in the practice of regional policy intervention (Böhme et al., 2008; Böhme et al., 2011). For these reasons, the 8th Cohesion Report (European Commission, 2022) emphasizes the need to strengthen the

territorial approach. This would be achieved by giving a superior position to the cohesion policy, which is to be the goal of every public intervention. Attention is also drawn to the need to give the cohesion policy a coordinating character, allowing it to influence the direction and implementation of intervention measures in other public policies. Finally, the need to extend the instrument of territorial strategies is also emphasized, paying attention to the possibility of their use in programming, and implementing interventions addressed not only to core areas, but also, for example, to areas with a lower level of socio-economic development, peripheral and marginalized areas, the identification of which should be based on an analysis of the ranges of functional links. Examples of this approach are initiatives within the framework of Integrated Territorial Instruments (ITIs), sometimes also applied at a lower level as regional territorial instruments (e.g., public transport hubs located in the centres of functional areas and serving surrounding peripheral areas).

2.2. New approach to defining inner peripheries

The inner periphery is a relatively new concept, but for a long time, the method of defining such areas with a relatively lower level of development has been a serious challenge. This is due to the ambiguity of understanding peripherality. As Gould (1969, p. 37) writes, peripherality is '*...a slippery notion...one of those common terms everyone uses until faced with the problem of defining and measuring it...*'. Classically, peripherality is understood as remote areas, located along the regional borders, which due to problems with spatial access to growth centres, develop more slowly and are often subject to economic marginalization. This approach is based on geographical peripherality (Boschma, 2005). Nowadays, however, it is emphasized that geographical proximity is only one of many different forms of closeness, including non-

spatial or institutional ones, involving, for example, social interaction and trust (Harvey, 1989; Gregory, 1994; Soja, 1996) or shared knowledge and information (Copus, 2001, Copus et all. 2017) or reflecting institutional or governance structures that are increasingly important (Torre and Rallet, 2005). The notion of inner periphery is based on this new, broader approach.

There are two theoretical concepts, created independently in the 1970s and 1980s: **geographical peripherality**, measured initially by various spatial models, including Newtonian gravity (Keeble et al., 1988, Schürmann et al., 1997), which is nowadays interpreted more through the prism of social and economic prosperity and the role of access to services of 'general interest', which diverts attention from the spatial diversification of economic potential; and the **modern world system** and '**organized proximity'**, in which the periphery is treated not as remote geographical areas, but social systems resulting from complex processes of changes in the economy, demography, or political conditions shaping the possibilities of making limited decisions, the binding system of socio-cultural norms and values (Wallerstein, 1991).

The issue of inner peripheries gained importance as a consequence of the financial crisis (2007–2009), which highlighted both the contrasting dynamics of the development process between Western and Eastern European countries, and clear differences between rural and urban areas, including metropolitan areas. The spatial effects of the crisis drew attention to the topicality of the concept of social justice and the need to consider it from both a territorial perspective (Soja, 2010) and the concept of the foundational economy (Bowman et al., 2014). In the face of the consequences of new shocks, such as the COVID-19 pandemic and the war in Ukraine, the importance of studying the development trajectories of less-developed areas, including inner peripheries, in explaining the spatial regularities of socio-economic

development and searching for more effective interventions has become particularly clear (European Commission, 2022).

Peripherality is also often identified with poor spatial accessibility. More developed measures of accessibility, such as potential accessibility (Spiekermann and Schürmann, 2007; Komornicki et al., 2010, Rosik et al., 2015) relate the location of territorial units to all other units within a region, country, or Europe. This allows a parallel assessment of peripherality in different dimensions, which are often not the same. Completing the analysis of accessibility at the regional level makes it possible to identify inner peripheries within larger zones originally assessed, as well accessible within the country or Europe. This is then confirmed when assessed using other indicators, concerning migratory outflows and depopulation, or problems of unemployment, poor accessibility to services, poverty and social exclusion (Śleszyński et al., 2017).

Against this background, we formulate our proposal for a new approach to the determination and typology of inner peripheries. We understand them as areas designated in the layout of FUAs that best reflect the actual ranges of socio-economic relations taking place in space, delimited based on an exhaustive division of the entire territory of the country into smaller units. The inner peripheries are characterized by the presence of dormant or lost development potentials, due to their social or economic peripherality caused, in particular, by low transport accessibility and a relatively long-time distance to economic centres, a limited scope of functional links and the lack of ability or difficulty to establish them permanently. Their characteristic features are lower functional effectiveness of the territorial socio-economic system, lower access to public goods and services and, consequently, generally lower quality of life (well-being). The consequence of these conditions is the decreasing competitive potential of a given area and its deepening marginalization. We are of the opinion that the extension of

the normative basis of the inner periphery requires the inclusion of the concept of territorial justice in the assumptions of territorial cohesion (spatial justice requires explicit consideration of space as a factor of social inequality reproduced by socio-economic mechanisms that organize society in space), and the concept of the foundational economy (the foundational economy encourages protection of those sectors of the economy that provide essential goods and services, such as services of general interest). We assume that the inner peripheries are not internally homogeneous, which leads to the formation of central areas and the surrounding area in their internal structure, similarly to the case of the general dichotomy of socio-economic space. Local 'poles' show similar limitations to those of their surrounding areas, and their position is only a consequence of the internal relativity of the scale of problems and the degree of concentration of economic activity and places of residence.

3. Typology of functional urban areas in Poland – in search of the inner periphery

The concept of an integrated territorial development (emphasizes the necessity for the integrated, place-based multilevel and participative governance between different types of areas. This leads to the engaging people and entities from different governance levels (global, European, national, regional, local), diverse policy sectors, and societal groups, as well as strengthened cooperation on long-term based-placed strategies, build on the foundation of functional links between neighbouring areas (The New Leipzig Charter, 2020; ESPON 2021; Pertoldi et al. 2022; The Territorial Agenda 2030). Since development policy must be conducted across the entire country, defining the functional scopes of urban centres cannot be limited, as it has been in the past, only to the main regional centres. Medium and small cities also have their spheres of influence, which sometimes have a distinctly local character.

Bartosiewicz (2016) addressed the demarcation of functional linkage zones for medium and small towns in Poland, but his delimitation was not exhaustive. It is also important to note the research of Ilnicki and Janca (2021), who identified linkages for county-level cities, considering however only one-way migrations and commutes between rural areas and county-level cities.

In searching for internal peripheries, the authors developed a completely novel methodology for classifying urban functional areas (Figure 1 and Table 1, Churski et al., 2023; see also Appendix A), which is distinguished primarily by covering the entire country and transcending the administrative boundaries of individual regions. The operationalization of the entire process in the context of the integrated territorial approach is also important, especially in relation to the recommendations for the future of European and national development policy contained in the Eighth Cohesion Report (Cohesion in the EU…, 2022).

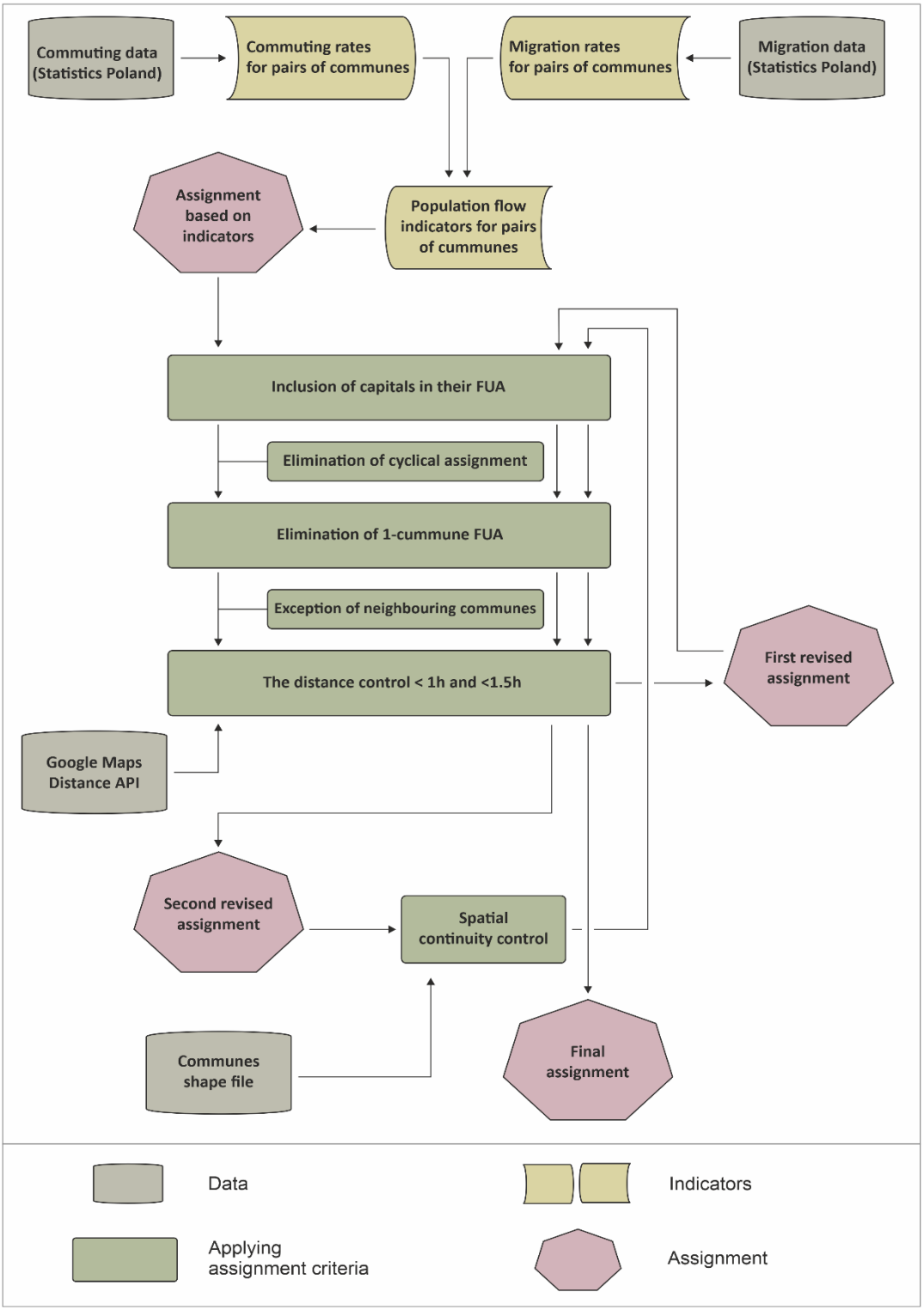

Fig. 1. Stages of assigning communes to functional urban areas (FUAs).

Source: Authors' own, on the basis of Churski et al., 2023

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Table 1.

Stages of assigning communes to functional urban areas (FUAs)

Stage	Number of FUAs after the step	Number of changes in commune assignments
1. Calculation of commuting, migration, and population flow rates, as well as rankings of potential central cities for all communes.	not applicable (baseline 2477 communes in the first stage of analysis)	
2. Assignment of communes to central cities according to the highest values of population flow rates.	429	
3. Inclusion of the capitals of FUAs into their own FUAs.	429	215
3. Elimination of FUAs consisting of only one commune.	404	25
4. Application of the distance criterion: reassignment of municipalities located more than 1 hour (1.5 hours for central cities over 500,000) from the central city to the FUA of the next city in terms of the population flow rate.	419	109
5. Inclusion of the capitals of FUAs into their own FUAs – applies to newly established FUAs.	419	15
6. Elimination of FUAs consisting of only one commune – applies to newly established FUAs.	416	3
7. Second application of the distance criterion, simultaneously controlling for other criteria.	416	6
8. Application of the criterion of spatial consistency of FUAs, simultaneously controlling for other criteria.	413	31

Source: Authors' own, on the basis of Churski et al., 2023

The necessity of cooperation between local government units of different levels, not necessarily within the administrative borders of one region, emphasized in this document, requires its institutionalization, manifested in the ability to prepare supra-local and supra-regional strategies, but above all equipping them with appropriate competencies and resources, enabling the conduct of active and effective development policy. It is also worth emphasizing that an innovative approach in the FUA's classification was applied also in the selection of data sources, which included not only commonly available public statistics but also results of other Polish researchers, unpublished data from the Ministry of Finance, as well as web-based data obtained from web service providers, including the Google Maps Distance Matrix API (Distance Matrix Api, 2023). Most data were obtained for 2,477 communes, the lowest level of territorial administration in Poland. As a result, a comprehensive classification of 413 urban functional areas with varying ranges was obtained (available at https://www.home.umk.pl/~czeslaw/mofy/). The degree of diversity and range of functional linkages of individual units directly results from the scale of influence of the central centre on the surrounding areas, which in turn conditions the possibilities for the diffusion of developmental processes (Churski, et al., 2023). The classification created a basis for searching for internal peripheries, which required conducting a typological procedure.

The starting point for the typology of FUAs were 47 variables, representing nine substantive dimensions of peripherality (from three to ten variables per dimension) (Figure 2). The process of the selection of indicators was strongly influenced by our understanding of inner peripheries, which in our specific approach are characterized by multidimensional accessibility and weakness of functional links leading to low effectiveness of the territorial socio-economic

system, lower access to public goods and services and generally lower quality of life (well-being). An important issue in the process of choosing indicators was also data availability; thus, a used indicator was not always the best first choice. The structure of variables and data sources are presented in the Appendix A.

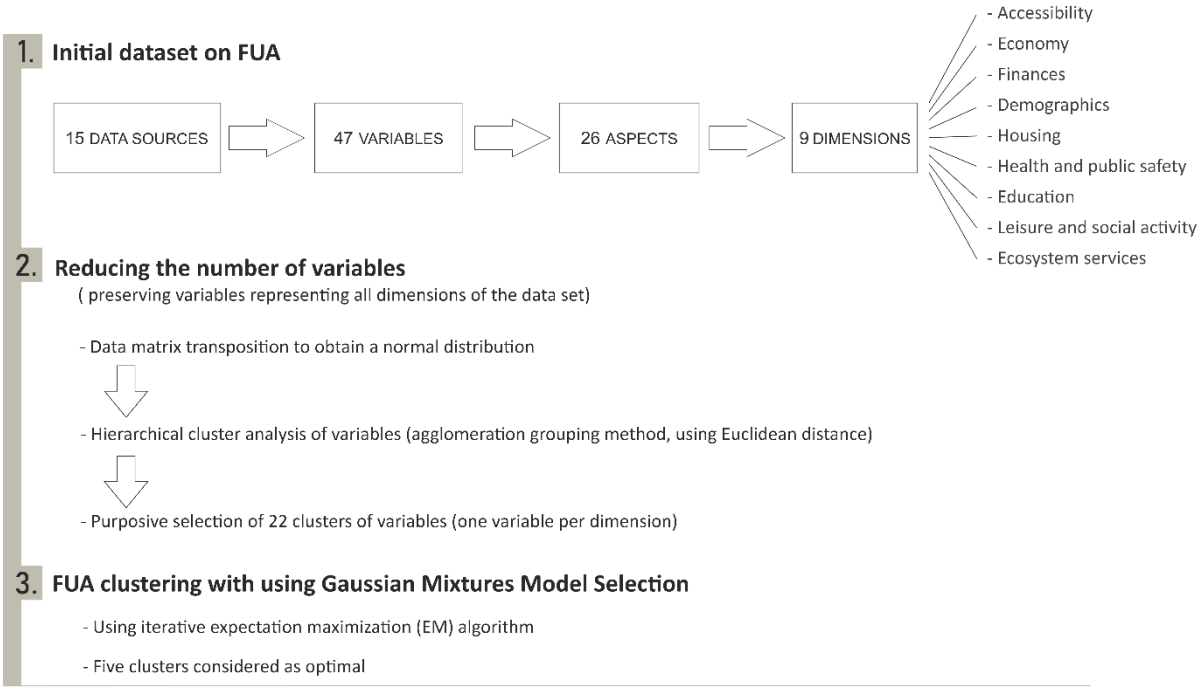

Fig. 2. Stages of typology of FUA

Source: Authors' own

Due to the varied, sometimes very asymmetrical distributions of the values of individual variables evident after the examination of histograms and Q-Q plots, most variables were transformed (using natural logarithm, square root, or more complex transformations, see Appendix X) to obtain distributions of values close to natural distribution.

The next step was reducing the number of variables. We considered various possibilities of calculating latent variables (through principal component analysis) or limiting the number of considered observed variables. Finally, we applied the latter approach, selecting variables based

on two conditions: removing variables closely correlated with other variables in the set of grouping variables (Appendix B); and preserving variables representing all dimensions of the data set.

Therefore, a two-stage variable selection procedure was applied. The first step was the analysis of clusters of variables. After data matrix transposition, hierarchical cluster analysis was applied on the variables with the agglomeration grouping method, using Euclidean distance and the complete linkage method (Everitt et al., 2011). After visual analysis of the cluster dendrogram, we decided to adopt the cut-off level, distinguishing 22 clusters of variables (as indicated in the last column of the table in Appendix A. Then, one from each group of variables was selected to eliminate redundant variables, but still represent all nine dimensions. The number of variables per dimension is between one (the dimension of free time and social activity) to five variables (the dimension of accessibility). The choice of the variables was therefore largely subjective yet informed by the results of variable clustering and correlation analysis.

The selected 22 variables were used in the procedure of grouping FUAs into types. We considered various methods of cluster analysis: hierarchical (Ward); centroid-based (k-means); density-based (DBSCAN and OPTICS); and distribution-based (Gaussian mixtures) (Bishop, 2006). Taking into account the possibilities of interpretation and application of the results of individual grouping methods for the identification and classification of inner peripheries, we chose the Gaussian mixtures method, implemented in the Python Scikit-learn package (Pedregosa et al., 2011). This model uses an iterative expectation maximization (EM) algorithm. Given an assumed number of clusters, the algorithm detects clusters of values of individual variables in multidimensional data space, assuming that they are sampled from the number of normal (Gaussian) distributions corresponding to the number of clusters. Compared

with other popular methods (hierarchical and k-means), the method is more effective for detecting clusters representing distributions with different standard deviations. It was useful in our case, as we could not assume neither the similarity in numbers of units assigned to each group, nor the same level of internal consistency of each of the groups.

Cluster analyses were carried out for the number of clusters from two to seven, using various types of variable matrices (Gaussian Mixture Model Selection). The results were examined in terms of the possibility of interpreting the results and comparing heuristic clustering quality measures (BIC, Caliński-Harabasz and Davies-Bouldin indexes, see Appendix C). In the end, using spherical variance matrix and grouping into five clusters was considered optimal. The clustering was repeated on multiple sets of random input parameters for the clustering procedures, converging to the same results each time. After clustering, we measured the influence of each of the variables on the cluster assignment using F-statistic (see last column of the table in Appendix A). Financial (e.g., personal income), economic (e.g., share of population running personal income) and housing variables (percentage of population with central heating and number of new population), turned out to be the most influential, followed by external transport accessibility characteristics. On the other hand, characteristics remotely related to the level of economic development, such as access to green areas or the level of traffic safety, were the least decisive in assigning FUAs to groups. Despite the assumed complex nature of the definition of inner peripheries, the level of economic development and activity remains the most influential dimension of their distance to the central areas.

4. Inner Peripheries in developmental diversification in Poland in the system of functional urban areas

As a result of the conducted research procedures (Figure 1), 413 FUAs were identified. As expected, the designated FUAs have different sizes and spatial extent, adequate to the strength, and, consequently, the range of functional relations. In 94 cases, two communes belong to the FUA, while the largest FUA – with Warsaw as the central city – has 92 communes. In terms of area, the smallest FUA has an area of 14 km^2, and the largest as much as 8.8 thousand km^2. In turn, in terms of the number of inhabitants, the smallest FUA has about 7.5 thousand inhabitants, and the largest 3.3 million inhabitants. It is natural that the largest FUAs are associated with large cities, - capitals of regions (voivodships), which, due to their potential, have a large range of spatial impact; while the smallest are those concentrated around small cities far away from regional cities, for which the range of functional relations is much smaller. The results of the delimitation therefore fully correspond to the research assumptions and give a realistic picture of the range of influence of central cities, as well as the functional relations binding these cities with their commuting zones. The universal nature of the applied research procedure should be emphasized: its application can be repeated in subsequent years and for other reference areas (also outside Poland), and the main limitation is the availability of data for a given level of administrative units.

It should be noted that the number of classified FUAs (413) is similar to the number of administrative counties (*powiat* – 380 units in Poland). As many as 307 out of 413 urban centres of functional areas are also the seat of a county; nearly two-thirds of communes in Poland belong to FUAs, with the centre being the same county town to which a given commune is administratively assigned. However, while the separated FUAs are characterized by different

sizes and spatial ranges in accordance with the impact of the central city on the surrounding areas, the administrative division of the country is more even (considering the area and number of communes) and does not fully reflect the range of real functional links. This leads to the conclusion that administratively-distinguished counties do not fully fulfil the role of reference areas for programming regional interventions at supra-local level. FUAs successfully fulfil this role. This thesis is also supported by the dynamic nature of functional relations –counties have been designated statically, for many years, for the implementation of public tasks of a supra-local nature, while the programming of regional interventions, if it is to be effective, should each time take into account the current scope of the functional area, which means the need for the cyclical updating of the scope of FUAs. Counties can play an important role in coordinating supra-local cooperation, thus strengthening the effectiveness of regional intervention, but this requires reformulation of the functioning model of public administration.

The next step in the conducted research procedure was the measurement of the degree of differentiation of the level of socio-economic development of the selected FUAs, in order to find areas with dormant or lost development potentials - inner peripheries. The authors understand this peripherality, as mentioned earlier, in the context of transport accessibility, the effectiveness of the functioning of the territorial socio-economic system, accessibility to public goods and services and, in general, the quality of life (well-being). The typological procedure made it possible to distinguish five types of areas due to the criteria used (Table 2 and Figure 3). The presented typology is used to isolate different types of FUA, with the intention of identifying in particular those struggling with the greatest development problems (internal peripheries), in accordance with the proposed methodology. This typology is not intended to serve the hierarchy of the settlement system, nor does it fully coincide with the usual hierarchy of cities based on the size of the population. In the descriptions of the distinguished types, we

use the usual terms large cities (population >150,000 inhabitants), medium-sized cities (30,000-150,000 inhabitants) and small cities (<30,000 inhabitants) to give a better idea of the development potential of individual types of FUA.

Table 2.

Typology of the functional urban areas in Poland

Area	**No of units**	**Out of Total**	**Location**
Core areas	25	6.05%	Central cities of the FUAs are mostly large cities (above 150,000 inhabitants), mostly capitals of voivodeships located throughout Poland.
Transition areas of large and medium-sized cities/towns	39	9.44%	Central cities of the FUAs are mostly large and medium-sized cities (above 30,000 inhabitants), concentrated in the Upper, Opole and Lower Silesian voivodeships.
Transition areas of middle-seized and small cities/towns	141	34.15%	Central cities of the FUAs are medium-sized and small cities (less than 150,000 inhabitants). Clear concentration of units in western and central Poland.

Second order inner peripheries	112	27.12%	Central cities of the FUAs are medium-sized and small cities less than 150,000 inhabitants). Units are present in every voivodeship, but less frequently in border regions.
First-order inner peripheries	96	23.24%	Central cities of the FUAs are mostly in small cities (less than 30,000 inhabitants), concentrated in eastern Poland.
Total	**413**	**100.00%**	

Source: Authors' own.

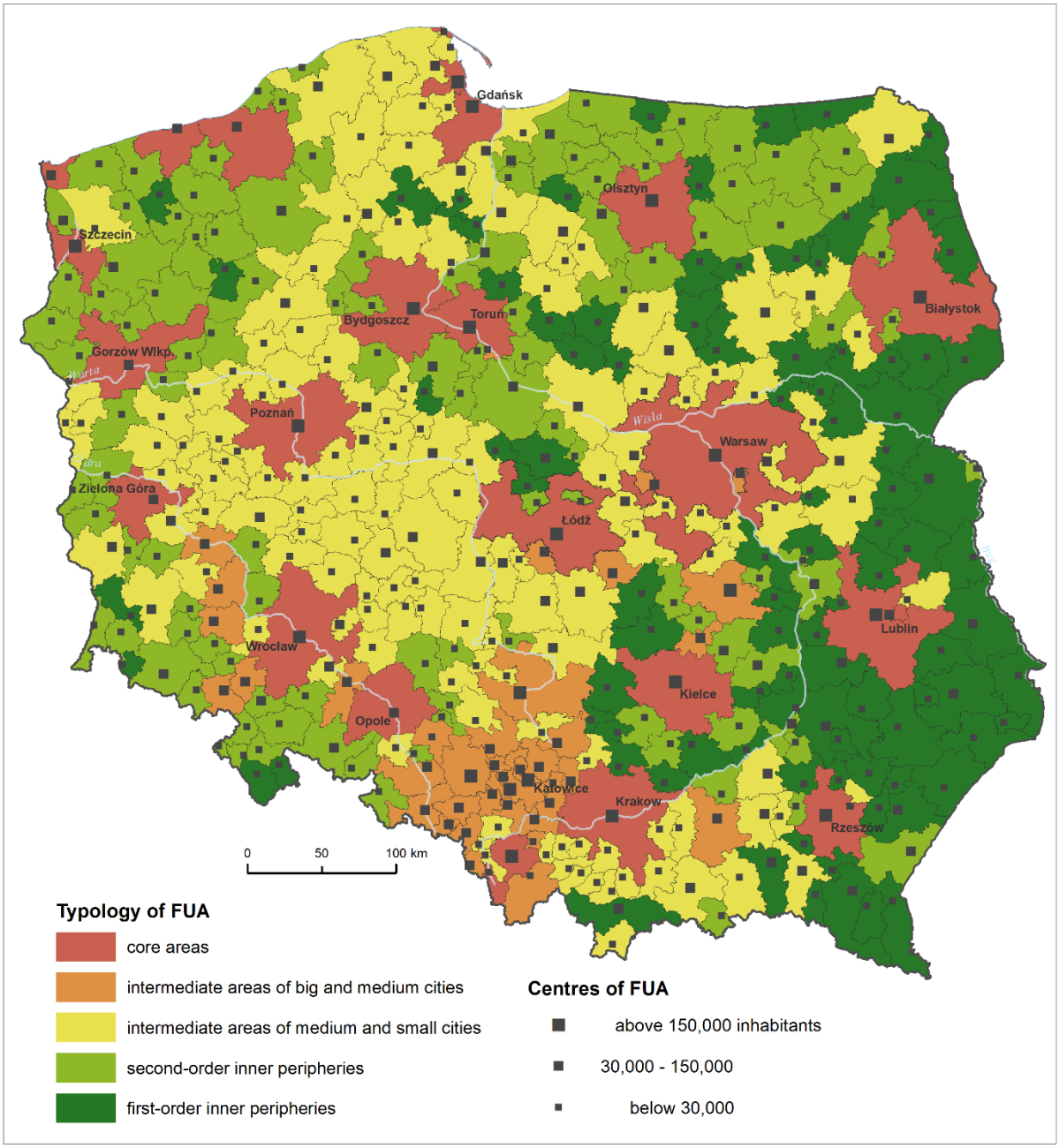

Fig.3 Classification of functional urban areas – spatial distribution

Source: Authors' own.

The distinguished types of areas have specific characteristics and specific development challenges.

4.1. Core areas

The central cities of those FUAs are mostly large cities (above 150,000 inhabitants)– mostly the main regional centres (capitals of voivodeships) located throughout the country, which, due to the high level of territorial capital, show the highest degree of development (Appendix D). These are usually large functional areas, with a spatially extensive range of relationships. These areas are characterized by a high degree of external and internal accessibility, as well as a high degree of saturation with technical and social infrastructure. The labour market is flexible and unemployment is low. A high level of economic activity and the good financial situation of the inhabitants translate into high streams of public income, which allows for the stabilization of public finances with high current and capital expenditures. The quality of life is also high, due to a favourable housing situation and wide access to public services, which also translates into a favourable demographic situation. In particular, the challenge is high anthropopressure resulting from high population density, lowering the perceived quality of life as a result of greater environmental problems and transport congestion along the transport corridors. It is characteristic that the surroundings of several cities that are not regional capitals (e.g., Koszalin, Bielsko-Biała) have qualified as core areas. This proves their special role in regional development. It may also indicate the need for other public intervention tools (e.g., strengthening public services of a higher order).

4.2.Transition areas of large and middle cities

The central cities of the FUAs are mainly large and medium-sized cities (above 30,000 inhabitants). Included in this category are many cities of the Upper Silesian conurbation in the south of the country, the largest raw material industrial region of Poland, the economy of which was formerly based on hard coal mining, steelmaking, and machine industry. After the political

transformation in the 1990s, the industry was restructured but remained important in the structure of the economy. The areas are characterized by relatively high transport accessibility, both internally and externally. These areas have a favourable position on the labour market, but a rather average one in public finances, which does not allow for high expenditures in the public sphere. There is a low share of people earning income from business activity. The level of technical and social infrastructure is also advantageous, which translates into relatively good access to public services (the best in the field of education), with well-equipped apartments and average dynamics of the housing market. The area is also characterized by a negative birth rate despite a relatively good economic situation. The challenge is to increase the flexibility of the economy and the scale of resilience to economic turmoil.

4.3.Transition areas of middle and small cities

Central cities of the FUAs of those areas are located in various types of medium-sized and small cities (less than 150,000 inhabitants). These regions are located primarily in the western part of the country, whose better levels of economic development in comparison to the eastern regions are historically conditioned and are the result of long-term differences in political and economic organization. It is characterized by high multimodal accessibility is characteristic, while at the same time low transport accessibility of the central city and major communication problems. They have a relatively good position on the labour market, but average income streams and low economic activity threaten the stability of public finances. A characteristic feature is also average access to public services, but a favourable demographic situation is manifested in a relatively low share of people of post-working age. The challenge is to diversify and stimulate the economy, improve transport accessibility, and improve the scope and quality of public services offered.

4.4.Second-order inner peripheries

The central cities of those areas are located in different types of medium-sized and small cities (less than 150,000 inhabitants). These regions are largely located in north-eastern and north-western Poland, regions with the lowest population density in the country and which experience difficulty in undergoing economic transformation in the 1990s, in particular due to the high degree of collectivization of agriculture. Those areas have relatively high internal accessibility, with low efficiency or even no public transport, and very low external accessibility is characteristic. The labour market in this type of area is inflexible and declining; incomes are low, as is economic activity. There are numerous tensions in the sphere of public finances, a dependence on state budget revenues, and limited access to public services, which are additionally of low quality. A feature of those areas is also a weak housing market and the level of infrastructure, with stagnation in the demographic sphere. The challenge is to create stable sources of financing for public investments and the economy, to improve the quality and accessibility of public services, and to adapt to negative demographic trends.

4.5.First-order inner peripheries

The central cities of those areas are located in small cities (less than 30,000 inhabitants), located mainly in the eastern part of the country, which underwent the most difficult and longest economic transformation. These areas are the geographical peripheries of the European Union, but it was other factors that decided to classify them as inner peripheries, including: the lowest indicators of internal accessibility; average indicators of time accessibility from the core to other communes; low digital accessibility; a stagnant labour market; a lack of greater economic activity; low individual purchasing power; low own income of local governments; and clear

problems with maintaining budget stability even with limited public investments. Areas are also characterized by high dependence on the central budget, a quite average scale of technical and social infrastructure, a bad housing situation, limited access to public services and high demographic regression. On the other hand, the situation in terms of public safety is exceptionally good. The challenge is primarily to look for competitive advantages that enable the generation of local income, counteracting the demographic regression and broadly understood exclusion.

5. Discussion – challenges of using functional urban areas in regional policy

The challenges of the delimitation and typology of FUAs became essential at the time of the paradigm shift of regional policy towards an integrated territorial approach. The role of FUAs in the regional intervention programming system should be looked at from two perspectives. First, the applicative perspective, which means focusing on identifying specific needs and tailor development policies for various types of such areas. Second, the methodological perspective, refers to the technical process of delimiting such areas and presenting the degree of their differentiation.

5.1.Applicative aspect

The delimitation of FUAs carried out by us and the measurement of the degree of differentiation among them are, in our opinion, of fundamental importance for the process of programming regional interventions, as they determine the proper programming of aid, and in particular, its adaptation to the specificity of each diagnosed area (territorial capital) in accordance with the territorial approach. The applied approach is an important contribution to

the discussion on rescaling subregional spatial policies and developing a functional way of understanding territory (Barca, 2009; Barca et al. 2012; Mendez 2013; Mendez et al., 2021). In our opinion, the development support policy must be anchored in FUAs. The legitimacy of this approach is emphasized by the 8th Cohesion Report (European Commission, 2022), which pointed to the need to strengthen the territorial approach based on FUAs, in particular in the context of major challenges related to climate change (including achieving climate neutrality by 2050) and the rapid digitization processes, which will require supra-local cooperation. Urban areas have been perceived as key sources of economic growth and innovation for years, which is mainly due to the benefits of agglomerations, the concentration of companies and a specialized workforce (Martin, 2015). Spatial proximity facilitates interaction and cooperation, in the sphere of information exchange and creation of knowledge and innovation, which, coupled with the high quality of human and social capital, dynamizes development processes. The belief that the development of urban centres can have a positive impact on the development of the surrounding areas has become the basis for formulating urban policy, programmed at the levels of both the EU and the Member States (McCann, 2015), and cooperation within functional urban areas has become a cornerstone of the European Union sustainable urban and regional development (e.g. The New Leipzig Charter, 2020; Territorial Agenda 2030, 2021; National Urban Policy 2030, 2022).

The correctness of our approach to using FUA in regional policy is also indicated by the analysis of the structure of the cohesion policy objectives in the current financial perspective 2021–2027, as well as the analysis of EU legislation in this area. Objective 5 of the cohesion policy *A Europe Closer to Citizens* is to be achieved by supporting the sustainable and integrated development of urban, rural, and coastal areas as part of local initiatives. Implementation of activities aimed at achieving this goal will require supra-local and cross-

sectoral cooperation at various levels of territorial organization. Financial support for such cooperation from the European Regional Development Fund (ERDF) fund (at least 8% of ERDF resources), also within FUAs, based on territorial strategies or community-led local development strategies, is officially included in Article 11 of the Regulation of the European Parliament and of the Council (EU, 2021/1058). Another Regulation (2021/1060) defines the implemented territorial tools, also referred to as Integrated Territorial Investments (ITIs), community-led local development (CLLD), and other territorial instruments.

The focus on FUAs as reference areas already took place in the 2014–2020 financial perspective but it encountered operational difficulties (Böhme et al., 2008, 2011). These difficulties in Poland resulted mainly from the lack of statutory authorization for FUAs, as well as in the institutional dimension of establishing cooperation, which was based mainly on the general provisions of local government and association acts. Moreover, the FUA delimitation and the process of programming the integrated regional intervention covered mainly regional centres (17 ITIs), and the process of delimitation of the remaining part of the country, although carried out at the regional level and not according to a uniform methodology, additionally often aroused controversy when the inclusion or detachment of individual areas was decided by political considerations (Mendez et al., 2021). The approach used resulted in a spatial typology of the level of Poland's territorial development which is different from similar studies that are based only on public administration units (LAU1 or LAU2). The added value of the study in the FUAs system is:

- It confirms that the territorial inequalities resulting from historical conditions are now to a large extent overlapped by the differentiations related to the current modernization processes taking place in the largest centres. This results in more mosaic, overlapping core-periphery systems at different levels (from European to regional),

- It identifies areas of high territorial inequality gradient, particularly in the vicinity of regional capitals in eastern and north-western Poland. There, core areas directly neighbour first-order inner peripheries. This is a strong indication of the need for a spatial policy that can expand the functional linkages of emerging metropolitan areas as the most effective mechanism to overcome marginalization.

The approach we have adopted eliminates some of the indicated problems, as the process covered the entire country and is based on objective indicators, eliminating the problem of political discretion. Certainly, this approach may be used to plan regional interventions on a national scale, and the FUA delimitation procedure can be adapted to the needs and possibilities of planning and monitoring at various scales – national, but also regional. We also believe that the applied procedure could be applied in other countries in the future, as well as throughout the EU when planning subsequent perspectives, while of course respecting certain specificities of individual countries. There are some limitations of applicability this methodology in other countries, from which the most important are the following: some indicators are specific for Poland (e.g., some accessibility indicators) and there can be also question of comparability of spatial units (communes in Poland are different from those in other countries). However, in the presented methodology, we take into account specific dimensions assessing the level of socio-economic development, which can be described by different indicators (also country-specific), which will have a similar nature. Also, spatial differences can be overcome, since we consider FUAs as a result of classification of smaller administrative units, where the most important factors are the spatial ranges of functional relations and linkages generated between nodal cities and surrounding areas. As a result, FUAs have different size, depending on the potential of the central city. Thus, the size of the geographical area covered by the FUA is less important. Applicability of the methodology in other countries, would certainly require further research.

5.2.Methodological aspect

Our approach of basing the analysis on functional urban areas (FUAs) is a novelty in Poland, and the entire procedure is simultaneously objective and flexible. The official, current methodology for determining FUAs was jointly defined by the European Union and the OECD (Dijkstra et al., 2019; OECD, 2012), although research on the relationship between the city and the surrounding areas has a much longer tradition, dating back to the first half of the 20th century. The most frequently used classifications of FUAs use labour flows between the central city and surrounding areas to define functional links (Partridge et al., 2010; ESPON, 2014). The research procedure we used additionally considered the migration of residents as an indirect indicator determining the spatial behaviour of residents. It is worth emphasizing that the migration data used are public but have so far been rarely used in research, due to the volume and complexity, and in our study, we used them for the first time to delimit functional areas throughout the country. Unlike the EU/OECD methodology, in our methodology we did not limit the selection of the central city of the functional area to cities with a population density above 1,500 inhabitants per km^2 and a population of 50,000 in adjacent grids (Dijkstra et al., 2019; OECD, 2012; OECD 2022). Such a procedure would have to exclude the majority of small, and a large part of medium-sized, cities, while our goal was to delimit the entire area of the country and to map the functional relationships in the classified spatial systems as accurately as possible. Our approach is also distinguished by using the most up-to-date data related to migration (aggregated for years 2011–2020) and commuting data from 2011 and 2016. The availability of data and the quality of the research material often led to a downgrading of the performed analyses (Ma and Long 2021). The same study was based on LAU2 units (ESPON, 2014), while a much more accurate mapping of the relationship can be made by analysing

LAU1 units. To meet these needs, in our approach we combined the analysis of LAU1 units for the purpose of the delineation of FUAs, then aggregated data at the level of the already separated FUAs.

Designated FUAs should be used to analyse the spatial differentiation of the level of socio-economic development. The procedure should make it possible to create types of areas with developmental problems characteristic of them, among which the greatest will certainly be in the case of peripheral areas. As emphasized earlier, peripherality today is not only geographical, and the growing polarization must be perceived as a complex phenomenon influenced by socio-economic, demographic, locational and other factors (Pociūtė-Sereikienė, 2019). Therefore, it is necessary to use several indicators relating to the socio-economic situation and quality of life. The methodology used in the study considered a number of new, previously unpublished data sources (e.g., data on population income at the commune level, crime rate, IT accessibility) or detailed indicators related to inter-branch accessibility. The data is current and comes from a short period (2018–2022). Also noteworthy is the innovativeness of the research techniques used: algorithms based on Google Maps Distance Matrix were used to measure the travel time, which have not been used in any known classification so far. For the grouping of FUAs, the Gaussian mixture model was used instead of the standard k-means method, which reduced the sensitivity of the model to outliers.

The methodology for determining peripheral areas was adapted to the adopted research assumptions, which allowed areas to be identified based on three main criteria: the effectiveness of the functioning of the territorial socio-economic system; access to public goods and services; and quality of life (well-being). These are different criteria in relation to the most well-known and universal methodology, developed in Europe as part of the ESPON project (2014), in which the delimitation of peripheral areas was based on conditions related to access to areas of

economic activity, access to services of general interest or specific exclusion resulting from the loss of relationships. The applied approach considering the multi-criteria analysis is confirmed in other studies (e.g., Komornicki et al. 2010; Heffner and Gibas, 2016; Śleszyński et al. 2017).

The applied approach seems to be testable in other countries. We are aware of the challenges arising from different territorial contexts and different data availability, but the research assumptions regarding the identification of spatial differences within FUAs, determined by grouping the smallest administrative units at least based on population movements (migrations and commuting), can be checked. Moreover, the multidimensional typology of areas, in our opinion, allows us to properly identify areas that meet the inner peripheries.

6. Conclusions

The paradigm shifts in regional policy in the previous EU financial perspective forced a change in the approach to programming regional interventions. In territorially-integrated policy, it is crucial to move away from perceiving areas through the prism of their administrative borders, and to define them based on endogenous potentials and development barriers, with the simultaneous existence of functional and spatial relations (Barca 2009), in a specific historical and cultural context. FUAs are much more suitable for programming regional policy than administratively designated areas, as they reflect the spatial extent of the real environment in which people live to a greater extent; moreover, through the analysis of functional links, the effects of agglomeration or the impact of undertaken activities on local labour markets are better considered (Dijkstra et al., 2019).

Programming of integrated regional interventions based on FUAs had already taken place in the previous financial perspective, but it encountered operational problems and only in the

current perspectives were proper programming and financial conditions for this process ensured. Objective 5 of the cohesion policy directly refers to cooperation in supra-local systems, and adequate funding has also been provided to support their development of supra-local systems. Determining FUAs on a European scale still encounters methodological problems, resulting mainly from the heterogeneity of LAU2 size and different settlement contexts (ESPON, 2014). According to the policy-based approach concept, regional interventions should not be carried out in a uniform manner throughout the area, but should be more targeted, depending on the scale of the diagnosed problems and the potentials of individual areas. Such an approach requires a much more detailed diagnosis of separate functional urban areas, and then, after identifying development problems and endogenous potentials, should precisely define areas of strategic intervention and adjust instruments of territorial intervention. The designed typology should take into account the diverse level of territorial capital of individual areas, as well as the diverse nature of development problems and challenges. Of particular importance in these territorial systems are the peripheral areas as the most vulnerable to the consequences of space differentiation processes.

The authors presented their own methodology for classifying functional urban areas, based on several spatial and non-spatial indicators, aggregated at the commune level (LAU1). The research procedure used allowed for the identification of 413 FUAs, divided according to the level of socio-economic development, including the identification of peripheral areas where negative social and economic phenomena accumulate. The classification covered the area of the whole country. Fifteen different data sources, often including original, previously unpublished indicators, enabled a multidimensional analysis of functional relationships, which allowed us to draw a precise picture of the scale of peripherality of areas in Poland. Importantly,

not all areas considered peripheral in accordance with the adopted research methodology are located in geographically-peripheral areas, and not all are located around small towns.

The conducted classification is a contribution to the redefinition of the regional intervention system under the integrated territorial approach in Poland. A precise mapping of areas characterized by developed functional relationships and thus constituting a coherent functional whole makes it possible to more rationally plan interventions tailored to the specificity of a given area, which will bring long-term results. In accordance with the new regional policy paradigm also implemented in the new financial perspective 2021–2027, it is not only peripheral areas that may benefit from support, but also more affluent areas. The classification makes it possible to plan interventions tailored to different needs for all types of areas. Importantly, the research methodology used may have a high value of universality and applicability; therefore, it can be replicated in other countries, while overcoming the previously mentioned limitations. Finally, it is worth emphasizing that the classification is dynamic, i.e., it is valid for the data set used. It is highly probable that the update of the data will bring changes in the number and allocation of individual communes, which also means that the regional development programming system must also be dynamic, i.e., adjusted to the current scale of functional links between individual areas, even within one financial perspective. Conducting constant analysis and updating the map of functional links may lead to an increase in the effectiveness of the cohesion policy and to greater cohesion of the European Union area.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Statement

Due to the sensitive nature of the questions asked in this study, survey respondents were assured raw data would remain confidential and would not be shared.

REFERENCES

Amin, S., 2014. Capitalism in the Age of Globalization: The Management of Contemporary Society. Zed Books. London & New York, 192 pp. https://doi.org/10.5040/9781350218888.

Antikainen, J., 2005. The concept of functional urban area. Findings of the ESPON project 1.1.1. Informationen zur Raumentwicklung 7, 447–452.

Arribas-Bel, D., Garcia-López, M. À., Viladecans-Marsal, E., 2021. Building (s and) cities: Delineating urban areas with a machine learning algorithm. Journal of Urban Economics 125, 103217. https://doi.org/10.1016/j.jue.2019.103217.

Baragwanath, K., Goldblatt, R., Hanson, G., Khandelwal, A. K., 2021. Detecting urban markets with satellite imagery: An application to India. Journal of Urban Economics 125, 103173. https://doi.org/10.1016/j.jue.2019.05.004.

Barca, F., 2009. An agenda for a reformed cohesion policy. A place-based approach to meeting European Union challenges and expectations. Independent report prepared at the request of Danuta Hübner, Commissioner for Regional Policy. European Commission, Brussels. "https://www.europarl.europa.eu/meetdocs/2009_2014/documents/regi/dv/barca_report_/barca_report_en.pdf"

Barca, F., McCann, P., & Rodríguez-Pose, A., 2012. The case for regional development intervention: Place-based versus place-neutral approaches. *Journal of Regional Science* 52(1), pp. 134–152. https://doi.org/10.1111/j.1467-9787.2011.00756.x.

Bartosiewicz, B., Pielesiak, I., 2011. How to measure territorial cohesion of a metropolitan area: proposal of a research concept. In: Marszał T. (Ed.), Urban regions as engines of development. Studia Regionalia 31. Warsaw, Committee for Spatial Economy and Regional Planning of Polish Academy of Sciences, pp. 65–75.

Berry, B. J. L., 1973. Growth centres in the American urban system. Ballinger, Cambridge, 195 pp.

Bishop, C. M., 2006. Pattern Recognition and Machine Learning. Springer: Singapore, 738 pp.

Böhme, K., Eser, T.W., Gaskell, F., Gusedt, E., 2008. The territorial cohesion principles. Position paper to the EU Green Paper on Territorial Cohesion. ARL 78, Hannover, German Academy for Spatial Research and Planning. https://www.arl-net.de/system/files/media-shop/pdf/pospaper_78.pdf.

Böhme, K., Doucet, P., Komornicki, T., Zaucha, J., Światek, T., 2011. How to strengthen the territorial dimension of Europe 2020 and EU cohesion policy. Warsaw, Ministry of Regional Development.

Boschma, R. A., 2005. Proximity and innovation: a critical assessment. Regional Studies 39.1, pp. 61–74. https://doi.org/10.1080/0034340052000320887.

Bowman, A., Ertürk, I., Froud, F., Johal, S., Law, J., Leaver, A., Moran, M., Williams, K., 2014. The end of the experiment? From competition to the foundational economy. Manchester Capitalism, Manchester University Press, 181 pp. https://doi.org/10.7765/9781847798930.

Camagni, R., 2008. Regional competitiveness: towards a concept of territorial capital. In Capello, R., Camagni, R., Chizzolini B., Fratesi, U. (Eds.), Modelling regional scenarios for the enlarged Europe: European competitiveness and global strategies, Berlin, Heidelberg, Springer, pp. 33–47. https://doi.org/10.1007/978-3-540-74737-6_3.

Camagni, R., 2009. Territorial capital and regional development. In Capello, R., Nijkamp, P. (Eds.), Handbook of regional growth and development theories. Cheltenham, Edward Elgar, pp. 124-148. https://doi.org/10.4337/9781788970020.00014.

Churski, P., Perdał, R., Konecka-Szydłowska, B., Herodowicz T., 2021a. European regional development. Contemporary regional and local perspectives of socio-economic and socio-political changes. Economic Geography Series, Springer, 382 pp. https://doi.org/10.1007/978-3-030-84659-6.

Churski, P., Ciesiółka, P., Kołsut, B., Mikuła, Ł., 2021b. Koncepcja strategii rozwoju ponadlokalnego. Materiał ekspercki dla potrzeb jednostek samorządu terytorialnego. Opracowano dla Ministerstwa Funduszy i Polityki Regionalnej. Wydział Geografii Społeczno-Ekonomicznej i Gospodarki Przestrzennej UAM. Lipiec 2021 (The concept of supra-local development strategy. Expert material for the needs of local government units. Prepared for the Ministry of Development Funds and Regional Policy. Faculty of Socio-Economic Geography and Spatial Management, Adam Mickiewicz University. July 2021). Warszawa-Poznań, https://www.gov.pl/web/fundusze-regiony/strategia-rozwoju-ponadlokalnego--poradnik-dla-jednostek-samorzadu-terytorialnego.

Churski P. Adamiak Cz., Szyda B., Dubownik A., Pietrzykowski M., Śleszynski P., 2023, Nowa delimitacja miejskich obszarów funkcjonlanych w Polsce i jej zastosowanie w praktyce zintegrowanego podejścia terytorialnego (place based approach) [A new delimitation of Functional Urban Areas in Poland and its application in the practice of the place-based approach], Przegląd Geograficzny 95, 1, pp. 29-55, https://doi.org/10.7163/PrzG.2023.1.2.

Copus, A., 2001. From core-periphery to polycentric development: concepts of spatial and aspatial peripherality. European Planning Studies 9.4, pp. 539–52. https://doi.org/10.1080/09654310123647.

Copus, A., Mantino, F., Noguera, J., 2017. Inner peripheries: an oxymoron or a real challenge for territorial cohesion? Italian Journal of Planning Practice 7.1, pp. 24–49.

Czyż, T., 2012. Conceptions of an urban agglomeration and a metropolitan area in Poland, Geographia Polonica 84(2), pp. 5–17. http://dx.doi.org/10.7163/GPol.2011.2.1.

Dąbrowski, M., 2014. EU cohesion policy, horizontal partnership and the patterns of sub-national governance: insights from Central and Eastern Europe. European Urban and Regional Studies 21 (4), pp. 364-83. https://doi.org/10.1177/0969776413481983.

De Toni, A., Vizzarri, M., Di Febbraro, M., Lasserre, B., Nouguera, J., Di Martino, P., 2021. Aligning inner peripheries with rural development in Italy: territorial evidence to support policy contextualization. Land Use Policy 100, 104899. https://doi.org/10.1016/j.landusepol.2020.104899.

Dijkstra, L., Poelman, H., Veneri, P., 2019. The EU OECD definition of a functional urban area. OECD Regional Development Working Papers 2019/11, OECD Publishing, Paris. https://dx.doi.org/10.1787/d58cb34d-en.

Distance Matrix API, 2023, Google Maps Platform. https://developers.google.com/maps/documentation/distance-matrix

Duranton, G., Rosenthal, S. S. (Eds.), 2021. Special issue on delineation of urban areas. Journal of Urban Economics 125, 103352. https://doi.org/10.1016/j.jue.2021.103352.

ESPON, 2021, Territorial evidence and policy advice for the prosperous future of rural areas, Policy Paper, Luxembourg, 2021. Available at: https://www.espon.eu/rural

European Commission, 2022. Cohesion in Europe towards 2050. Eighth report on economic, social and territorial cohesion. European Commission Directorate-General for Regional and Urban Policy Unit B1 — Policy Development and Economic Analysis, European Union, Luxembourg. https://ec.europa.eu/regional_policy/information-sources/cohesion-report_en

Everitt, B. S., Landau, S., Leese, M., Stahl, D., 2011, Hierarchical Clustering, In: Everitt, B. S., Landau, S., Leese, M., Stahl, D., (Eds.) Wiley Series in Probability and Statistics, pp. 71–110. https://doi.org/10.1002/9780470977811.ch4.

Functional urban areas (FUA) and European harmonization. A feasibility study from the comparison of two approaches: commuting flows and accessibility isochrones, Draft Report. ESPON, 2014. https://www.espon.eu/sites/default/files/attachments/M4D-DFR_TR-FUA-construction_20140630.pdf.

Garcilazo, J. E., Martins, J.O., Tompson, W., 2010. Why policies may need to be place-based in order to be people-centred. http://voxeu.org/article/why-policies-may-need-be-place-based-order-be-people-centred, [October 18, 2022].

Garcilazo, J. E., Martins, J.O., 2021. New trends in regional policy: Place-based component and structural policies. In: Fischer, M.M., Nijkamp, P. (Eds.), Handbook of Regional Science. Springer Berlin Heidelberg, pp. 1031–1051. https://doi.org/10.1007/978-3-662-60723-7_139.

Gregory, D., 1994. Geographical imaginations. Wiley-Blackwell, 456 pp.

Harvey, D., 1989. The condition of postmodernity. Wiley-Blackwell, 392 pp.

Harvey, D., 2016. The ways of the world. Oxford University Press, 384 pp.

Hay, D., Hall, P., 1977. Urban regionalization of Great Britain: 1971. Department of Geography, University of Reading

Heffner, K., Gibas, P., 2016. Functional areas in the regions and their links to scope sub-regional centres impact. Studia Regionalia 46, pp. 27–39, https://doi.org/0.12657/studreg-46-02.

Ilnicki, D., Janc, K., 2021. Obszary intensywnych powiązań funkcjonalnych miast na prawach powiatu w Polsce – autorska metoda delimitacji (Areas of strong functional linkage of Polish cities granted county status – the authors' own method of delimitation). Przegląd Geograficzny 93, 2, pp. 141–60. https://doi.org/10.7163/PrzG.2021.2.1.

Keeble, D., Offord, J., Walker, S., 1988. Peripheral regions in a community of twelve member states. Office for Official Publications of the European Community, Luxembourg

Kołsut, B., Stryjakiewicz, T., (Eds.), 2022. The economic geography of the car market. The automobile revolution in an emerging economy. Routledge – Taylor & Francis Group, Routledge Advances in Regional Economics, Science and Policy, 193 pp.

Komornicki, T., Rosik, P., Stępniak, M., Śleszyński, P., Goliszek, S., Pomianowski, W., Kowalczyk, K., 2018. Evaluation and monitoring of accessibility changes in Poland using the MAI indicator. Ministry of Investment and Economic Development, Warsaw, 91 pp.

Komornicki, T., Śleszyński, P., Rosik, P., Pomianowski, W., 2010. Dostępność przestrzenna jako przesłanka kształtowania polskiej polityki transportowej. (Spatial accessibility as a premise for shaping Polish transport policy). Biuletyn (Bulletin) KPZK PAN 241, Warsaw 163 pp.

Korcelli, P., 1977. An Approach to the Analysis of Functional Urban Regions: A Case Study of Poland. IIASA Research Memorandum, RM-77-052. IIASA, Laxenburg.

Linge, G. J. R., 1965. The delimitation of urban boundaries for statistical purposes with special reference to Australia. Australia National University, Canberra

Liu, B., Deng, Y., Li, M., Yang, J., Liu, T., 2021. Classification Schemes and Identification Methods for Urban Functional Zone: A Review of Recent Papers. *Applied Sciences 11*(21), 9968. https://doi.org/10.3390/app11219968.

Ma, S., Long, Y., 2020. Functional urban area delineations of cities on the Chinese mainland using massive Didi ride-hailing records. *Cities 97*, 102532. https://doi.org/10.1016/j.cities.2019.102532.

Martin, R., 2015. Rebalancing the spatial economy: the challenge for regional theory. Territory, Politics, Governance 3(3), pp. 235–272.

Maynou, L., Saez, M., Kyriakou, A., Bacaria, J., 2014. The impact of structural and cohesion funds on eurozone convergence, 1990–2010. Regional Studies 50, 7, pp.1127–1139. https://doi.org/10.1080/00343404.2014.965137

McCann, P., 2015. The regional and urban policy of the European Union. Cohesion, Results-Orientation and Smart-Specialisation. Edward Elgar Publishing, Northampton. 304 pp.

McCann, P., Ortega-Argiléz, R., 2012. Some practical elements associated with the design of an integrated and territorial place-based approach to EU cohesion policy, In Crescenzi, R., Perocco M. (Eds.), Geography, institutions and regional economic performance. Springer, New York, pp. 95–119.

Mendez, C., 2013. The post-2013 reform of EU Cohesion Policy and the place-based narrative. Journal of European Public Policy 20.5, pp. 639–59. https://doi.org/10.1080/13501763.2012.736733.

Mendez, C., A. van der Zwet, A., Borkowska-Waszak S., 2021. Rescaling urban development policy in the EU: the impact of integrated place-based approaches in Cohesion Policy. Regional Studies 55, 6, 1154–1165. https://doi.org/10.1080/00343404.2021.1891215.

Moodie, J. R., Salenius, V., Wøien Meijer M. W., 2022. Why territory matters for implementing active subsidiarity in EU regional policy. Regional Studies, 56, 5, pp. 866-878. https://doi.org/10.1080/00343404.2021.1966404.

Morgan, K., 2016. Nurturing novelty: regional innovation policy in the age of smart specialization. Environment and Planning C: Politics and Space 35, 4, pp. 569-583. https://doi.org/10.1177/0263774X16645106.

National Urban Policy 2030, 2022, Ministry of Development Funds and Regional Policy, Poland. https://www.gov.pl/web/funds-regional-policy/national-urban-policy [July, 11, 2023].

OECD, 2012. Redefining "urban": a new way to measure metropolitan areas, OECD Publishing.

OECD, 2022. Urban-rural linkages in Poland, OECD Publishing.

Partridge, M., Ali, K., Olfert, M., 2010. Rural-to-urban commuting: three degrees of integration. Growth and Change 41/2, 303–35. https://doi.org/10.1111/j.1468-2257.2010.00528.x

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R., Dubourg, V., Vanderplas, J., Passos, A., Cournapeau, D., Brucher, M., Perrot, M., Duchesnay, E., 2011. Scikit-learn: Machine Learning in Python. Journal of Machine Learning Research 12, pp. 2825–2830.

Pertoldi, M., Fioretti, C., Guzzo, F., Testori, G., De Bruijn, M., Ferry, M., Kah, S., Servillo, L.A. and Windisch, S., 2022, Handbook of Territorial and Local Development Strategies, Pertoldi, M.,

Fioretti, C., Guzzo, F. and Testori, G. editor(s), EUR 31263 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-58444-5, doi:10.2760/133519, JRC130788.

Pociūtė-Sereikienė, G., 2019. Peripheral regions in Lithuania: the results of uneven development. Regional Studies, Regional Science 6, 1, pp. 70–77, https://doi.org/10.1080/21681376.2019.1571437.

Rafael, Ch., Diego, A. M., Vargas, J. F., 2021. Measuring the size and growth of cities using nighttime light. Journal of Urban Economics 125, 103254. https://doi.org/10.1016/j.jue.2020.103254.

Rodríguez-Pose, A., 2013. Do institutions matter for regional development? Regional Studies 47, 7, pp. 1034–1047. https://doi.org/10.1080/00343404.2012.748978.

Rodríguez-Pose, A., Garcilazo, E., 2015. Quality of government and the returns of investment: examining the impact of cohesion expenditure in European regions. Regional Studies 49, 8, pp.1274–1290. https://doi.org/10.1080/00343404.2015.1007933.

Rosik, P., Stępniak, M., Komornicki, T., 2015. The decade of the big push to roads in Poland: impact on improvement in accessibility and territorial cohesion from a policy perspective. Transport Policy 37, 134–146. https://doi.org/10.1016/j.tranpol.2014.10.007.

Scenarios for integrated territorial investments. European Commission, Directorate-General for Regional and Urban Policy, 2015, Brussels. https://ec.europa.eu/regional_policy/en/information/publications/reports/2015/scenarios-for-integrated-territorial-investments.

Schürmann, C., Spiekermann, K., Wegener, M., 1997. Accessibility indicators. Berichte aus dem Institut für Raumplanung 39. IRPUD, Dortmund.

Servillo, L., Russo, A.P., Barbera, F., 2016. Inner peripheries: towards an EU place-based agenda on territorial peripherality. Italian Journal of Planning Practice 6, 1, pp. 42-75.

Sherrill, K. (1976). Functional Urban Regions in Austria. IIASA Research Memorandum, RM-76-071. Laxenburg: IIASA.

Śleszyński, P., 2013. Delimitation of the Functional Urban Areas around Poland's voivodship capital cities. Przegląd Geograficzny 85(2), pp. 173–197. http://dx.doi.org/10.7163/PrzG.2013.2.2.

Śleszyński, P., 2014. Delimitation and typology of functional urban regions in Poland based on commuting. Geographia Polonica 87, 2, pp.317–320. http://dx.doi.org/10.7163/GPol.2014.20.

Śleszyński, P., Bański, J., Degórski, M., Komornicki, T., 2017. Delimitation of problem areas in Poland. Geographia Polonica 90(2), pp. 131–138. https://doi.org/10.7163/GPol.0088.

Soja, E. W., 1996. Third space journeys to Los Angeles and other real-and-imagined places. Blackwell Publishers, London. 348 pp.

Soja, E. W., 2010. Seeking spatial justice. University of Minnesota Press, Minneapolis. 280 pp.

Spiekermann, K., Schürmann, C., 2007. Update of selected. Potential accessibility. Indicators. Final report. Spiekermann & Wegener Urban and Regional Research (S&W), RRG Spatial Planning and Geoinformation. https://www.espon.eu/sites/default/files/attachments/espon_accessibility_update_2006_fr_070207.pdf.

Spilanis, I., Kizos, T., Giordano, B., 2013. The effectiveness of European regional development fund projects in Greece: Views from planners, management staff and beneficiaries. European Urban and Regional Studies 23, 2, pp.182-197. https://doi.org/10.1177/0969776413498761.

Statistics Poland, 2022. Local Data Bank. Available at: https://bdl.stat.gov.pl/bdl/start

Territorial Agenda 2030 – A future for all places, 2020, Germany. https://ec.europa.eu/regional_policy/en/information/publications/brochures/2021/territorial-agenda-2030-a-future-for-all-places.

The New Leipzig Charter. The transformative power of cities for the common good, 2020, Bundesministerium des Innern und für Heimat, Germany. https://www.bmi.bund.de/SharedDocs/downloads/EN/eu-presidency/gemeinsame-erklaerungen/new-leipzig-charta-2020.pdf?__blob=publicationFile&v=8.

Torre, A., Rallet, A., 2005. Proximity and localization. Regional Studies 39, 1, pp. 47–59. https://doi.org/10.1080/0034340052000320842.

Villaverde, J., 2006. A new look to convergence in Spain. A spatial econometric approach. European Urban and Regional Studies 13, 2, pp. 131–41. https://doi.org/10.1177/0969776406062556.

Wallerstein, I., 1991. Geopolitics and geoculture. Essays on the changing world system. Cambridge University Press, Cambridge. 252 pp.

Whittlesey, D., 1957. The regional concept and the regional method. In James, P. E., Jones, C. F. (Eds.), American Geography: Inventory and Prospect. Syracuse University Press, Syracuse, pp. 19–68.

Zaucha, J., Brodzicki, T., Ciołek, D., Komornicki, T., Mogiła, Z., Szlachta J., Zaleski, J., 2015. Terytorialny wymiar wzrostu i rozwoju (Territorial dimension of growth and development). Wydawnictwo Difin (Difin Press), Warszawa. 456 pp.

Zaucha, J., Komornicki, T., Świątek, D., Bohme, K., Żuber, P., 2014. Territorial keys for bringing closer the Territorial Agenda of the EU and Europe 2020. European Planning Studies 22, 2, pp. 246–267. https://doi.org/10.1080/09654313.2012.722976.

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Appendix A.

Variables used in the classification of functional urban areas (FUAs[1])

Dimension	Aspect	Variables	Data source	Date of data	Tranformation	Included in grouping (F score)
Accessibility	Internal transport accessibility	Average car travel time from all communes to FUA central city	Google Maps Distance Matrix API[2] (data collection as in the delimitation of FUAs)	March 2022	Square root	Yes (15.8)
		Average distance of pupils' homes to primary schools	Statistics Poland	31.12. 2018	Square root	No
		Passenger cars per 1,000 inhabitants	Adam Mickiewicz University (Kołsut and Stryjakiewicz, 2022)	31.12. 2020	None	Yes (33.0)
	External transport accessibility	Multimodal Accessibility Indicator	IGSO PAS[3] Komornicki et al. (2018)	2020	Square root	Yes (59.9)
		Car travel time from FUA central city to nearest regional capital of voivodeship	IGSO PAS Komornicki et al. (2018)	2019	Square root	No
		Car travel time from FUA central city to nearest 100k+ city	IGSO PAS Komornicki et al. (2018)	2019	Square root	Yes (67.1)
		Number of daily public transport connections from FUA central city to regional city (capital of voivodeship) during a working day	Data obtained from e-podroznik.pl – a major online timetable	01.02. 2022	Natural logarithm	No

Dimension	Aspect	Variables	Data source	Date of data	Tranformation	Included in grouping (F score)
			aggregator and ticket sales agent			
	E-accessibility	Share of population with access to broadband Internet	Office of Electronic Communications	31.12. 2020	None	No
		Indicator of Internet access points without access to broadband	Office of Electronic Communications	31.12. 2020	Square root	Yes (46.4)
		Share of population with access to mobile LTE[4] network	Office of Electronic Communications	31.12. 2020	25th power	No
Economy	Land use	Urbanized area per 1,000 inhabitants (CLC level 2 classes: 1.1, 1.2, and 1.3)	CORINE Land Cover	31.12. 2018	Natural logarithm	No
	Business infrastructure	Business environment institutions per 10,000 businesses (all NACE sections)	Statistics Poland	31.12. 2020	Natural logarithm	No
		All year-round hotel bed-places per 1,000 inhabitants	Statistics Poland	31.12. 2020	Natural logarithm	Yes (13.6)
	Economic structure	Share of new economic entities in creative sector among all new entities (NACE J59, J60, M71, M73, M74, R90)	Statistics Poland	31.12. 2020	None	No
	Economic activity	Number of economic entities per 1,000 inhabitants of productive age	Statistics Poland	31.12. 2020	Natural logarithm	No
		Number of large (>49 employees) economic entities per 10,000 inhabitants	Statistics Poland	31.12. 2020	None	No
	Employment	Share of unemployed in population of productive age	Statistics Poland	31.12. 2020	Natural logarithm	Yes (45.3)
		Share of population of productive age employed as contract workers	Ministry of Finance	31.12. 2020	None	No

Dimension	Aspect	Variables	Data source	Date of data	Tranformation	Included in grouping (F score)
		Share of population of productive age running personal businesses	Ministry of Finance	31.12. 2020	Natural logarithm	Yes (87.7)
Finances	Local governments	Own income of local governments per inhabitant	Statistics Poland	31.12. 2020	Natural logarithm	No
		Investment expenditures of local governments per inhabitant	Statistics Poland	31.12. 2020	Natural logarithm	Yes (24.0)
		Net operational surplus of local governments	Statistics Poland	31.12. 2020	8th power	Yes (8.1)
	Inhabitants	Personal income per adult inhabitant	Ministry of Finance	31.12. 2020	Natural logarithm	Yes (152.6)
	Economic development	Businesses income per one taxpayer	Ministry of Finance	31.12. 2020	Natural logarithm	No
Demographics	Demographic structure	Population in post-working age per 100 inhabitants of working age	Statistics Poland	31.12. 2020	Natural logarithm	Yes (37.3)
		Share of population of pre-working age	Statistics Poland	31.12. 2020	Natural logarithm	No
	Natural increase	Rate of natural increase per 1000 population	Statistics Poland	Average 2018-2020	Natural logarithm after adding 20	Yes (49.7)
	Permanent residential migration	Net registered migration increases per 1000 inhabitants	Statistics Poland	Average 2018-2020	Natural logarithm after adding 10	No
Housing	Housing dynamics	Dwellings completed per 1000 inhabitants	Statistics Poland	Average 2018-2020	Natural logarithm	Yes (76.3)
	Housing infrastructure	Share of population in dwellings with central heating	Statistics Poland	31.12. 2020	2nd power	Yes (86.1)
		Share of housing buildings connected to sewerage system	Statistics Poland	31.12. 2020	None	No
	Housing quality	Useful floor space per inhabitant	Statistics Poland	31.12. 2020	Natural logarithm	No

Dimension	Aspect	Variables	Data source	Date of data	Tranformation	Included in grouping (F score)
Health and public safety	Health	Number of outpatients using health-care advice per 10,000 inhabitants	Statistics Poland	Average 2018-2020	None	No
	Public safety	Identified crimes per 10,000 inhabitants	Polish police (National Police Headquarters)	2018-2020	Natural logarithm	Yes (31.3)
		Car accidents and collisions per 10,000 inhabitants	Polish police (National Police Headquarters)	2018-2020	Natural logarithm	Yes (4.0)
Education	Access to education	Places in kindergartens per 1,000 children 3–6 years old	Statistics Poland	31.12. 2018	None	Yes (55.89)
		Number of pupils per class in primary schools	Statistics Poland	31.12. 2020	None	No
	Results of education	Average result of the matura exam in mathematics	Central Examination Board	31.12. 2021	2nd power	Yes (20.6)
		Average result of the matura exam in English	Central Examination Board	31.12. 2021	3rd power	No
Leisure and social activity	Social activity	Non-governmental organizations per 10,000 inhabitants	National Court Register	31.12. 2021	Natural logarithm	No
		Graduates of courses organized by culture institutions per 10,000 inhabitants	Statistics Poland	Average 2018-2020	Natural logarithm	Yes (7.2)
	Leisure	Sport and recreation institutions per 10,000 inhabitants	Statistics Poland	31.12. 2020	Natural logarithm	No
		Attendees of sport and cultural events per 10,000 inhabitants	Statistics Poland	Average 2018-2020	Natural logarithm	No
Ecosystem services	Accessibility to green areas	Share of population with large (>25 ha) green areas within 1 km of home	IGSO PAS (Śleszyński, 2021)	2018	1.3rd power	Yes (1.1)

Dimension	Aspect	Variables	Data source	Date of data	Tranformation	Included in grouping (F score)
		Share of protected areas in commune's area	Statistics Poland (Śleszyński, 2021)	31.12. 2020	Natural logarithm	No
	Level of pollution	Deviation from the norm of atmospheric pollution (mean of BaP[5], PM10[6], PM25[6])	Chief Inspectorate for Environmental Protection (Śleszyński, 2021)	Average 2019-2020	Natural logarithm	No
	Ecological development	Number of applications to 'Pure Air' programme per 1,000 single-family homes	National Fund for Environ-mental Protection and Water Management	2021	Natural logarithm	Yes (18.8)

Source: Authors' own

[1] Functional Urban Areas

[2] Application Programming interface

[3] Institute of Geography and Spatial Organisation Polish Academy of Science

[4] Long Term Evolution

[5] Benzopyrene

[6] Particulate matter

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Appendix B. Correlation matrix between the transformed values of variables used in FUA grouping.

Indicator	Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Average time car travel time from all communes to FUA central city	1	NA	-0,09	-0,11	-0,04	-0,05	0,03	0,23	0,10	-0,03	-0,15	-0,05	0,00	0,25	0,15	0,15	0,16	-0,08	0,02	0,16	0,14	0,18	-0,02	0,11	0,22	-0,08	0,12	0,18	0,20	0,27	0,11	0,11	0,10	0,23	0,06	0,07	0,10	0,04	0,28	0,20	0,18	0,27	0,22	0,26	-0,06	0,22	0,11	0,02
Average distance of pupil homes to primary schools	2	-0,09	NA	0,23	0,38	0,46	-0,45	-0,47	-0,55	0,49	0,26	0,39	-0,12	-0,30	-0,32	-0,40	-0,41	0,28	-0,48	-0,38	-0,35	-0,15	-0,22	-0,54	-0,38	-0,15	-0,02	-0,16	-0,45	-0,27	-0,49	-0,43	-0,03	-0,42	-0,25	0,20	-0,50	-0,30	-0,20	-0,44	0,12	-0,17	-0,42	-0,26	-0,09	-0,06	-0,63	-0,05
Passenger cars per 1,000 inhabitants	3	-0,11	0,23	NA	0,08	0,13	0,17	-0,14	-0,12	0,14	0,00	0,24	-0,28	-0,13	-0,15	-0,04	-0,06	-0,21	0,18	0,17	-0,06	-0,07	0,00	0,11	0,03	-0,16	0,25	0,14	0,04	0,10	-0,13	-0,24	0,24	-0,15	-0,16	0,10	0,00	-0,04	-0,05	-0,19	-0,02	-0,11	-0,06	-0,11	-0,13	-0,07	-0,11	0,11
Car travel time from FUA central city to nearest regional capital of voivodeship	4	-0,04	0,38	0,08	NA	0,77	-0,55	-0,55	-0,31	0,29	0,21	0,26	-0,06	-0,06	-0,28	-0,23	-0,32	0,26	-0,44	-0,27	-0,23	-0,07	-0,13	-0,45	-0,35	-0,02	-0,16	-0,20	-0,45	-0,31	-0,27	-0,16	-0,01	-0,35	-0,15	0,00	-0,28	-0,34	-0,12	-0,21	0,01	-0,07	-0,18	-0,14	0,02	0,05	-0,27	-0,04
Car travel time from FUA central city to nearest 100k+ city	5	-0,05	0,46	0,13	0,77	NA	-0,60	-0,46	-0,37	0,42	0,29	0,32	-0,09	-0,08	-0,28	-0,33	-0,36	0,22	-0,48	-0,36	-0,31	-0,04	-0,15	-0,51	-0,36	-0,12	-0,07	-0,12	-0,46	-0,29	-0,36	-0,21	-0,04	-0,36	-0,19	0,00	-0,35	-0,38	-0,11	-0,25	0,04	-0,04	-0,24	-0,17	0,01	0,03	-0,39	-0,17
Multimodal Accessibility Indicator	6	0,03	-0,45	0,17	-0,55	-0,60	NA	0,41	0,34	-0,33	-0,26	-0,21	-0,19	-0,02	0,34	0,18	0,27	-0,35	0,58	0,33	0,21	-0,06	0,15	0,57	0,46	0,13	0,14	0,11	0,42	0,17	0,20	0,00	0,19	0,24	0,09	0,12	0,36	0,31	0,24	0,22	-0,21	0,13	0,17	0,11	-0,09	-0,11	0,62	0,30
Number of daily public transport connections from FUA central city to regional city (capital of voivodeship) during a working day	7	0,23	-0,47	-0,14	-0,55	-0,46	0,41	NA	0,34	-0,24	-0,21	-0,23	0,06	0,14	0,33	0,27	0,28	-0,20	0,41	0,34	0,23	0,09	0,06	0,46	0,34	0,12	0,07	0,16	0,42	0,26	0,29	0,13	0,03	0,41	0,14	0,00	0,38	0,28	0,26	0,34	-0,05	0,20	0,29	0,19	-0,01	0,01	0,38	-0,04
Share of population with access to broadband Internet	8	0,10	-0,55	-0,12	-0,31	-0,37	0,34	0,34	NA	-0,74	-0,42	-0,26	0,04	0,10	0,21	0,26	0,41	-0,33	0,44	0,29	0,27	0,00	0,15	0,46	0,36	0,09	0,04	0,15	0,32	0,20	0,40	0,36	-0,03	0,31	0,04	-0,15	0,46	0,36	0,15	0,32	0,03	0,15	0,26	0,23	0,00	0,08	0,41	0,12
Indicator of Internet access points without access to broadband	9	-0,03	0,49	0,14	0,29	0,42	-0,33	-0,24	-0,74	NA	0,55	0,29	-0,19	-0,07	-0,10	-0,30	-0,34	0,24	-0,40	-0,28	-0,23	0,10	-0,19	-0,40	-0,25	0,00	-0,09	-0,18	-0,28	-0,14	-0,41	-0,43	0,22	-0,18	-0,15	0,12	-0,38	-0,35	-0,03	-0,24	0,08	-0,05	-0,21	-0,17	-0,06	-0,01	-0,35	-0,15
Share of population with access to mobile LTE4 network	10	-0,15	0,26	0,00	0,21	0,29	-0,26	-0,21	-0,42	0,55	NA	0,11	0,10	-0,08	-0,13	-0,15	-0,14	0,13	-0,27	-0,23	-0,11	0,03	-0,04	-0,29	-0,23	0,03	-0,14	-0,17	-0,28	-0,22	-0,19	-0,16	-0,05	-0,13	0,02	-0,03	-0,17	-0,16	-0,18	-0,21	0,03	-0,08	-0,11	-0,11	-0,07	-0,04	-0,28	-0,08
Urbanized area per 1,000 inhabitants (CLC level 2 classes: 1.1, 1.2, and 1.3)	11	-0,05	0,39	0,24	0,26	0,32	-0,21	-0,23	-0,26	0,29	0,11	NA	-0,12	-0,22	-0,17	-0,25	-0,26	0,09	-0,22	-0,27	-0,15	-0,01	-0,12	-0,29	-0,21	0,12	-0,22	-0,27	-0,26	-0,25	-0,34	-0,15	0,27	-0,32	-0,18	0,13	-0,16	-0,31	-0,08	-0,22	-0,02	-0,05	-0,20	-0,20	0,00	-0,08	-0,28	-0,10
Business environment institutions per 10,000 businesses	12	0,00	-0,12	-0,28	-0,06	-0,09	-0,19	-0,06	-0,04	-0,19	-0,10	-0,12	NA	-0,23	-0,02	-0,35	-0,32	-0,00	-0,23	-0,01	-0,35	-0,03	-0,00	-0,18	-0,20	-0,31	-0,26	-0,24	-0,06	-0,04	-0,28	-0,35	-0,21	-0,20	-0,59	-0,04	-0,28	-0,29	-0,26	-0,17	-0,12	-0,04	-0,24	-0,12	-0,02	-0,05	-0,11	-0,07
All-year round hotel bed-places per 1,000 inhabitants	13	0,25	-0,30	-0,13	-0,06	-0,08	-0,02	-0,14	-0,10	-0,07	-0,08	-0,22	-0,23	NA	-0,08	-0,49	-0,31	-0,12	-0,24	-0,38	-0,38	-0,26	-0,05	-0,30	-0,12	-0,18	-0,01	-0,03	-0,31	-0,35	-0,35	-0,28	-0,19	-0,34	-0,30	-0,02	-0,30	-0,20	-0,05	-0,28	-0,28	-0,17	-0,47	-0,23	-0,07	-0,24	-0,18	-0,16
Share of new economic entities in creative sector among all new businesses	14	0,15	-0,32	-0,15	-0,28	-0,28	-0,34	-0,33	-0,21	-0,10	-0,13	-0,17	-0,02	-0,08	NA	-0,10	-0,17	-0,11	-0,26	-0,12	-0,17	-0,13	-0,03	-0,29	-0,28	-0,12	-0,00	-0,08	-0,30	-0,17	-0,15	-0,02	-0,13	-0,30	-0,08	-0,00	-0,21	-0,07	-0,29	-0,30	-0,05	-0,19	-0,20	-0,15	-0,03	-0,05	-0,32	-0,03
Number of economic entities per 1,000 population in productive age	15	0,15	-0,40	-0,04	-0,23	-0,33	-0,18	-0,27	-0,26	-0,30	-0,15	-0,25	-0,35	-0,49	-0,10	-0,84	-0,55	-0,35	-0,53	-0,84	-0,65	-0,18	-0,11	-0,68	-0,15	-0,23	-0,10	-0,11	-0,56	-0,52	-0,56	-0,37	-0,33	-0,40	-0,50	-0,08	-0,48	-0,48	-0,01	-0,39	-0,23	-0,07	-0,73	-0,22	-0,18	-0,15	-0,21	-0,13
Number of large (>49 employees) economic entities per 10,000 inhabitants	16	0,16	-0,41	-0,06	-0,32	-0,36	-0,27	-0,28	-0,41	-0,34	-0,14	-0,26	-0,32	-0,31	-0,17	-0,55	-0,37	-0,63	-0,46	-0,53	-0,11	-0,09	-0,62	-0,40	-0,18	-0,10	-0,10	-0,41	-0,38	-0,53	-0,40	-0,07	-0,47	-0,34	-0,00	-0,43	-0,45	-0,16	-0,37	-0,19	-0,03	-0,45	-0,34	-0,05	-0,08	-0,20	-0,02
Share of unemployed in population in productive age	17	-0,08	-0,28	-0,21	-0,26	-0,22	-0,35	-0,20	-0,33	-0,24	-0,13	-0,09	-0,00	-0,12	-0,11	-0,35	-0,37	-0,47	-0,42	-0,37	-0,14	-0,05	-0,56	-0,40	-0,12	-0,33	-0,32	-0,43	-0,35	-0,32	-0,24	-0,25	-0,05	-0,13	-0,03	-0,39	-0,42	-0,02	-0,21	-0,05	-0,02	-0,27	-0,17	-0,06	-0,01	-0,21	-0,07
Share of population in productive age employed as contract workers	18	0,02	-0,48	-0,18	-0,44	-0,48	-0,58	-0,41	-0,44	-0,40	-0,27	-0,22	-0,23	-0,24	-0,26	-0,53	-0,63	-0,47	-0,53	-0,56	-0,07	-0,17	-0,89	-0,49	-0,20	-0,24	-0,20	-0,55	-0,48	-0,54	-0,32	-0,16	-0,41	-0,36	-0,10	-0,55	-0,58	-0,10	-0,33	-0,02	-0,05	-0,42	-0,33	-0,04	-0,00	-0,31	-0,06
Share of population in productive age running personal businesses	19	0,16	-0,38	-0,17	-0,27	-0,36	-0,33	-0,34	-0,29	-0,28	-0,23	-0,27	-0,01	-0,38	-0,12	-0,84	-0,46	-0,42	-0,53	-0,46	-0,46	-0,17	-0,09	-0,70	-0,28	-0,00	-0,36	-0,34	-0,65	-0,62	-0,50	-0,23	-0,34	-0,35	-0,25	-0,15	-0,42	-0,44	-0,16	-0,35	-0,13	-0,12	-0,60	-0,20	-0,14	-0,13	-0,27	-0,02
Own income of local governments per inhabitant	20	0,14	-0,35	-0,06	-0,23	-0,31	-0,21	-0,23	-0,27	-0,23	-0,11	-0,15	-0,35	-0,38	-0,17	-0,65	-0,53	-0,37	-0,56	-0,46	-0,39	-0,42	-0,10	-0,69	-0,31	-0,23	-0,03	-0,09	-0,43	-0,47	-0,56	-0,39	-0,28	-0,34	-0,46	-0,10	-0,45	-0,48	-0,00	-0,35	-0,15	-0,04	-0,54	-0,35	-0,13	-0,13	-0,12	-0,13
Investment expenditures of local governments per inhabitant	21	0,18	-0,15	-0,07	-0,07	-0,04	-0,06	-0,09	-0,00	-0,10	-0,03	-0,01	-0,03	-0,26	-0,13	-0,18	-0,11	-0,14	-0,07	-0,17	-0,42	-0,39	-0,02	-0,16	-0,14	-0,01	-0,08	-0,14	-0,20	-0,30	-0,10	-0,10	-0,22	-0,10	-0,04	-0,07	-0,04	-0,11	-0,13	-0,20	-0,15	-0,15	-0,20	-0,19	-0,10	-0,20	-0,02	-0,20
Net operational surplus of local governments	22	-0,02	-0,22	-0,00	-0,13	-0,15	-0,15	-0,06	-0,15	-0,19	-0,04	-0,12	-0,00	-0,05	-0,03	-0,11	-0,09	-0,05	-0,17	-0,09	-0,10	-0,02	-0,16	-0,16	-0,09	-0,14	-0,18	-0,13	-0,11	-0,19	-0,10	-0,10	-0,09	-0,06	-0,01	-0,08	-0,14	-0,01	-0,05	-0,06	-0,03	-0,09	-0,02	-0,05	-0,03	-0,11	-0,09

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Personal income per adult inhabitant	23	0,11	-0,54	0,11	-0,45	-0,51	0,57	0,46	0,46	-0,40	-0,29	-0,29	0,18	0,30	0,29	0,68	0,62	-0,56	0,89	0,70	0,69	0,16	0,16	NA	0,50	0,09	0,34	0,33	0,66	0,59	0,65	0,35	0,26	0,42	0,38	0,08	0,58	0,63	0,17	0,43	-0,01	0,12	0,54	0,33	0,08	0,04	0,38	0,06
Businesses income per one taxpayer	24	0,22	-0,38	0,03	-0,35	-0,36	0,46	0,34	0,36	-0,25	-0,23	-0,21	-0,20	0,12	0,28	0,15	0,40	-0,40	0,49	0,28	0,31	0,14	0,16	0,50	NA	-0,07	0,27	0,31	0,37	0,38	0,35	0,15	0,10	0,28	0,01	0,05	0,31	0,32	0,29	0,26	-0,12	0,11	0,20	0,30	-0,04	0,03	0,35	0,09
Population in post-working age per 100 inhabitants in working age	25	-0,08	-0,15	-0,16	-0,02	-0,12	0,13	0,12	0,09	0,00	0,03	0,12	0,31	0,18	0,12	0,23	0,18	0,12	0,20	0,00	0,23	-0,01	-0,09	0,09	-0,07	NA	-0,78	-0,80	-0,10	-0,25	-0,02	-0,05	0,33	0,35	0,34	-0,06	0,25	0,01	0,03	0,25	0,18	-0,02	0,16	0,08	-0,06	0,08	0,16	-0,17
Share of population in pre-working age	26	0,12	-0,02	0,25	-0,16	-0,07	0,14	0,07	0,04	-0,09	-0,14	-0,22	-0,26	-0,01	0,00	0,10	0,10	-0,33	0,24	0,36	0,03	0,08	0,14	0,34	0,27	-0,78	NA	0,87	0,35	0,53	0,21	0,11	-0,17	-0,07	-0,13	0,17	-0,06	0,28	0,07	-0,06	-0,16	0,05	0,05	0,07	0,03	-0,05	0,00	0,13
Rate of natural increase per 1000 population	27	0,18	-0,16	0,14	-0,20	-0,12	0,11	0,16	0,15	-0,18	-0,17	-0,27	-0,24	0,03	0,08	0,11	0,10	-0,32	0,20	0,34	0,09	0,14	0,18	0,33	0,31	-0,80	0,87	NA	0,38	0,55	0,37	0,24	-0,20	-0,04	-0,18	0,08	0,03	0,28	0,11	0,01	-0,09	0,10	0,17	0,12	0,07	-0,01	0,01	0,12
Net registered migration increases per 1000 population	28	0,20	-0,45	0,04	-0,45	-0,46	0,42	0,42	0,32	-0,28	-0,28	-0,26	0,06	0,31	0,30	0,56	0,41	-0,43	0,55	0,65	0,43	0,20	0,13	0,66	0,37	-0,10	0,35	0,38	NA	0,65	0,49	0,28	0,24	0,31	0,21	0,10	0,49	0,48	0,21	0,38	0,05	0,14	0,50	0,21	0,03	0,04	0,34	0,05
Dwellings completed per 1000 inhabitants	29	0,27	-0,27	0,10	-0,31	-0,29	0,17	0,26	0,20	-0,14	-0,22	-0,25	-0,04	0,35	0,17	0,52	0,38	-0,35	0,48	0,62	0,47	0,30	0,11	0,59	0,38	-0,25	0,53	0,55	0,65	NA	0,49	0,25	0,29	0,31	0,13	0,14	0,27	0,45	0,20	0,27	0,11	0,09	0,43	0,29	0,02	0,08	0,08	-0,11
Share of population in dwellings with central heating	30	0,11	-0,49	-0,13	-0,27	-0,36	0,20	0,29	0,40	-0,41	-0,19	-0,34	0,28	0,35	0,15	0,56	0,53	-0,32	0,54	0,50	0,56	0,10	0,19	0,65	0,35	-0,02	0,21	0,37	0,49	0,49	NA	0,47	0,00	0,35	0,32	-0,06	0,52	0,53	0,03	0,34	0,02	0,05	0,54	0,34	0,05	0,07	0,21	0,13
Share of housing buildings connected to sewerage system	31	0,11	-0,43	-0,24	-0,16	-0,21	0,00	0,13	0,36	-0,43	-0,16	-0,15	0,35	0,28	0,02	0,37	0,40	-0,24	0,32	0,23	0,39	0,10	0,10	0,35	0,15	-0,05	0,11	0,24	0,28	0,25	0,47	NA	-0,15	0,18	0,26	-0,10	0,35	0,35	-0,11	0,24	-0,01	0,10	0,38	0,19	0,17	0,10	0,08	-0,04
Useful f Useful floor space per inhabitant loor area per inhabitant	32	0,10	-0,03	0,24	-0,01	-0,04	0,19	0,03	-0,03	0,22	-0,05	0,27	-0,21	0,19	0,13	0,33	0,07	-0,25	0,16	0,34	0,28	0,22	-0,10	0,26	0,10	0,33	-0,17	-0,20	0,24	0,29	0,00	-0,15	NA	0,12	0,02	0,09	0,19	0,05	0,13	0,17	0,18	0,07	0,30	0,05	0,02	0,10	0,14	-0,15
Number of outpatients using health-care advice per 10,000 population	33	0,23	-0,42	-0,15	-0,35	-0,36	0,24	0,41	0,31	-0,18	-0,13	-0,32	0,20	0,34	0,30	0,40	0,47	-0,05	0,41	0,35	0,34	0,10	0,09	0,42	0,28	0,35	-0,07	-0,04	0,31	0,31	0,35	0,18	0,12	NA	0,33	-0,02	0,39	0,23	0,20	0,31	0,22	0,10	0,38	0,31	-0,11	0,09	0,27	-0,07
Identified crimes per 10,000 inhabitants	34	0,06	-0,25	-0,16	-0,15	-0,19	0,09	0,14	0,04	-0,15	0,02	-0,18	0,59	0,30	0,08	0,50	0,34	-0,13	0,36	0,25	0,46	0,04	0,06	0,38	0,01	0,34	-0,13	-0,18	0,21	0,13	0,32	0,26	0,02	0,33	NA	0,08	0,31	0,36	-0,15	0,22	0,02	0,01	0,36	0,18	0,10	0,03	0,12	-0,11
Car accidents and collisions per 10,000 inhabitants	35	0,07	0,20	0,10	0,00	0,00	0,12	0,00	-0,15	0,12	-0,03	0,13	-0,04	-0,02	0,00	0,08	0,00	-0,03	0,10	0,15	0,10	0,07	-0,01	0,08	0,05	-0,06	0,17	0,08	0,10	0,14	-0,06	-0,10	0,09	-0,02	0,08	NA	-0,03	0,02	0,06	-0,06	0,00	-0,03	-0,03	0,01	0,03	-0,02	-0,09	-0,03
Places in kindergartens per 1,000 children 3–6 years old	36	0,10	-0,50	0,00	-0,28	-0,35	0,36	0,38	0,46	-0,38	-0,17	-0,16	0,28	0,30	0,21	0,48	0,43	-0,39	0,55	0,42	0,45	0,04	0,08	0,58	0,31	0,25	-0,06	0,03	0,49	0,27	0,52	0,35	0,19	0,39	0,31	-0,03	NA	0,44	0,05	0,38	0,07	0,12	0,46	0,30	0,06	0,05	0,39	0,04
Number of pupils per class in primary schools	37	0,04	-0,30	-0,04	-0,34	-0,38	0,31	0,28	0,36	-0,35	-0,16	-0,31	0,29	0,20	0,07	0,48	0,45	-0,42	0,58	0,44	0,48	0,11	0,14	0,63	0,32	0,01	0,28	0,28	0,48	0,45	0,53	0,35	0,05	0,23	0,36	0,02	0,44	NA	0,00	0,27	-0,08	0,02	0,38	0,30	0,07	0,01	0,25	0,07
Average result of the matura exam in mathematics	38	0,28	-0,20	-0,05	-0,12	-0,11	0,24	0,26	0,15	-0,03	-0,18	-0,08	-0,26	0,05	0,29	0,01	0,16	-0,02	0,10	0,16	0,00	0,13	-0,01	0,17	0,29	0,03	0,07	0,11	0,21	0,20	0,03	-0,11	0,13	0,20	-0,15	0,06	0,05	0,00	NA	0,64	0,03	0,15	0,09	0,09	-0,01	0,02	0,28	-0,01
Average result of the matura exam in English	39	0,20	-0,44	-0,19	-0,21	-0,25	0,22	0,34	0,32	-0,24	-0,21	-0,22	0,17	0,28	0,30	0,39	0,37	-0,21	0,33	0,35	0,35	0,20	0,05	0,43	0,26	0,25	-0,06	0,01	0,38	0,27	0,34	0,24	0,17	0,31	0,22	-0,06	0,38	0,27	0,64	NA	0,13	0,17	0,38	0,16	0,13	0,10	0,34	-0,04
Non-governmental organizations per 10,000 inhabitants	40	0,18	0,12	-0,02	0,01	0,04	-0,21	-0,05	0,03	0,08	0,03	-0,02	0,12	0,28	0,05	0,23	0,19	0,05	-0,02	0,13	0,15	0,15	-0,06	-0,01	-0,12	0,18	-0,16	-0,09	0,05	0,11	0,02	-0,01	0,18	0,22	0,02	0,00	0,07	-0,08	0,03	0,13	NA	0,04	0,32	0,04	-0,07	0,19	-0,19	-0,15
Graduates of courses organized by culture institutions per 10,000 inhabitants	41	0,27	-0,17	-0,11	-0,07	-0,04	0,13	0,20	0,15	-0,05	-0,08	-0,05	-0,04	0,17	0,19	0,07	0,03	-0,02	0,05	0,12	0,04	0,15	-0,03	0,12	0,11	-0,02	0,05	0,10	0,14	0,09	0,05	0,10	0,07	0,10	0,01	-0,03	0,12	0,02	0,15	0,17	0,04	NA	0,10	0,06	0,02	0,08	0,22	0,07
Sport and recreation institutions per 10,000 inhabitants	42	0,22	-0,42	-0,06	-0,18	-0,24	0,17	0,29	0,26	-0,21	-0,11	-0,20	0,24	0,47	0,20	0,73	0,45	-0,27	0,42	0,60	0,54	0,20	0,09	0,54	0,20	0,16	0,05	0,17	0,50	0,43	0,54	0,38	0,30	0,38	0,36	-0,03	0,46	0,38	0,09	0,38	0,32	0,10	NA	0,23	0,13	0,24	0,25	-0,10
Attendees of sport and cultural events per 10,000 inhabitants	43	0,26	-0,26	-0,11	-0,14	-0,17	0,11	0,19	0,23	-0,17	-0,11	-0,20	0,12	0,23	0,15	0,22	0,34	-0,17	0,33	0,20	0,35	0,19	0,02	0,33	0,30	0,08	0,07	0,12	0,21	0,29	0,34	0,19	0,05	0,31	0,18	0,01	0,30	0,30	0,09	0,16	0,04	0,06	0,23	NA	-0,06	0,10	0,13	-0,05
Share of population with large (>25 ha) green areas within 1 km of home	44	-0,06	-0,09	-0,13	0,02	0,01	-0,09	-0,01	0,00	-0,06	-0,07	0,00	0,02	0,07	-0,03	0,18	-0,05	-0,06	-0,04	0,14	0,13	0,10	-0,05	0,08	-0,04	-0,06	0,03	0,07	0,03	0,02	0,05	0,17	0,02	-0,11	0,10	0,03	0,06	0,07	-0,01	0,13	-0,07	0,02	0,13	-0,06	NA	0,13	0,07	-0,12
Share of protected areas in commune’s area	45	0,22	-0,06	-0,07	0,05	0,03	-0,11	0,01	0,08	-0,01	-0,04	-0,08	0,05	0,24	0,05	0,15	0,08	0,01	0,00	0,13	0,13	0,20	0,03	0,04	0,03	0,08	-0,05	-0,01	0,04	0,08	0,07	0,10	0,10	0,09	0,03	-0,02	0,05	0,01	0,02	0,10	0,19	0,08	0,24	0,10	0,13	NA	0,03	-0,05
Deviation from the norm of atmospheric pollution (mean of BaP5, PM106, PM256)	46	0,11	-0,63	-0,11	-0,27	-0,39	0,62	0,38	0,41	-0,35	-0,28	-0,28	-0,11	0,18	0,32	0,21	0,20	-0,21	0,31	0,27	0,12	0,02	0,11	0,38	0,35	0,16	0,00	0,01	0,34	0,08	0,21	0,08	0,14	0,27	0,12	-0,09	0,39	0,25	0,28	0,34	-0,19	0,22	0,25	0,13	0,07	0,03	NA	0,31
Number of applications to ‘Pure Air’ programme per 1,000 single-family homes	47	0,02	-0,05	0,11	-0,04	-0,17	0,30	-0,04	0,12	-0,15	-0,08	-0,10	-0,07	-0,16	0,03	-0,13	0,02	-0,07	0,06	-0,02	-0,13	-0,20	0,09	0,06	0,09	-0,17	0,13	0,12	0,05	-0,11	0,13	-0,04	-0,15	-0,07	-0,11	-0,03	0,04	0,07	-0,01	-0,04	-0,15	0,07	-0,10	-0,05	-0,12	-0,05	0,31	NA

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Source: Authors' own

Appendix C. Criteria used to select number of clusters in Gaussian mixtures method using a spherical variance matrix.

Number of clusters	Bayesian information criterion (BIC)	Caliński-Barabasz index	Davies-Bouldin index
2	25.150	70.079	2.340
3	25.082	48.256	2.718
4	24.891	41.634	2.720
5	24.824	35.823	2.506
6	24.774	32.191	2.414
7	24.706	30.861	2.313

Source: Authors' own

This work was funded by the National Science Centre in Poland under the project
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Appendix D. Average values of indicators for five types of FUAs

Indicator	All FUAs	Core areas	Intermediate areas of big and medium cities	Intermediate areas of medium and small cities	Second-order inner peripheries	First-order inner peripheries
Average car travel time from all communes to FUA central city (hour)	0,13	0,24	0,13	0,14	0,11	0,13
Average distance of pupils' homes to primary schools(hour)	1604,23	1167,89	1045,42	1569,91	1674,64	1913,12
Passenger cars per 1,000 inhabitants	445,60	405,23	424,40	471,22	431,07	444,03
Car travel time from FUA central city to nearest regional capital of voivodeship (hours)	0,88	0,44	0,60	0,85	0,96	1,09
Car travel time from FUA central city to nearest 100k+ city (hour)	0,76	0,27	0,36	0,75	0,78	1,04
Multimodal Accessibility Indicator	28,66	33,14	52,69	32,27	21,69	20,57
Number of daily public transport connections from FUA central city to regional city (capital of voivodeship) during a working day	45,21	371,80	56,95	24,76	18,35	16,75
Share of population with access to broadband Internet (%)	53,55	69,42	73,84	56,65	50,87	39,74
Indicator of Internet access points without access to broadband (bpa)	121,94	89,76	59,57	110,70	109,56	186,63
Share of population with access to mobile LTE4 network (%)	96,43	96,62	93,95	97,11	95,89	97,01
Urbanized area per 1,000 inhabitants (CLC level 2 classes: 1.1, 1.2, and 1.3)	5,83	4,28	4,88	5,56	5,89	6,93
Business environment institutions per 10,000 businesses	761,53	889,33	884,91	622,47	1043,83	553,01
All year-round hotel bed-places per 1,000 inhabitants	6,38	21,41	4,79	4,81	6,88	4,84
Share of new economic entities in creative sector among all new businesses (%)	4,78	6,51	6,03	4,73	4,04	4,75
Number of economic entities per 1,000 inhabitants of productive age	164,66	254,14	183,08	168,88	161,09	131,84
Number of large (>49 employees) economic entities per 10,000 inhabitants	6,58	9,09	7,84	6,90	6,49	5,05
Share of unemployed in population of productive age (%)	5,42	4,04	4,55	4,18	6,41	6,81
Share of population of productive age employed as contract workers (%)	45,17	52,15	52,17	47,62	43,38	38,99
Share of population of productive age running personal businesses (%)	8,69	12,08	9,08	9,64	7,96	7,10
Own income of local governments per inhabitant (PLN)	2532,09	3830,81	3034,33	2574,37	2384,28	2100,18
Investment expenditures of local governments per inhabitant (PLN)	864,48	1346,01	820,64	873,06	717,39	915,89
Net operational surplus of local governments (%)	2,27	4,66	3,87	4,01	1,61	-0,77
Personal income per adult inhabitant (PLN)	32763,69	43828,96	39539,36	35237,92	30011,35	26706,53
Businesses income per one taxpayer (PLN)	314280,20	460994,87	465009,03	393191,71	203673,70	227979,29
Population of post-working age per 100 inhabitants in working age (%)	34,74	37,35	39,00	32,06	35,71	35,12
Share of population of pre-working age (%)	15,13	15,20	14,38	16,40	14,33	14,49
Rate of natural increase per 1000 inhabitants	-2,28	-1,05	-3,60	-0,34	-3,50	-3,48
Net registered migration increases per 1000 inhabitants	-2,10	2,09	-1,02	-1,01	-3,30	-3,85
Dwellings completed per 1000 inhabitants	3,33	8,06	2,87	4,19	2,29	2,26
Share of population in dwellings with central heating (%)	78,35	88,86	83,70	80,19	79,03	69,95
Share of housing buildings connected to sewerage system (%)	49,57	60,22	60,87	50,56	51,90	38,03
Useful floor area per inhabitant (m^2)	28,25	32,16	28,50	28,43	26,76	28,60
Number of outpatients using healthcare advice per 10,000 population	62492,26	79559,19	70978,41	60820,60	62373,73	57193,78
Identified crimes per 10,000 inhabitants	29,42	36,44	39,09	27,25	32,27	23,53
Car accidents and collisions per 10,000 inhabitants	0,93	0,93	0,78	1,00	0,85	0,96
Places in kindergartens per 1,000 children 3–6 years old	707,09	846,13	910,26	742,75	705,04	538,34
Number of pupils per class in primary schools	15,86	17,75	17,34	16,43	15,59	14,26

Average result of the matura exam in mathematics (%)	51,83	56,94	54,61	52,68	47,25	53,47
Average result of the matura exam in English (%)	71,30	79,13	76,84	71,65	68,54	69,71
Non-governmental organizations per 10,000 inhabitants	34,62	44,57	29,78	33,08	34,72	36,12
Graduates of courses organized by culture institutions per 10,000 inhabitants	18,42	21,69	21,95	19,56	11,69	22,32
Sport and recreation institutions per 10,000 inhabitants	20,82	31,34	22,77	21,15	20,38	17,34
Attendees of sport and cultural events per 10,000 inhabitants	2453,73	8994,69	5348,91	2238,12	1458,48	1052,00
Share of population with large (>25 ha) green areas within 1 km of home (%)	63,30	68,11	67,66	62,47	63,96	60,73
Share of protected areas in commune's area (%)	9,83	13,97	10,64	9,35	8,84	10,28
Deviation from the norm of atmospheric pollution (mean of BaP5, PM106, PM256) (average=100)	76,95	79,52	136,88	78,92	66,19	61,57
Number of applications to 'Pure Air' programme per 1,000 single-family homes	28,90	20,10	42,11	30,86	28,44	23,49

Source: Authors' own