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Innovation level and local development of EU regions. A new assessment approach

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ABSTRACT

The main purpose of the study is to present a new approach to comparing EU regions according to their level of innovation. For many years, different organizations have published reports related to the innovation level of EU countries and regions. Usually, taxonomic methods are used to measure development in this area. The main disadvantage of this approach is that it offers an assessment of EU innovation level based only on the mean, while the main goal of this kind of analysis should include an assessment of results compatibility obtained in different areas constituting a composite measure. For this purpose, a different procedure based on the multi-criteria taxonomic method is proposed. In this method, the innovation level of every object (in the paper, EU regions) is assessed using results obtained in every group of indicators taken into account for this purpose. This means that EU regions can be divided into groups according their level of innovation in all considered areas, not only according to their mean value of development. This is the basic advantage of this type of analysis. An added value of the considerations presented in the paper is the possibility of obtaining supplementary information about the internal structure of the innovation of socio-economic objects. It should be emphasized that such analysis is a new approach to this kind of assessment. The results are especially relevant to associations such as the European Union, in which internal cohesion is one of its strategic developmental goals.

1. Introduction

For years, the European Union's regional policy has supported the development of innovation in its member states. This is done by many programs and initiatives whose priorities and measures are co-funded from structural funds. This has led to considerable progress in industry and science: A lot of jobs have been created, the conditions and quality of life has improved and technologies limiting the consumption of materials and energy have been implemented, which in turn enables cleaner and more socially responsible production (Dziallas and Blind, 2018). However, in spite of considerable expenses and effort, it is apparent that models in regional innovation structures remain diverse, non-linear and complex (i.e. Becheikh et al., 2006; Hajek and Henriques, 2017). This is the main reason why policies, vision and governance of development in European regions must be under pressure of permanent assessment from both society and researchers, especially in the field of innovation development and implementation. It is also the reason why the results of various types of rankings of innovation level published for years have been so popular among scientists and business practitioners (e.g., Global Innovation Index, European Innovation Scoreboard and Regional Innovation Scoreboard).

It is worth noting, however, that these rankings assess the level of innovation (innovativeness) of, for example, countries or world regions primarily in terms of mean values determined on the basis of a selected set of indicators divided most often into several different groups, usually including: human resources, financial resources, employment impact or sales impact. This is a dominant approach to the study of the level of innovation of various socio-economic objects, yet it may produce distorted results, particularly when there is considerable differentiation within the various areas normally considered in innovation level assessment. It is natural for surveyed countries or regions to be significantly diverse in this respect, and high results regarding, for

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example, human or financial resources may not correlate with high results regarding obtained patents or exports and sales of innovative products, even though the main goal of various types of innovation programs and strategies is to strive for high results in each of these areas at the same time. This is why research and analyses are so important, the goal being not only to build rankings of innovation level but also analysis of the internal structure of this innovation. According to the authors of this article, analyses which enable the study of similarities of the examined objects in this respect are also important, while such research should focus on the results obtained in each of the analyzed areas at the same time. This means that regions will be considered as similar whose results in each of the analyzed areas are similar, and not only those that achieve a similar overall average level of innovation development. It also means that the results of the analysis presented in the paper should be treated as supplementary to the results of various types of work in this field published so far (e.g. Afuah, 2003; Tello and Yoon, 2008; Szopik-Depczyńska et al., 2018a, 2018b). In particular, the results presented in the paper should be treated as complementary to the Regional Innovations Scoreboard reports, which formed their basis.

The main purpose of the present study is to present a new approach to comparing EU regions according to their level of innovation. The authors' intention is to gain a profound understanding of the structure and quality of innovation and to identify groups of objects that are similar in light of specific indicators. For these purposes, the results of The Regional Innovation Scoreboard (RIS) were used. The RIS is a regional extension of the European Innovation Scoreboard (EIS), in which the innovation of European regions is assessed. The results from 202 regions across 22 EU countries in 2017 were used; however, the following countries have been excluded from the research: Cyprus, Estonia, Latvia, Lithuania, Luxembourg, and Malta, for which the results were only presented at the national level.

The article is divided into 5 sections. The first presents the aim of the research, the research tasks and important innovation-related elements that make up the background for further discussion. Next, there is a detailed review of the literature on the essence and complexity of measuring the innovation level of EU regions. The third section is dedicated to the presentation of the statistical data that are the subjects of the study and contains a description of the mathematical research methods. The next one presents the research results, followed by conclusions and recommendations for further research.

The added value of the analysis presented in the paper is a comparison of the innovativeness of Europe's regions from a different point of view than is usually adopted in the literature. It is a new approach to comparing indicators that measure the innovation development of regions. Using the same analytical tools, in further years it will be possible to assess the structure and quality of innovation in individual regions and to examine the directions of implementing innovation development policy.

2. Literature background

Innovativeness is now recognized as one of the most important factors determining the competitiveness of regions. It could be defined in many different ways: from micro- and macro- perspectives, in relation to selected areas of human activity, e.g., innovativeness in industry, agriculture, tourism—or in conjunction with new development strategies, including the latest sustainable development strategies, Agenda 2030, the so-called responsible innovations system (i.e. Cheba and Szopik-Depczyńska, 2017; Guimarães et al., 2019; Cheba, 2019)

For the deliberations presented in this paper, however, the division of innovativeness is crucially considered at the microeconomic level in terms of, for example, enterprises, and at the macroeconomic level in the context of countries or regions. Due to the nature of the analysis within which the comparisons of the level of innovation of regional economies of EU countries are being conducted, the definitions of innovativeness that refer to regions are particularly important for the authors. It is worth emphasizing that by reason of the complexity and multifaceted nature of the phenomenon at this level, this term is difficult to define unequivocally. Regions are organisms that are complex in terms of organization, territoriality and functionality which do not compete with each other in a direct way like companies do. On the other hand, considering the numerous interactions occurring at the regional level between enterprises, research and development units, non-governmental institutions and public administration units and the public, regional innovativeness is not only the sum of the innovativeness of its individual components (the innovativeness of enterprises, science and research, etc.) (Klerkx et al., 2017; Świadek, 2018).

The first usage of the term "regional innovations" dates from the paper published by Cooke and Cardiff (1992), later reviewed by Braczyk et al. (1998) and also by Cooke et al. (1998). In these papers, innovativeness at this level was defined as: "a system stimulating innovation capabilities of firms in a region so as to enhance the region's growth potential and regional competitiveness. Interaction is a social process involving feedback at different stages of knowledge development, diffusion and deployment stimulate innovation in a region" (Cooke and Cardiff, 1992).

In the literature (e.g., Lundvall, 2010; Yigitcanlar, 2014a, 2014b), there may be other definitions of regional innovations; however, they all involve a combination of the concepts of region, innovation and system, and hence are not much different than the one presented above.

When considering innovativeness at the regional level, it is worth emphasizing that in numerous publications in this field (i.e. Cooke, 2001; Tödtling and Trippl, 2005; Yigitcanlar et al., 2017), it is more and more frequently emphasized that the gravitational center of industrial and innovative dynamics is increasingly visible at the regional level, but it is not a process that develops in a linear way. It is the result of interactions between various factors that may determine the level of innovativeness. This means that innovation is both the effect of resources and actions. Nowadays, regions are presented as areas constituting an important platform for the creation, absorption and diffusion of innovation, and their innovativeness is regarded as a key determinant affecting the improvement of the competitive position of the centers both in the national and international arenas. Regions are increasingly recognized as a key place for national and transnational innovation achievements (Doloreux and Parto, 2004,). In the literature on the subject (Asheim and Coenen, 2005; Drucker, 2014), the assessment of the level of innovation of various socio-economic objects, including regions, is usually based on an often very complex set of indicators. These indicators describe various areas relevant to creating effective regional innovation systems, such as: human and intellectual resources, public and private financial resources used for the development of innovation (e.g., in enterprises), the ability to create innovation or institutional support for the development of regional innovation systems. Each of these factors is equally important for the creation of innovation systems. Building a competitive advantage, which is based on knowledge and innovation, most often increases the innovativeness of the territorial unit and can guarantee its sustainable socio-economic development.

The impact of innovation and knowledge on economic development is widely described in the contemporary literature on the subject. According to many authors (i.e. Neef et al., 1998; Dunning, 2002; Boden and Miles, 2000; Metaxiotis et al., 2010; Yigitcanlar et al., 2012; Pancholi et al., 2015; Wu et al., 2017; Szopik-Depczyńska et al., 2018b), the creation of a "knowledge society" and a "knowledge-based economy" is even the next stage in the evolution of humanity. Knowledge is necessary not only to create infrastructure (technologies), but also and perhaps above all to use it well. The growing complexity of technology and increasing global competition are the main reasons why the knowledge requirements of people creating organizations and knowledge of the organizations themselves are growing. Only appropriate knowledge resources can guarantee that the means invested in infrastructure will bring the expected results and enable the stimulation of further development (activating positive feedback). The skillful accumulation of knowledge therefore results in the easier absorption of technology and the creation of an innovative environment conducive to development. As Drucker (1992: 120) writes: "Knowledge-based innovation is a superstar of entrepreneurship."

Thus, in this case, we have a change in the view of the resource factor, which in traditional regional development assessment systems is perceived as passive goods—i.e., the so-called existing resources resulting from historical conditions and the location of the region in a specific environment. However, when assessing the innovativeness of regions, intellectual and human resources become an active factor which changes over time. These resources can also be obtained from other regions. The activating factor in this case is the attractiveness of the region as a place to work and live.

Another important factor influencing the development of regional innovation systems is access to external financial resources that can be used to develop innovation, e.g., in enterprises. Studies of regional innovation systems evidence that innovations are not evenly distributed (Ferreira and Hugo, 2010). Many regions in Central and Eastern European countries, as well as some regions in Southern Europe, do not have enough of a supporting foundation to be able to benefit from, e.g., the smart specialization policy of the EU, which is focused on innovations. Some factors (the industry structure, for example) have a direct impact on the scale and size of R&D, promoting countries that are more involved in such programs (Mathieu and van Pottelsberghe de la Potterie, 2010). Edquist and Zabala-Iturriaga (2015) warn that only taking "input" indicators into account can lead to many unnecessary and unproductive ideas in R&D teams. Lansu et al. (2013) also write about the increasing role of universities in knowledge-based social networking. This situation can lead to increased integration between disciplines and the perspectives of stakeholders, and lead to so-called "cross-border competences" (Qu, 2017). The role of cooperation between universities and enterprises, in the context of regional innovation, is also noted by Duarte et al. (2017) and Etzkowitz and Klofsten (2005). Models of cooperation between universities and industry in Portugal and in Poland were compared in the first case, while in the second case, data from the Swedish region was used and international comparisons were made. It has been pointed out that innovation policy is a "triple helix" and created 'bottom-up' as an outcome of "collective entrepreneurship" through collaboration among business, government and academic partners. The idea of university links inside a region within the field of sustainable development was also discussed by Radinger-Peer and Pflitsch (2017). Brenner and Pflitsch (2017) analyzed whether university research on sustainability is influenced by local circumstances. Mian et al. (2012) pointed out that technology parks can be perceived as regional platforms for the incubation of technology and science-based businesses.

Those approaches to the study of the impact of regional innovativeness on the international arena was also reflected in the EU cohesion policy implemented in the past (2007–2013) as well as the current (2014–2020) programming period. However, the European Commission's (2003) changed approach to the possibility of implementing EU cohesion policy in this area needs to be realized. In this case, the division of EU regions into strong ones, which are capable of creating innovations, and weak ones, demonstrating only the ability to adapt innovations (Grossman and Helpman, 2001), seems to be insufficient. Thus, striving for a balanced development of regions, marked by different strategic documents, is becoming more and more important. It also has an impact on reducing the role of external factors in creating innovation for endogenous factors that give a greater guarantee for a more permanent, though perhaps slower and less spectacular, development of indigenous innovations. Numerous studies in this field (e.g., Gault, 2018) underline the role of innovative activities and the knowledge that is produced by specific sectors of the economy. It is important to select growth factors which strengthen regional cohesion and the convergence process. Many recent studies on regional development concern refinement of the basic economic insights of economic geography. Some researchers have focused on the study of individual indicators as sources and fundamental elements of regional innovation in the European Union (Sleuwaegen and Boiardi, 2014). Other researchers point out that the literature in the Regional Innovation System does not embrace network methods (Cantner et al., 2010). They try to apply social network methods to quantitatively assess the extent to which innovating actors engage in systemic forms of collaboration and knowledge exchange in the region. They suggest that regions with a strong knowledge base, specializing in broad fields of technology, tend to have relatively fragmented network structures.

Scientists are trying to work out methods for measuring innovation determinants to identify best practices and to stimulate countries (and companies) to implement them (Balatsas et al., 2009). A mechanism that could be used, particularly by lagging regions that have not yet been able to significantly improve their innovation performance, is, e.g., the CARIS (Complex Adaptive Regional Innovation System) model (Ponsiglione et al., 2018). The aim of this model is to evaluate the self-sustainability of RIS and to investigate which resources, competencies and mechanisms are able to trigger economic growth processes and powerful innovation.

Some researchers explore the so-called "regional paradox of innovation" (Oughton et al., 2002), which refers to the visible contradiction between the greater need to spend on innovation in lagging regions and the lower capacity of those regions to absorb public funds that are earmarked for the promotion of innovation, as compared to more advanced regions. This regional paradox shows that while there are strong complementarities between science, business and government spending on R&D, innovation policies and industrial policies tend to work in opposite directions.

Some researchers point out that one of the main factors affecting the development of innovations is related to the development of a policy of smart specialization. The relationship between innovations and smart specialization from a regional perspective is discussed by McCann and Ortega-Argilés (2014), who point out that the approach to the topic of smart specialization also depends on the regional economic specifics. As a consequence, there is no single smart specialization template that can be transplanted to each region. Regions have to work within their own governance experience and framework to find their own best practices and solutions.

Camagni and Capello (2013) discuss the need to overcome the simplistic dichotomy between the core of the European Union and its periphery, between an advanced "research area" (the core) and a "co-application area" of general purpose technologies (the periphery), as opposed to local technological specificities. They emphasize that the identification of "innovation patterns" is necessary to design "smart innovation" policies. They propose innovation policies for each regional innovation model.

Sol et al. (2013) draw attention to the growing importance of "social learning" in regional innovation networks. They consider it as an important prerequisite for sustainable development in the context of regional development. Arbolino et al. (2018) present a novel approach in the performance evaluation of Italian regions, taking into account the development of a sustainable industrial ecology.

Some researchers also explain issues related to the so-called "new regionalism" in the European Union (Helmsing, 2002; Rogers, 2004; Morgan, 2007). They explore the potential of regional innovation strategies in with respect to less favored regions. They argue that regions have an important role to play in regional renewal despite the fact that their impact so far has been small. They point out that the most limiting aspect of the "new regionalism" debate is that all contributions tend to confine themselves to an inordinately narrow metric of development and tend to connect what is instrumentally significant with what is intrinsically significant.

The measurement of innovativeness in the dynamic and competitive environment in individual regions is crucial to discovering a relevant method of measurement and assessment of innovations both in enterprises and in the scale of the whole economy (Gimbert et al., 2010). There are a lot of indicators assessing the innovation of individual economies.

The publications that regard the assessment of indicators and rankings used in measurements of innovativeness can also be found in the literature (Archibugi et al., 2009). Richtner et al. (2017) show that a large number of different factors and indicators can be considered in assessment of innovation. The most important thing is to understand the problem and try to match the measurement to the organizational needs. They also point out that the researchers use too many indicators and data in the assessment models, which leads to divergent results. Yigitcanlar (2014a, 2014b) points out that for this purpose, a complex model can be created in which the indicators may be considered as key success factors for specific industries, regions or countries.

However, it should be noted that innovativeness measurement tools may concern the whole world, a country, a region or just an industry. For this reason, the methods used may vary depending on the purpose of the study. Scientists are trying to measure the level of innovation in developing countries and their regions, where the meaning of technology and science is taken into account when increasing the level of innovation for a long time (Sainio and Puumalainen, 2007; Khayyat and Jeong-Dong, 2010).

This study of literature gives the authors the conviction that all of the methods and formulas of measuring innovativeness are still insufficient. The most common practice is to conduct analyses based on many indicators describing various areas of regional innovation development. The final result is usually the average result of a given region calculated on the basis of partial indicators. However, averaging partial results can lead to over-generalization. In practice, regions often produce very different results in various areas. It is often important to look for regions similar to each other due to groups of indicators. Analysis of the results of the present research shows that the regions that we normally consider the best are similar to the regions that achieve slightly worse. The internal structure of the level of innovativeness of regions is in this case much more varied than it would seem from standard research in this area.

3. Methodology

3.1. Statistical data

The analysis presented in the paper utilizes information on the indicators used to assess the innovation performance of European regions published by the European Commission in the Regional Innovation Scoreboard (RIS) reports, which is a regional extension of the European Innovation Scoreboard. Data from the report published in 2017 is used, with indicators describing the innovativeness of 202 regions from 22 EU countries were taken into account; however, results are not included for such EU countries as: Cyprus, Estonia, Latvia, Lithuania, Luxembourg, and Malta, for which the results are available only at the national level.

In RIS, 18 of the 27 indicators used for this purpose in the EIS, are used to monitor the level of innovativeness in EU regions. The criterion for their selection is primarily the availability of statistical data at the regional level. These indicators are additionally divided into four groups, within which ten subgroups have been separated:

a) in the framework conditions group: human resources (3 indicators), attractive research systems (3) and innovation-friendly environment (2);
b) in the investments group: finance and support (2 indicators) and firm investments (3);
c) in the innovation activities group: innovators (3 indicators), linkages (3) and intellectual assets (3);
d) in the impact group: employment impacts (2 indicators) and sales impacts (3).

In this list, the largest number of indicators was qualified for the description of the third group (innovation activities – 9 indicators).This group consists of indicators describing a) the innovativeness of enterprises, such as SMES with product or process innovations, b) the linkages between the public and private sectors in the area of innovations activities, such as public-private co-publications, and c) the intellectual assets with design and patents applications. In the literature on the subject (i.e. Neef et al., 1998; Boden and Miles, 2000; Caloghirou et al., 2004; Carolan, 2009; Guan and Chen, 2010; Lanjouw and Schankerman, 2004; Asheim and Coenen, 2005; Archibugi et al., 2009; Herrera and Nieto, 2016; Duarte et al., 2017; Zygmunt, 2019), particular importance in the context of research on innovativeness is attributed to the group of indicators describing the last subgroup, referred to as intellectual assets. The indicators included in this subgroup are particularly important for the development of innovation and the possibilities for the effective use of opportunities that are created in the enterprises' environment (e.g., through accepted systemic solutions, including national and regional innovation systems) to increase the level of the innovativeness of economies. As a result, the authors of this work have decided to distinguish a separate group defined as intellectual activities, to which the indicators describing the subgroup of intellectual assets in the RIS study were qualified. Indicators included in this area describe the effects of innovative activities based on intellectual resources in the form of EPO patent applications, European trademark applications and EPO design applications. Thus, the system of indicators divided into the five groups adopted in the study is presented in Table 1.

All of the indicators presented in Table 1 have been used in this study to assess the similarities of the analysed regions of the European Union according to their level of innovativeness. The first group of indicators (framework conditions) aims to show the supply of advanced skills of a region's community and considers every type of education, not just in the fields of science and technology. This is because, besides industry, innovation also takes place in services, management and marketing. The age limit, in turn, makes it possible to readily identify any changes in education policy reflected in the number of college graduates. A region's innovation potential is largely determined by the willingness of its people to embrace lifelong learning. In this way, one can see whether a region has formal or informal educational opportunities that can readily help to improve knowledge, skills and competences. The next framework condition is the quality of scientific research, improving as a result of the growth of international relationships. The result of an improved quality of research is, of course, an increase in the number of quotations in leading international magazines.

The second group of indicators (investments) covers expenditures on research and development, a key element for the quality and structure of innovation and economic growth. These values indicate a region's competitiveness and affluence. Both public sector outlays and those of private enterprises, of research and development laboratories and entities with close ties to them, are equally important. It is also important to consider other vehicles of innovation, such as investments in new equipment and machines, and the purchase of patents and licenses, which is a measure of the dissemination of new technologies. Another group (innovation activities) largely focuses on SMEs. The premise that a greater share of product, process, marketing and organisational innovations accurately reflects a higher level of innovation activity is important. Special attention is given to the considerable improvement of products or production processes through in-house innovation and the SME sector through the flow of knowledge between public R&D institutions and enterprises, as well as between private companies. Indicators for intellectual activities describe the non-material dimensions of measures taken to increase the level of innovation in the regions studied. This group includes, for example, indicators describing the number of scientific publications that are the result of collaborations. One of the important signs of innovation activity is the

Table 1
Final set of diagnostic indicators.
Source: own elaboration on the basis of RIS, 2017.

Groups	Subgroups	Indicators
1 Framework conditions	Human resources	x_1 - percentage of population aged 30 − 34 having completed tertiary education,
		x_2 - life-long learning, share of population aged 25 − 64 enrolled in education or training aimed at improving knowledge, skills and competences
	Attractive research systems	x_3 - international scientific co-publications per million population,
		x_4 - scientific publications among the top-10% most cited publications worldwide as percentage of total scientific publications of the country
5 Investments	Finance and support	x_5 - R&D expenditure in the public sector as percentage of GDP
	Firm investments	x_6 - R&D expenditure in the business sector as percentage of GDP,
		x_7 - non-R&D innovation expenditures as percentage of total turnover (for SMEs only)
8 Innovation activities	Innovators	x_8 - SMEs introducing product or process innovations as percentage of SMEs,
		x_9 - SMEs introducing marketing or organisational innovations as percentage of SMEs,
		x_{10} - SMEs innovating in-house as percentage of SMEs
	Linkages	x_{11} - innovative SMEs collaborating with others as percentage of SMEs,
		x_{12} - public-private co-publications per million population
13 Intellectual activities	Intellectual assets	x_{13} - EPO patent applications,
		x_{14} - European trademark applications,
		x_{15} - design applications
16 Impacts	Employment impacts	x_{16} - employment in medium-high and high tech manufacturing and knowledge-intensive services
	Sales impacts	x_{17} - exports of medium-high and high technology-intensive manufacturing industries,
		x_{18} - sales of new-to-market and new-to-firm innovations as percentage of total turnover (for SMEs only).

number of patent applications, trademarks (especially in the service sector) and design in relation to the regional GDP.

The final impact group concerns such quantifiers like employment, the export of mid- and hi-tech products, and the revenue of SMEs from the sale of new-to-market and new-to-firm innovations. The share of employment in hi-tech production sectors is an indicator of a manufacturing economy based on constant innovation through creative activity. Knowledge-based services may be provided directly to customers and ensure innovation in all sectors of the economy. This group of indicators reflects the region's international technological competitiveness, because mid- and hi-tech products are the key factors of economic growth, productivity and prosperity, a source of high added value and well-paid jobs. All the indicators described above, which are being used to study the internal structure of EU regions according to their level of innovativeness, are characterized by a significant level of diversification. It is worth noting that the standard values available in the RIS report (Table 2) are taken into account in the paper.

The high values of the coefficient of variation (V_s) and high asymmetric coefficient (A) confirm the existing of significant disproportions between the analysed regions. The following indicators were characterized by the highest level of differentiation (over 60 %): x_{11} – innovative SMEs collaborating with others as percentage of SMEs, x_{12} – public-private co-publications per million population and x_{13} – EPO patent applications. The lowest value of this differentiation, 28 %, applies to the indicator x_4 – scientific publications among the top ten percent of the most cited publications worldwide, as a percentage of the country's total scientific publications.

It is clear that differences must exist between the studied EU regions owing to their different stages of socio-economic development and innovation. However, the relevant questions are whether the internal structures of the performance indicators are similar in different regions? In other words, did the regions with the highest groupings according to the base RIS ranking of 2017 (the so-called leader groups) achieve high results in each of the analyzed groups of indicators in the study? The answer to these questions is provided by the results of the research presented in the subsequent parts of this paper.

Table 2
The values of selected descriptive statistics of the analysed diagnostic indicators.
Source: own calculations, where: $\bar{x}$ – mean value, V_{Se} – coefficient of variation, A_t – asymmetry.

Group	Indicators	Descriptive statistics		
		$\bar{x}$	V_{Se} (%)	A_t
1 Framework conditions	x_1	0.500	33.699	0.341
	x_2	0.419	51.416	0.414
	x_3	0.368	49.085	0.545
	x_4	0.602	27.654	−0.628
5 Investments	x_5	0.481	36.331	0.237
	x_6	0.335	56.937	0.521
	x_7	0.301	39.057	0.521
8 Innovation activities	x_8	0.433	40.986	−0.331
	x_9	0.366	47.727	−0.299
	x_{10}	0.426	43.533	−0.346
	x_{11}	0.337	61.285	0.841
	x_{12}	0.244	62.960	0.708
13 Intellectual activities	x_{13}	0.293	64.786	0.673
	x_{14}	0.329	30.756	0.053
	x_{15}	0.447	43.188	−0.174
16 Impacts	x_{16}	0.501	34.565	0.100
	x_{17}	0.572	35.874	−0.515
	x_{18}	0.380	35.504	0.971

3.2. Description of mathematical methods

In the paper, the multi-criteria taxonomy is used to study the disparities between the European regions in the field of innovations. The mathematical algorithm of this method takes place in several stages. A detailed description of this method can be found in Malina (2004); Cheba and Bąk (2019); Wątróbski et al. (2019) and Kiseľáková et al. (2019). The first step of the multi-criteria taxonomy requires the transformation of each indicator utilized in the analysis. For this purpose, the zero unitarization method is used in line of following formula (Kukuła, 2000):

$$\text{for the stimulant} \quad z_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad \max_i x_{ij} \neq \min_i x_{ij} \tag{1}$$

$$\text{for the destimulant} \quad z_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad \max_i x_{ij} \neq \min_i x_{ij} \tag{2}$$

In the next step, $\mathbf{D}^{\mathbf{K}}$ distance matrices are defined for each of the distinguished classification criteria of $K_l (l = 1, \ldots, r)$. In the multi-criteria taxonomy method, this distance matrix should be normalised in the [0,1] interval. On the basis of the values in the distance matrix, a threshold value d should be defined. The following formula can be utilised for this goal:

$$d = \min_i \max_j \{d_{ij}\} \quad (3)$$

The transformation of the $\mathbf{D}^{\mathbf{K}}$ distance matrices is carried out. For each classification criterion, a $\mathbf{C}^{\mathbf{K}}$ affinity matrix of dimension $(n \times n)$ is defined. The elements of this matrix: $c_{ij}^{K}\,(i, j = 1, ...,n)$ are equal to:

$$c_{ij}^{K} = 1 \text{ for } d_{ij} \leq d \quad (4)$$

$$c_{ij}^{K} = 0 \text{ for } d_{ij} > d \quad (5)$$

It should be notice that if inequality (4) is satisfied, the objects designated as *i* and *j* are treated as similar. Alternately, if inequality (5) is satisfied, the analysed objects are deemed as dissimilar. In the second case, the affinity measure of c_{ij} is equal to zero. In the last step, a final $\mathbf{C}_{(n\times n)}$ affinity matrix is determined. For this purpose, the next formula is applied in which the c_{ij} elements of the $\mathbf{C}$ matrix are equal to the product of the relevant elements of the $\mathbf{C}^{\mathbf{K}}$ matrix for all the analysed criteria; i.e.:

$$c_{ij} = \prod_{K=1}^{r} c_{ij}^{K} \quad (6)$$

If $c_{ij} = 1(i, j = 1, ...,n)$, then each of the corresponding c_{ij}^{K} elements in the $\mathbf{C}^{\mathbf{K}}$ matrices are equal to one. At the same time, $c_{ij} = 0$ if one of the c_{ij}^{K} elements corresponding to it is equal to zero.

In conclusion, two objects (in the paper, two regions) are considered to be similar to one another on account of all the criteria simultaneously if they are similar to one another separately taking into account each of those criteria separately and opposite. Two objects are treated as dissimilar with respect to all the examined criteria if they are not similar to one another even with respect to one such criterion. According to this assumption, a large number of small-sized groups (one- and two-element groups) can be obtained as the result of this method. Sometimes it is very difficult to find many similar objects with regard to every criterion.

In the next step, the objects are divided into typological groups. For this purpose, the *vector elimination method* (Wawrzyniak, 2012) can be used. The procedure in this method, as in the multi-criteria taxonomy, involves several stages. In the first step, the final $\mathbf{C}_{(n\times n)}$ affinity matrix is transformed into a $\mathbf{C}^*_{(n\times n)}$ dissimilarity matrix. Next, on the basis of the $\mathbf{C}^*$ matrix, a $\boldsymbol{c}_0$ column vector is estimated with *n* components. Each of these column vectors is the sum of the previous raw data of that matrix. In the next step, the raw data is eliminated from the $\mathbf{C}^*$ matrix, along with a corresponding column for which the $\boldsymbol{c}_0$ vector component has a maximum value. It should be noted: If the $\boldsymbol{c}_0$ vector contains several components whose value reaches the maximum, the raw data and column are eliminated (usually: the lowest or the highest number). This procedure is repeated until $\boldsymbol{c}_0$ vector components are equal to zero. The first typological group is formed by the objects corresponding to the rows and columns that have not been crossed off and still remain in the $\mathbf{C}^*$ matrix. They form the first sub-group.

4. Study results

4.1. Variability of indicators and their impact on results of classification

On the basis of 18 indicators characterizing level of innovativeness divided into 5 areas, 16 typological groups were gathered, bringing together EU regions similar in terms of the studied phenomenon. Before going into a detailed discussion of the grouping results, it is worth looking closely at which indicators have the greatest impact on the allocation of the studied regions to the 16 designated typological groups.

According to the literature (Szopik-Depczyńska et al., 2018a, 2018b; Cheba and Bąk, 2019; Mačerinskienė and Survilaitė, 2019), the division of objects into groups is mostly influenced by a limited number of indicators. This means that in a set of indicators describing a phenomenon, many different indicators may be considered, but as a rule only some of them differentiate the examined objects and allow them to be assigned to individual typological groups. This is a standard situation in classification studies; however, it is important that this type of regularity is deliberately present and analyzed. It can be assumed that the indicators with the highest level of variability significantly influence the results of the classification. They may cause classification changes in the case of countries whose indicators differ significantly from the average level. The assessments of correlation coefficients calculated between the synthetic measures and individual indicators are also taken into account. In practice, it is not so easy to decide which indicators have the greatest impact on the calculated synthetic measures. If only the assessment of correlation coefficients were taken into account, one could already determine the group of factors most closely correlated with each other, which in effect should also determine the effects, before proceeding to calculating the synthetic measure. The results of ordering the objects depend on both the indicators that are most closely correlated with the calculated synthetic measure; however, they are also influenced by indicators characterized by significant differentiation, which changes the ordering of the objects. It appears that in the study of the level of innovativeness of the EU regions, the most varied results were obtained in the case of:

- x_6 - R&D expenditure in the business sector as a percentage of GDP;
- x_{11} - innovative SMEs collaborating with others as a percentage of SMEs;
- x_{12} - public-private co-publications per million population; and
- x_{13} - EPO patent applications.

However, it is worth noting that those characteristics that formed a separate group—intellectual activities—primarily comprised the group of indicators with the largest variability. The literature points to a growing importance of such indicators for research on the level of innovativeness of both the regions and countries of the world. These indicators are also characterized by significant regional differences. In order to show these differences in individual groups, their mean values have been calculated and are presented in Figs. 1–4.

4.2. Classification results - a new approach to dividing regions into groups according their level of innovation

As can be seen from the information presented in the figures above, the results of individual regions within the scope of the analyzed indicators are significantly different. Certainly, the established groups cannot be interpreted in such an unambiguous manner as in the case of the base RIS ranking, in which the regions are assigned to four groups as follows (RIS, 2017):

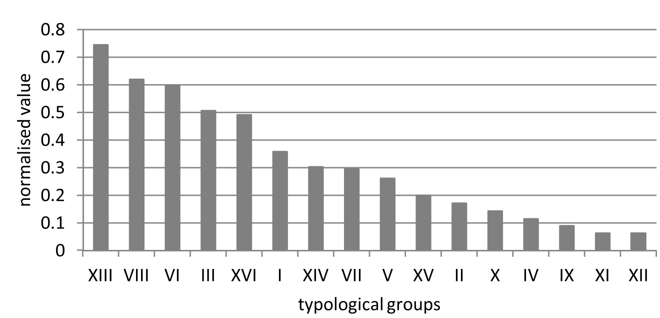

Fig. 1. The mean values of normalised R&D expenditure in the business sector as percentage.
Source: author's elaboration.

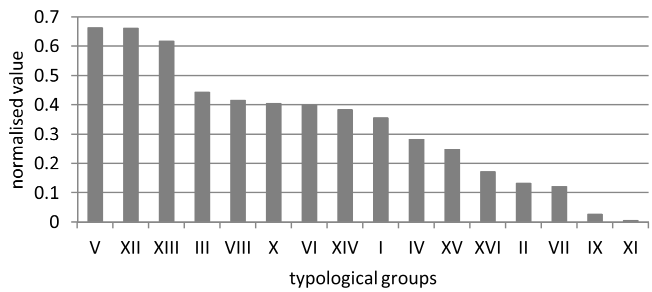

Fig. 2. The mean values of normalised values of innovative SMEs collaborating with others as percentage of SMEs.
Source: author's elaboration.

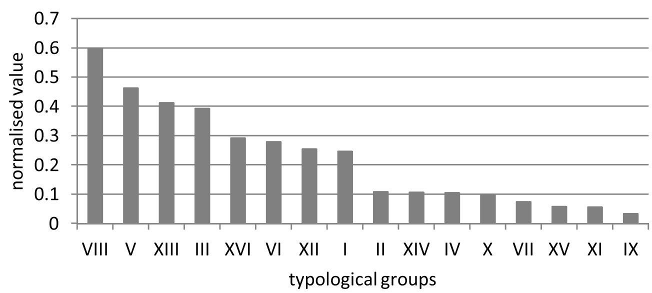

Fig. 3. The mean values of normalised values of public-private co-publications per million population.
Source: author's elaboration.

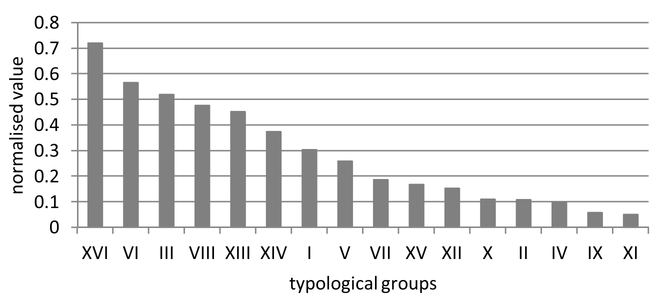

Fig. 4. The mean values of normalised values of EPO patent applications.
Source: author's elaboration.

- the first group, Innovation Leaders, includes 53 regions performing at more than 20 % above the EU average.
- the second group, Strong Innovators, includes 60 regions performing at between 90 % and 120 % of the EU average.
- the third group, Moderate Innovators, includes 85 regions performing at between 50 % and 90 % of the EU average.
- the fourth group, Modest Innovators, includes 22 regions performing at below 50 % of the EU average.

In addition, regions within these groups can get "plus" and "minus" scores, which means that in the first group, there are regions referred to as leader +, leader and leader-.

In contrast, the method proposed to study similarities of the internal structure leads to even more detailed divisions due to more stringent assumptions (the similarity within the largest number of designated groups of indicators, not only understood as the average similarity of the regions studied). This can already be seen through analysis of the results presented in the figures above.

The regions with the highest average values of x_6 (the R&D expenditure in the business sector) qualify for group XIII, but their results for the other three most impactful indicators are slightly lower. Only two regions form this group: the Belgian Vlaams Gewest region and the German Braunschweig region.

The situation with the Group V regions is similar. The average results in terms of the values of innovative collaborating SMEs as a percentage of SMEs and the values of public-private co-publications per million population are the highest, and yet reach only average values in the other two indicators. The group is formed by nine regions located in five countries: Belgium, Germany, the Netherlands, Slovakia and the United Kingdom. These are therefore regions located in different parts of Europe, so it is difficult to talk about similarities resulting, for example, from geographical proximity. However, by far the lowest values concerned the regions classified into groups IX and XI. Group IX consists of three Romanian regions: Sud-Muntenia, Sud-Vest Oltenia and Vest. On the other hand, only one region, Nord-Est, also located in Romania, is also classified in group XI. These regions were also classified in the weakest group, referred to as "Modest," in the RIS 2017 ranking.

The next table (Table 3) presents the basic information characterizing all of the groups. It also presents the distribution of EU regions between the different groups.

The analysis shows that the first group is the most numerous. There are as many as 88 regions located in 17 different EU countries, including: all (2) regions of Ireland, over 80 % of regions from Italy (17 regions out of 21) and France (7 out of 8), as well as over 70 % of regions from the Czech Republic (6 out of 8) and Spain (12 out of 17). Attention is also drawn to Germany: In the first group, there were the most regions from this country (18 out of 38). However, there were no regions from such countries as Bulgaria, Croatia, Poland, Romania, and Slovakia—that is, countries indicated in the literature on the subject (Cheba and Bąk, 2019), as they are less economically developed compared to other EU member states. In the RIS ranking, regions which qualified for this group did not create one cluster but qualified for the first three groups with performance more than 50 % above the EU average, including: 11 Group Leaders, 37 Strong Innovators and 40 Moderate Innovators. None of the regions in the original RIS ranking qualified as Modest Innovators. The results obtained by the countries qualified to this group in terms of the four indicated indicators with the highest impact on the classification of regions can, however, be define as average.

The second group comprises 32 regions, of which almost 44 % are from Poland (14 out of 16). It also includes the two regions from Bulgaria and Croatia. It is worth emphasizing that this group only consists of regions of countries located in southern and eastern Europe. Therefore, in contrast to the previous group, they are defined as areas characterized by worse socio-economic situations and lower level of innovativeness. In the RIS ranking, these regions were classified into the Moderate and Modest groups.

Objects belonging to the third group primarily represent the countries of northern and western Europe. Most of them (11) are German regions. In the base RIS 2017 rankings, these regions were classified mainly as "leaders" (19 regions) and "strong" (6 regions), while only two of them were defined as "moderate."

The next group comprises 16 regions, 10 of which (62.5 %) being located in Greece. In this group, as in the second one, there were less developed regions in southern and eastern European countries. There is one exception: a Dutch region, which in the RIS 2017 basic survey was classified as a member of the "strong-" group. Of the others, ten are classified as "Moderate" and another five, "Modest".

Groups from five to sixteen are definitely less numerous: Five of them are single-element groups, and three are two-element groups.

The greatest diversity is the characteristics of German regions, which qualify for up to nine different groups, including four single or two-element groups. A large dispersion is also visible in the case of the Netherlands. The regions of this country are in five different typological groups.

These results confirm the considerable diversity of the regions studied in terms of their level of innovativeness. In many cases, there is a lack of similarity, despite the location of regions in the same countries.

Table 3
The division into typological groups.
Source: own calculation.

UE countries	Number of regions	Typological groups:															
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
BE	3	1				1								1			
BG	2		2														
CZ	8	6							1							1	
DK	5	2		2					1								
DE	38	18		11		1	4	1						1	1	1	1
IE	2	2															
EL	13	1			10						1		1				
ES	17	12	2		2						1						
HR	2		2														
FR	8	7		1													
IT	21	17	2	2													
HU	7	1	4					2									
NL	12	6		1	1	3	1										
AT	3	1		2													
PL	16		14					2									
PT	7	4	1		2												
RO	8		3		1					3		1					
SI	2	1					1										
SK	4		2			1		1									
FI	4	2		1			1										
SE	8	2		3			1		2								
UK	12	5		4		3											
SUM	**202**	**88**	**32**	**27**	**16**	**9**	**8**	**6**	**4**	**3**	**2**	**1**	**1**	**2**	**1**	**1**	**1**

This is also evident in the RIS study, but due to the stricter assumptions adopted at the stage of typological group formation in accordance with the proposal of using multi-criteria taxonomy presented by the authors, the distribution of regions between the designated groups is greater. It is also clearly visible that regions which were classified in the RIS 2017 study according to their average level of innovativeness may be classified into different typological groups. As already mentioned, this is the effect of the assumptions and the desire to combine groups of countries similar in terms of the largest number of indicators, and not only similar due to the achieved average level of the phenomenon in question.

5. Discussion and conclusion

The main purpose of the study was to present a new approach in comparing EU regions according to their level of innovativeness. The authors' goal was to examine whether the methodology usually proposed in the literature (based on the mean value of various indicators) accurately reflects the diversity of the regions in this area. The authors conclude that the traditional methodology does not produce accurate results, especially in research conducted based on various indicators divided into many groups. The authors' intention is to find an alternative method which can help to discover accurate results of the innovativeness at the regional level.

For this purpose, a quite simple but more adequate method based on multi-criteria analysis was adopted. The starting point was the normalized values of indicators measuring the level of innovativeness of EU regions, and their results are presented periodically in Regional Innovation Scoreboard reports. The division of EU regions into typological groups was compared with the results of this study published in the RIS report in 2017.

In the original RIS study, the EU regions are assigned to four main groups (leader, strong, moderate and modest EU regions). In order to internally differentiate the regions classified into these groups, the division into "plus" and "minus" regions is used if a region diverges from the designated average level for each group. This allows the studied regions to be divided into 12 subgroups—three in each main group.

On the other hand, the least numerous group are the regions referred to as the modest group, in which there are only 23 regions. However, the results of the research presented in the paper divide the studied regions into 16 groups, with as many as seven groups with a maximum of two regions. These regions clearly stand out with plusses and minuses from the other analyzed regions of the EU. Let's take a closer look at these groups and regions. First of all, the groups to which only single regions were classified are analyzed:

- in group XI, the previously mentioned Romanian region, Nord-Est, which in the RIS 2017 survey was classified in the Modest group;
- in group XII, the Greek region of Kriti, in the RIS 2017 survey classified in the Moderate group;
- in the XIV group, the German Trier region, in the Strong group in the RIS 2017 survey;
- in the XV group, the Czech Severozápad region, in the Moderate group in the RIS 2017 survey;
- in the XVI group, the German Oberpfals region, in the Strong group in the RIS 2017 survey.

Only the first of these regions (the Nord-Est region) achieved the lowest result in the RIS 2017 survey, which could be the reason for separating the region and creating a separate typological group for it. However, as shown by the results of the original study presented in the paper, the remaining regions did not achieve results placing them at the first or last places on the ranking list in the RIS 2017 base survey. The average results obtained in the base ranking did not differ from other results of regions classified into the same groups. This means that the methodology proposed in the paper, distinguishing similar level of innovativeness for typological groups, classifies the regions in a different way than in the RIS study.

The key here is the division of indicators into five different areas and the search for similarities between regions, considering their results separately. This allows us to overcome one of the most frequently indicated shortcomings in the literature (Goda et al., 2016; Cheba and Szopik-Depczyńska, 2017; Cheba, 2020), of the joint analysis of a set of indicators, which by using the mean value as a measure of innovativeness, may, with extreme values (a low value of one or a group of indicators and higher values of the remaining ones), lead to the

Table 4
The comparison of selected results of regional classification in RIS 2017 research and authors' original research.
Source: own calculation.

Division into group according to:			
RIS 2017			Authors proposition
Group	Country	Region's name	Group
Leader +	Finland	Länsi-Suomi	I
	Germany	Tübingen	III
		Stuttgart	VI
		Oberbayern	VI
	Sweden	Sydsverige	III
		Stockholm	VIII
		Östra Mellansverige	VIII
	United Kingdom	South East	III
		London	V
	Denmark	Hovedstaden	VIII
	Belgium	Vlaams Gewest	XIII
Modest -	Bulgaria	Severna i iztochna Bulgaria	II
	Poland	Swietokrzyskie	II
	Romania	Nord-Vest	II
		Centru	II
		Nord-Est	XI
		Sud-Est	IV
		Sud - Muntenia	IX
		Sud-Vest Oltenia	IX
		Vest	IX

classification of such objects as average. Meanwhile, the partial results indicate significant internal differentiation. Table 4 compares the results of the classification of selected regions in both studies: RIS 2017 and authors' own research.

Firstly, we examine the regions the RIS 2017 survey classified in the best subgroup - Leader +. In this sub-group, there were 11 regions analyzed as a part of the classification proposal presented in the paper. These are such regions as: the Belgian Vlaams Gewest region; three German regions: Stuttgart, Tübingen and Oberbayern; the Danish Hovedstaden region; the Finnish region of Länsi-Suomi; three regions located in Sweden: Stockholm, Östra Mellansverige, and Sydsverige; and two regions located in the UK: London and South Est. These are regions located in well-developed economies of Northern and Western Europe; thus, their high position in the RIS 2017 ranking is not surprising. However, in the present study, these regions were classified in up to six different groups. This means that they are not as similar to each other as it would seem from the original study.

A similar situation applies to the "Modest" group, comprising regions which in the RIS 2017 ranking were classified in the lowest positions. By far, the most members of this group consist of regions located in Romania: Nord-Vest, Centru, Nord-Est, Sud-Est, Sud-Munitenia, Sud-Vest Oltenia and Vest; there is also one Polish region (świętokrzyskie) and one Bulgarian region (Severna and Iztochna Bulgaria). These are, therefore, regions belonging to countries which very often are indicated as less economically developed, with a smaller level of innovativeness development than in the developed countries of Western or Northern Europe. The differences between the present classification of these regions and the results of the RIS 2017 survey are, as in the previous case, significant. In the research described in this paper, these regions are separated into four different groups.

The next table presented in the paper (Table 5) contains a comparison of the results of the regional classification obtained on the basis of both research studies. This table shows how groups selected for the present study are classified in the RIS 2017 study.

The information presented in this table confirms previous observations concerning the distribution of regions between the separated typological groups, other than in the RIS 2017 study. Due to the large number of regions forming the first typological group proposed by the authors, the differences in the distribution of these regions in comparison to the results of the RIS 2017 survey are the largest. It is worth noting, however, that none of these regions was signed to the Modest group, with the lowest results in the RIS 2017 ranking. A similar situation applies to groups III and VI. In RIS 2017, The regions from these groups ranking are classified as Leader, Strong or Moderate; none of them were in the lowest group from the RIS 2017 survey. Group II is also noteworthy, with regions classified in the RIS 2017 survey as Moderate and Modest, which means that the results obtained by these regions are lower than the results of regions classified into the two higher groups (Leader and Strong groups).

The results obtained show that the internal structure of EU regions in terms of their level of innovation is even more varied than could be concluded from the RIS 2017 survey. This is mainly related to the unique method of indicating similarities between regions. The main difference is related to the way of identifying similar innovation level between the analysed regions. In the research proposed by the authors, regions that achieve similar results in all groups of indicators are classified in the same typological group, while in the RIS 2017 study, similarity is sought on the basis of the overall average result obtained by the surveyed regions. It should be emphasized that the method proposed by the authors to distinguish EU regions similar in terms of the level of innovation should not be treated as competitive in relation to the approach used so far presented in RIS reports. Its purpose is to provide new knowledge about the diversity of EU regions and to identify regions similar in terms of results considered separately from the perspective of each of the analyzed groups of indicators.

The proposed method of researching regional innovation level allows for a more comprehensive analysis. In the literature on the subject (Simmie, 2003), it is increasingly emphasized that knowledge and innovation are closely concentrated in a few regions. This is also confirmed by the research presented in this work and the results published in RIS reports. Therefore, it is important to pursue analyses that promote a better understanding of the internal structure of the innovation processes taking place in those regions. Such knowledge can help, for example, regional authorities develop better strategies focusing on areas requiring financial support. At the institutional level, it can be a valuable source of information for decision makers developing future assumptions for the strategic directions of development of the European Union, projecting financial support toward those areas that actually need it. This is also important for the selection and identification of regional smart specializations, which by definition should focus on those areas in the region that have the greatest potential for creating innovation. In accordance with the assumptions of the new EU development financing program for 2020–2024, it is necessary to take measures to equalize the development opportunities of all regions. The proposed approach to researching innovation enables the identification of real leaders in this area and outliers in all analyzed areas.

CRediT authorship contribution statement

Katarzyna Szopik-Depczyńska: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Katarzyna Cheba:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Iwona Bąk:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Angelika Kędzierska-Szczepaniak:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Krzysztof Szczepaniak:** Conceptualization, Methodology, Validation, Formal analysis,

Table 5
A comparison of selected results of regional classification in RIS 2017 research and authors' original research.
Source: own calculation.

Division into group according to:																	
RIS 2017		Authors proposition															
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
Leader	Leader +	1		3		1	2		3								
	Leader	2		10		1	2							1			
	Leader -	8		6		3								1			
	SUM	**11**	–	**19**	–	**5**	**4**	–	**3**	–	–	–	–	**2**	–	–	–
Strong	Strong +	9		6		2	2										
	Strong	15				2	1										1
	Strong -	13			1			1	1						1		
	SUM	**37**	–	**6**	**1**	**4**	**3**	**1**	**1**	–	–	–	–	–	**1**	–	**1**
Moderate	Moderate +	23	1	2			1				1						
	Moderate	13	5		2			2			1		1				
	Moderate -	4	14		8			2								1	
	SUM	**40**	**20**	**2**	**10**	–	**1**	**4**	–	–	**2**	–	**1**	–	–	**1**	–
Modest	Modest +		3		3			1									
	Modest		6		1												
	Modest -		3		1					3		1					
	SUM	–	**12**	–	**5**	–	–	**1**	–	**3**	–	**1**	–	–	–	–	–
TOTAL		**88**	**32**	**27**	**16**	**9**	**8**	**6**	**4**	**3**	**2**	**1**	**1**	**2**	**1**	**1**	**1**

Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Giuseppe Ioppolo:** Conceptualization, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.landusepol.2020.104837.

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