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The smart village concept from 1.0 to 4.0 in the context of ICT entrepreneurship development in the Polish villages

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ABSTRACT

Objective: The article aims to show the development process of smart villages from 1.0 to 4.0, analogous to the smart cities development, along with indicating the conditions of this process. Moreover, the goal was to examine how ICT enterprises influence the development of smart villages at the 1.0 level in rural areas and what their connections are with other sections of economic activity (based on the example of Poland).

Research Design & Methods: The study used statistical data from Statistics Poland (GUS). We used methods of cartographic presentation of data on the share of technology enterprises (Section J 62) and support enterprises (Section J63) in the total number of enterprises in rural areas in Poland, as well as changes in the share of these companies in Poland in 2012-2023. We analysed the enterprise structure in municipalities characterised by a high share of ICT enterprises according to the type of municipality (functional urban, border, and other). We used the network analysis method to identify ICT enterprises' links with other economy sectors.

Findings: The ICT enterprises have numerous linkages with other sections, indicating their key role in providing the ICT technologies necessary for the smart villages development. We also found that rural municipalities with the highest share of ICT firms located in close proximity to cities have a high concentration of firms providing business-related services and services to residents. In the border municipalities with the highest share of ICT companies, we identified a high share of the sections responsible for administration and defence, tourism, and agriculture, while a distinctive feature of the other municipalities is the high share of companies involved in transport and storage management.

Implications & Recommendations: Among the actions to support the further development of smart villages, we identified the following: strengthening the links between ICT entrepreneurship and other key economic activities for smartification processes, expanding ICT infrastructure, supporting local initiatives through funding and advice, promoting education and training in new technologies for villagers, and encouraging cross-sectoral cooperation through the creation of platforms for the exchange of knowledge and experience.

Contribution & Value Added: We may consider the smart villages concept in analogy to the smart city concept as an innovation organising spatial structures according to a new pattern. We present the development of smart villages from 1.0 to 4.0 in analogy to the development of the smart city, together with a presentation of the conditions of this process related to the specificity of rural areas.

Article type:	research article
Keywords:	smart villages; entrepreneurship; rural areas; ICT; smartification processes; network analysis
JEL codes:	O18, O31, R12

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INTRODUCTION

Smart villages are rural areas and local communities that, based on their own resources and new opportunities, leverage digital technologies, telecommunications, innovations, and knowledge to im-

prove the life quality, enhance public services for citizens, better utilize resources, reduce environmental burdens, and create new opportunities for local products and improved processes (EU Action, 2019). In the literature, there is a view that research on smart cities can contribute to the development of research on smart villages (Adamowicz & Zwolińska-Ligaj, 2020; Visvizi & Lytras, 2018a; Visvizi & Lytras, 2018b). Digital technologies significantly impact the development of smart cities through digitization. These technologies can also help build digital and smart villages, provided that authorities establish appropriate network and communication infrastructure in rural areas (Malik *et al.*, 2022). Rural residents need better digital connectivity due to their distance from growth poles. However, research on developed countries shows that the availability and quality of infrastructure are greater in cities than in rural areas, and this difference is deepening (Salemink *et al.*, 2017).

The concept of smart villages represents an innovative approach to the complexity of local rural development, illustrating current dynamic development processes and civilizational challenges (Wolski, 2018). Similarly to the concept of a smart city, a smart village constitutes an ecosystem composed of various elements aimed at improving the quality of life for the community and the rural environment, engaging various stakeholders (Syaodih, 2019). This means that the concept of a smart village is an innovation based on a sustainable approach to village-level planning, promoting knowledge-based development through continuous human resource education as an integral part of village resource development, particularly in encouraging the development of rural areas perceived as part of more complex spatial structures. Such an approach is justified in the context of network-based information system development and the virtualization of socio-economic life (Maja *et al.*, 2020).

We may consider the concept of a smart village as analogous to the concept of a smart city as an innovation organizing spatial structures according to a new pattern, initially based on information technologies. In the initial phase of evolution, similarly to Smart City 1.0, technology creators encourage the administration of rural settlement units (*e.g.*, rural municipalities, rural counties) to adopt their technologies so as to achieve greater efficiency in managing rural entities. However, rural areas are often not even prepared to use these technologies or to properly assess what is actually beneficial from the perspective of achieving the goals of the local community. An example of this can be the implementation of modern public service solutions using digital technologies. Therefore, the manifestation of a given rural unit entering this phase is the development of local specialization in IT entrepreneurship. We may treat specialization in this field as a sign of the emerging phenomenon of Smart Village 1.0. It involves creating the potential necessary for the actual implementation of digital solutions for the socio-economic development of a given rural area. We will present the analysis of this stage of smart village development in the empirical part of this work using the example of rural areas in Poland.

The next stage, analogous to Smart City 2.0, involves the creation of Smart Village 2.0 through the activation of local government actions, which, as a result of their own innovative initiatives, create pro-development solutions for the rural community in the form of special programs and projects that serve the implementation of modern technologies in various areas of rural life. An example of this could be the implementation of programs dedicated to the local community aimed at improving living conditions and the sustainable development of the rural area, for example, by using the Internet of Things to improve lighting and monitor key infrastructure elements.

A more advanced stage of smart village development could be Generation 3.0, analogous to Smart City 3.0. This stage is characterized by the fact that citizens take on a key role in local development supported by modern IT technologies. In the third-generation smart village, residents begin to co-create their innovative environment, their habitat.

In the phase of creating Smart Village 4.0, analogous to this phase of city development, the creation of smart villages should be based on conscious actions aligned with sustainable development. These could include, for example, social projects: equality-focused, social inclusion, affordable housing, etc. (Korneluk *et al.*, 2019). Attention is also drawn to the potential for networking (Kinelski, 2022).

For the wide application of communication and information resources, as well as computer techniques in rural areas, it is essential to have a broad group of knowledge workers, enabling the use of the technological potential for local development management. It is also necessary to attract specific

geographical market interest from providers of modern communication and information infrastructure, who primarily see cities as large markets. On the other hand, however, the diffusion of innovation often has not only a hierarchical character but also shows characteristic spatial directions from centres to peripheries. Therefore, Smart Village 1.0 can develop in a place where such solutions are introduced thanks to personal contacts between ICT solution providers and business or public clients.

In the next phase of smart village development, the significant importance of the attitudes of local and regional authorities, *i.e.* the institutional environment, which has the power to set the direction of rural municipality development, spatial planning principles, and public space investments, comes to the fore. It is essential to adjust the volume and technological level of planned smart services to the actual opinions and citizens' needs (Lee & Lee, 2014; Novotný *et al.*, 2014) to address local priorities and citizen requirements.

Therefore, the institutional environment, which is largely conditioned by the quality and adequacy of legal regulations to actual development needs, as well as by the level of awareness of modern technologies and openness to them by decision-makers, such as city mayors, supportive local leaders, or even regional councils or city councils, is also a key resource for smart village development. Such resources are characteristic in the development of smart cities (Smart City 2.0).

The local community, *i.e.*, residents and other stakeholders living or operating in the intelligent rural area, is the key resource for the development of Smart Village 3.0. It is only at this stage that the proactive nature of local community self-organization becomes apparent, with their needs reflected in the organization of public life, adopted solutions regarding housing, health infrastructure, or related to the leisure sector.

Therefore, making capital-intensive investments requires social consensus, trust, and cooperation among all stakeholders, from entrepreneurs to residents to representatives of local and regional administration. This requires openness to inclusiveness needs and engagement in networking (Smart Village 4.0).

The considerations in the article encompass both theoretical and empirical sections. The theoretical part analyzes the development process of smart villages from version 1.0 to 4.0, analogous to the evolution of smart cities, while identifying the conditions influencing this process. Furthermore, the specific characteristics of rural areas in the context of the smartification process are presented, emphasizing the diversity of such areas. The empirical part utilizes statistical data from the Central Statistical Office of Poland (GUS). The analysis examines the share of technological enterprises (section J 62) and support enterprises (section J 63) in the total number of businesses in rural areas of Poland, as well as changes in the share of these enterprises in Poland during the years 2012–2023, complemented by cartographic representations. The study also investigates the structure of enterprises in municipalities characterized by a high share of ICT enterprises, categorized by municipality type (urban functional, borderland, and others). Subsequently, a network analysis method is applied to identify the connections between ICT enterprises and other sectors of the economy. The discussion that follows explores entrepreneurship development in rural areas based on modern technologies and the concept of smart villages. The article concludes with a summary of the findings from the conducted research.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

The Specificity of Rural Areas and The Process of Smartification

There is a distinction between developing a smart city and modelling a smart village due to the different characteristics of these areas, as well as the distinct priorities and needs of cities compared to rural areas. The concept of smart villages should be more rooted in local conditions and resources, as well as in the external (primarily urban) demand for products from rural areas (Ranade *et al.*, 2015). Unlike smart cities, information and communication technologies (ICT) in smart villages are only significant to the extent that they promote human development, such as education, employment, and health (Murty & Shankar, 2020). Another study highlights environmental factors as distinguishing features of smart villages, alongside ICT infrastructure, human capital and education, and social and relational capital (Fajrillah *et al.*, 2018).

The contribution of new technologies to smart villages primarily occurs through the installation of new infrastructure, whereas in the smart city concept, the emphasis is directly on new technologies. One reason for the differing focus on the development of smart cities and smart villages is the significantly lower availability of infrastructure in rural areas (Fennell *et al.*, 2018). The development of the Internet of Things (IoT) – a foundation of smart city development – can also contribute to the growth of smart villages. However, while we may characterize IoT applications in smart cities by their density in everyday life, reflecting the structural features of densely populated cities, smart villages supported by IoT typically represent a system of dispersion and scarcity (Cvar *et al.*, 2020).

According to Polish authors, social innovations play an important role in the smart village concept, as they can drive positive changes in rural areas (Kalinowski *et al.*, 2021). Moreover, these authors point to other differences between the smart city and smart village concepts due to the specific characteristics of these areas. They emphasize that the goal of a smart city is to increase territorial competitiveness, improve resource efficiency, and enhance the quality of life in response to rapid technological changes, innovations, and environmental challenges. Therefore, access to modern technologies and human capital, with a special role for private entities and city authorities, are fundamental factors in smart city development. In contrast, the main issues in rural areas are demographic problems, limited access to public services, and low social activity. Hence, the key goals of smart villages include improving living conditions, retaining residents, digitization, and developing social capital. Local leaders, non-governmental organizations, and local authorities are crucial in smart village development, with social capital, local heritage, and the promotion of digital and social innovations being the main development factors.

Noteworthy, significant diversity characterizes rural areas. Implementing smart village solutions is much more challenging in peripherally located rural areas (often struggling with depopulation) than in areas close to large cities (Paniagua, 2020). Peripheral rural areas often have relatively low endogenous development potential due to factors such as limited access to markets and resources, dispersion, an ageing population, a low level of education among residents, and weaker access to services (*e.g.*, educational or health services) compared to cities. Therefore, one of the main goals of smart village development is to improve the attractiveness and satisfaction of living in rural areas, create jobs, and ensure access to infrastructure (including digital) and services to prevent the migration of young people to cities (Park & Cha, 2019). In the context of smart village development, building specialized connections with urban supply and demand, as well as implementing place-based policies (*e.g.*, regional innovation systems, clusters, public-private partnerships, and focus on selected sectors or niches), is crucial (Naldi *et al.*, 2015). Moreover, the level of advancement in the multifunctional development of these units is of great importance in the development of smart villages in peripheral rural areas. Quantitative research conducted in a peripheral region of Poland (Lublin Voivodeship) showed a relationship between the level of potential for intelligent development of territorial units and the degree of diversification in the functional structure of local economies (Zwolińska-Ligaj *et al.*, 2018).

Despite the differences between the smart city and smart village concepts, there are many connections between them, and changes in cities impact rural areas and vice versa (Kalinowski *et al.*, 2021). In this context, the evolution of the smart city from concept 1.0 to 4.0 and its possible implementation in the development of smart villages seems interesting. This aspect has not been studied in the literature. Although the term village 4.0 can be found, synonymous with the digital village, it is understood as the use of digitization technologies (*e.g.*, IoT, big data, and AI) in smart villages to integrate them into the digital network (Malik *et al.*, 2022).

The main objective of the article is to show the development process of smart villages from 1.0 to 4.0, analogous to the development of smart cities, along with indicating the conditions of this process. Moreover, the goal is to examine how ICT enterprises influence the development of smart villages at the 1.0 level in rural areas and what their connections are with other sections of economic activity (based on the example of Poland). As part of this goal, we formulated the following research hypothesis:

H1: Smartification of villages, considered as a diffusion process, is reflected in a greater degree of specialization in services driven by entrepreneurship in the ICT sector.

RESEARCH METHODOLOGY

The conceptualization of research on smart villages in the context of ICT enterprise development and their connections with other economic activities can provide valuable insights into the dynamics and development potential of these areas. To verify the hypothesis, we conducted statistical data analyses regarding the structure of enterprises in rural municipalities.

We analysed the location of enterprises operating in smart villages, with a particular focus on the PKD 2007 sections J62 (programming, consultancy, and related activities) and J63 (information service activities). This analysis identified the share of technology and supporting companies in the total number of enterprises in these areas, reflecting their level of innovation and digital technology adoption. Subsequently, we conducted in-depth analyses on municipalities characterized by a high share of ICT enterprises in the structure of economic entities, in terms of the co-occurrence of enterprises from other sectors. This allowed for the preliminary identification of connections between ICT companies and other industries, depending on the type of municipality. The next step was to assess changes in the development of sectors J62 and J63 in smart villages. Such an analysis helps understand the trends and challenges faced by ICT enterprises in rural areas. We will present the results on cartograms.

Next, we examined the connections between sections J62 and J63 with other economic activities using network analysis methods. This method identified which economic sectors are linked to ICT enterprises, which may indicate cooperation, dependencies, or the flow of knowledge and innovation between different industries. Such connections may be crucial for developing synergies between the ICT sector and other branches of the economy, supporting the sustainable development of smart villages. This comprehensive approach to studying smart villages provides valuable information for formulating policies that support the development of these areas in the context of the growing importance of information and communication technologies.

As part of the research tools, we used JASP software for network analysis, allowing for the visualization and analysis of connections between different variables. The empirical part of the study included data collected from public databases of the REGON (National Official Business Register) from the Statistics Poland (GUS) concerning business activities in Poland, particularly from sections J62 and J63 and other related sections, in 2023. In the network analysis, we defined variables (percentage of enterprises in a given section) as nodes, and correlations between them as edges. Then, using the EBICglasso method, we extracted the most important connections, resulting in a clear network. The analysis of node centrality (betweenness, closeness, degree) allowed for identifying key sectors connected with J62 and J63.

RESULTS AND DISCUSSION

When analysing the spatial distribution of ICT enterprises in Poland, several significant patterns and spatial regimes emerged. First and foremost, the regions surrounding Warsaw, Wrocław, Poznań, Kraków, and Rzeszów exhibited the highest index values, indicating a strong concentration of ICT enterprises in these areas. As the largest city and economic hub of the country, Warsaw attracts many companies from the ICT sector. Wrocław, known for its dynamic technological development, and Kraków, a major academic and technological centre, also stand out with a high share of ICT enterprises. We observed a similar trend in Poznań and Rzeszów, where the ICT sector is growing rapidly. In contrast, rural and less urbanized areas, characterized by a low share of ICT enterprises, are dominated by traditional industries. This spatial dichotomy reflects the broader economic and demographic disparities, where technological development is concentrated in more urbanized and well-connected regions. The moderate index values observed in areas such as the vicinity of Gdańsk, Szczecin, and Lublin are also noteworthy, suggesting that these local centres of technological development could become future ICT hubs. The map clearly shows a spatial division in the distribution of ICT enterprises in Poland, where major urban agglomerations serve as centres of concentration for technology companies, while peripheral areas significantly lag behind in terms of the share of ICT enterprises (Figure 1).

Table 1 presents the average shares of enterprises in selected groups of municipalities with a high degree of ICT development in 2023 and the overall structure of enterprises in rural areas in Poland. We divided the studied municipalities into three groups: functional urban, border, and others. Functional urban municipalities include those located within areas designated for Integrated Territorial Investments (ITI); border municipalities include those situated directly on the national border and their immediate vicinity; the remaining municipalities comprise units that do not belong to either of the two categories.

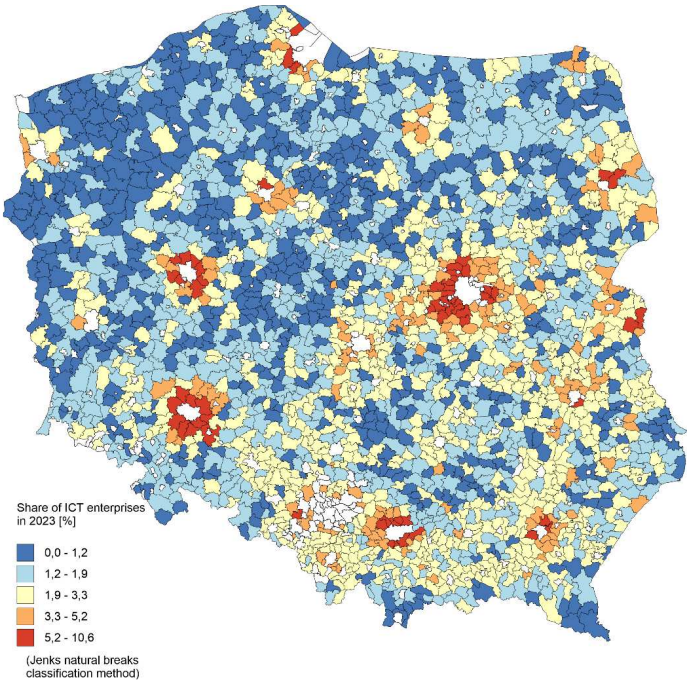

Figure 1. The share of ICT enterprises in the total number of enterprises by municipality in Poland in 2023
Source: own elaboration.

Rural and urban-rural municipalities with a high share of ICT enterprises located within the areas designated for Integrated Territorial Investments in Poland exhibited an above-average share of enterprises from Section M according to the Polish Classification of Activities (PKD, 2007), which includes professional, scientific, and technical activities. This is associated with the provision of business-related and research-scientific services to entities located within the city. We observed a similar pattern with the high share of enterprises from Section K (financial and insurance activities) and Section N (administrative and support service activities) in these types of municipalities. Municipalities located near major cities also have a relatively high share of entities providing services to residents, such as healthcare and social assistance (Section Q), education (Section P), and repair and maintenance of computers and personal and household goods (Section S, Division 95).

Border municipalities with a high share of ICT enterprises are also characterized by a relatively high share of enterprises from Section O (public administration and defence, compulsory social security) in the total number of entities, which is related to their specificity and the current geopolitical situation on Poland's eastern border. Moreover, in border areas, we identified a significant share of enterprises from Section B (mining and quarrying), Section A (agriculture, forestry, hunting, and fishing), Section D (electricity, gas, steam, and air conditioning supply), Section I (accommodation and food service activities), Section R (arts, entertainment, and recreation), and Section S, Division 94 (activities of membership organizations). In the remaining studied municipalities, we recorded an above-average share of entities from Section M, Section N, as well as Section S, Section P, and Section H (transportation and storage).

The map illustrating changes in the share of ICT companies in Poland between 2012 and 2023 clearly shows the spatial variation of this sector (Figure 2). The highest values of the indicator are concentrated around large urban agglomerations such as Warsaw, Wrocław, Poznań, Kraków, Rzeszów, Olsztyn, and Bydgoszcz. Due to their infrastructure availability, educated workforce, and favourable

Table 1. Average values of enterprise shares in selected groups of municipalities with a high level of ICT development in 2023

Section according to PKD 2007	Functional	Border	Others	Rural areas overall
Number of municipalities	129	13	80	2175
A	1.123	5.598	2.153	3.988
B	0.086	0.245	0.131	0.137
C	9.214	7.405	9.245	9.934
D	0.235	0.303	0.194	0.231
E	0.329	0.304	0.395	0.407
F	14.356	18.829	19.849	21.139
G	20.234	16.595	20.721	19.806
H	5.900	6.083	6.730	6.376
I	2.548	4.017	2.347	2.923
J	5.238	3.971	4.035	1.909
J (div. 62)	4.890	3.738	3.726	1.751
J (div. 63)	0.348	0.233	0.309	0.158
K	2.256	1.873	1.608	1.748
L	3.149	2.452	1.424	2.887
M	12.013	5.201	7.382	5.817
N	3.843	2.291	3.498	2.938
O	0.390	3.362	1.785	1.710
P	3.546	2.580	3.141	2.905
Q	6.275	4.222	3.964	4.141
R	1.714	2.535	1.967	1.996
S (div. 94)	2.202	8.130	4.479	4.397
S (div. 95)	0.615	0.453	0.557	0.494
S (div. 96), T (divs. 97, 98)	3.551	2.894	3.608	3.362

Source: own study.

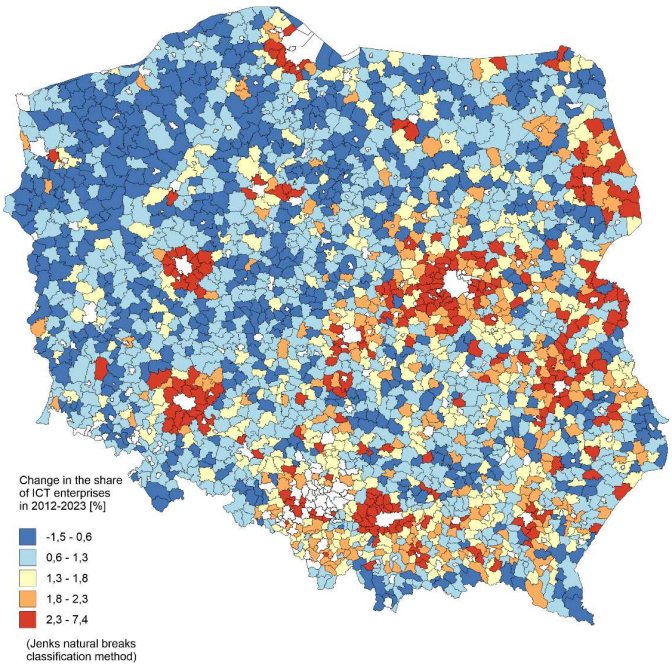

Figure 2. Changes in the share of ICT companies in the total number of companies by municipalities in Poland from 2012 to 2023

Source: own elaboration.

economic conditions, these regions attract a significant number of ICT firms. In contrast, rural and less urbanized areas, marked in blue on the map, show a significantly lower share of ICT companies, resulting from limited access to resources and lower investment levels in technological infrastructure. Cities such as Gdańsk, Szczecin, and Lublin display moderate indicator values, suggesting the presence of local technology development centres that may play a larger role in the future. The overall picture reveals a dichotomy between highly urbanized centres and peripheral regions, reflecting economic and demographic trends in Poland over the past eleven years.

Analysis of the Development Level of the Smart Village Concept in Rural Areas Based on Network Analysis Results

Network analysis is a statistical method used to examine relationship structure between variables represented as nodes connected by edges. It allows for the visualization and interpretation of complex data sets by constructing networks that highlight the connections and interactions between observed variables. This method supports various types of networks, such as correlation networks, partial correlation networks, and more advanced models like EBICglasso and Mixed Graphical Models. Scholars use this approach in fields requiring the analysis of complex interdependencies among multiple variables, offering a robust framework for both visualization and statistical inference.

Network analysis of variables is an advanced method for studying the structure of relationships between variables in a data set. In this context, variables are represented as nodes and the relationships between them as edges. We focus on analysing the connections between sections J62 and J63 and other sections, using various centrality measures. The following Tables present the results of the network analysis tables (Table 2, Table 3, Table 4) and the network diagram (Figure 3).

Table 2. Network summary

Number of nodes	Number of non-zero edges	Sparsity
26	271 / 325	0.166

Source: own study.

Table 3. Centrality measures per variable

Variable	Network			
	Betweenness	Closeness	Strength	Expected influence
J section 62	-0.248	0.262	-0.106	0.492
J section 63	-0.617	-1.067	-0.953	1.015

Source: own study.

Table 4. Clustering measures per variable

Variable	Network			
	Barrat	Onnela	WS	Zhang
J section 62	0.981	0.303	1.725	-0.061
J section 63	-1.996	-1.084	0.117	-1.348

Source: own study.

In the context of the development and functioning of a smart village, network analysis is a key tool for understanding the structure and dynamics of interactions between various activity sections. The network includes 26 nodes, representing different economic or functional sections within the smart village, and 271 non-zero edges, indicating a significant number of connections between them.

Centrality analysis revealed different roles and influences of sections within the smart village network. Section J (information and communication) in Division 62 showed moderate levels of centrality. Its betweenness centrality was -0.248, suggesting average mediation in paths between other nodes. Closeness centrality at 0.262 indicated relatively good proximity to other nodes, while strength at -0.106 showed a moderate strength of connections with other nodes. The expected influence at 0.492 suggests a significant impact on the network. Additional centrality measures, such as Barrat (0.981), Onnela

(0.303), WS (1.725), and Zhang (-0.061), also indicated balanced values, confirming Section J62's stable position in the network. In contrast, Section J in Division 63 showed lower centrality levels, suggesting less influence and less intense connections with other sections. Its betweenness centrality was -0.617, closeness centrality was -1.067, and strength was -0.953, indicating weaker and less central connections in the network. Nevertheless, the expected influence at 1.015 suggests that Section J63 had a significant impact in specific contexts. Additional centrality measures, such as Barrat (-1.996), Onnela (-1.084), WS (0.117), and Zhang (-1.348), confirmed this section's marginal role in the network structure.

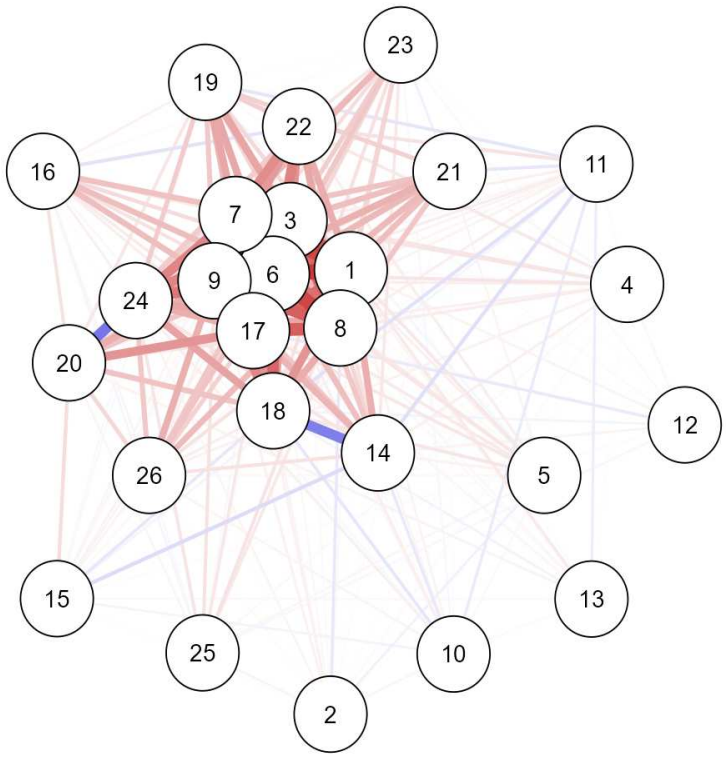

Figure 3. Network diagram

Notation on the network diagram: 1: Section A, 2: Section B, 3: Section C, 4: Section D, 5: Section E, 6: Section F, 7: Section G, 8: Section H, 9: Section I, 10: Section J, Division 58, 11: Section J Division 59, 12: Section J Division 60, 13: Section J Division 61, 14: Section J Division 62, 15: Section J Division 63 16: Section K, 17: Section L 18: Section M 19: Section N, 20: Section O, 21: Section P, 22: Section Q 23: Section R 24: Section S Division 94, 25: Section S Division 95, 26: Section S Division 96 and Section T Division 97 and 98.

Explanations: The line colours on the network diagram represent the type of relationship between variables. Blue lines indicate positive associations, where an increase in one variable is associated with an increase in the other. Red lines denote negative associations, where an increase in one variable is associated with a decrease in the other. The thickness and intensity of the line colour reflect the strength of the association – thicker and more saturated lines represent stronger connections, while thinner and less intense lines indicate weaker relationships.

Source: own elaboration.

Centrality analysis plays a crucial role in identifying the role of individual sections within the network. For instance, Section J62, dealing with information and communication, exhibits moderate centrality levels. Its centrality values, such as betweenness, closeness, and strength, suggest that it was relatively well connected to other sections, confirming its stable position without a dominant role. In contrast, Section J63 in the same division showed lower centrality values, indicating less influence and weaker connections. However, its high expected influence suggests that it may play an important role in specific contexts.

Based on the document analysis, key sections in the context of the Smart Village concept include financial and insurance activities (Section K), wholesale and retail trade (Section G), transport and storage (Section H), professional, scientific, and technical activities (Section M), and real estate activities (Section L). Section K is characterized by high values in betweenness centrality (0.073) and closeness

centrality (0.218), indicating its significant role in information flow and collaboration with other sections, crucial for financing and managing Smart Village projects. Section G shows high values in closeness centrality (0.245) and strength (0.065), suggesting its key role in the distribution and access to goods and services in rural areas. Section H, with significant values in closeness centrality (0.242) and strength (0.052), was important for logistics and goods flow, which is crucial for the effective functioning of rural areas. Section M, with high values in betweenness centrality (0.066) and closeness centrality (0.212), played a significant role in developing and implementing innovative technological solutions within the Smart Village framework. Section L, characterized by high values in closeness centrality (0.237), played a key role in managing space and infrastructure in rural areas.

Sections J62, related to software activities, and J63, related to information services, had numerous connections with other sections, indicating their crucial role in providing the information and communication technologies necessary for Smart Village functioning. The betweenness centrality values for Sections J62 and J63 are 0.057 and 0.054, respectively, while the expected influence values are 0.041 for J62 and 0.036 for J63. Although these values were significant, they were not the highest, suggesting that these sections play a supportive role in the network, facilitating information flow and integrating technology with other sectors.

Conclusions from the analysis indicate that Sections K, G, H, M, and L were dominant in the network, playing a key role in information flow and collaboration among enterprises. Sections J62 and J63, while not dominant, were important as providers of information and communication technologies that support Smart Village functioning by integrating with other key sectors. Integrating these technologies with financial, commercial, transport, professional, and real estate activities is crucial for the sustainable development and effective functioning of rural areas, forming the basis of the Smart Village concept.

In summary, the diversity of centrality values in the network indicated the need for a balanced approach to investment and support. Investing in digital technologies in sections with higher centrality can enhance overall efficiency and integration within the Smart Village, while sections with lower centrality may require specialized support from ICT enterprises to strengthen their connections and impact, contributing to increased coherence and innovation across the Smart Village community.

Network analysis of Sections J62 and J63 revealed significant differences in their positions within the network structure. Section J62 shows moderate centrality values, suggesting it is well-integrated with other sections responsible for rural development. Its betweenness, closeness, and strength centrality values indicate solid connections and influence on other areas, potentially leading to the effective implementation of Smart Village technologies, such as smart resource management, digital public services, and the development of information and communication infrastructure. Section J63, with lower centrality values, may indicate a focus on more specialized and innovative aspects of the Smart Village concept. While its overall impact was smaller, it remained important in specific contexts, such as implementing innovative technological solutions or supporting local initiatives.

Discussion

Smart villages aim to significantly improve the quality of life for residents through enhancements in education, healthcare, infrastructure, and overall community well-being (Mohanty *et al.*, 2020; Singh *et al.*, 2022). A key element of smart village development was the adoption of modern technologies such as electronic sensors, the Internet of Things (IoT), advanced healthcare, innovative education, and digital infrastructure (Singh *et al.*, 2022). Entrepreneurship in smart villages is fostered by small and medium-sized enterprises (SMEs) that create and implement local solutions to local problems, operating under the philosophy of 'I can do it for you,' which means offering services and solutions tailored to the specific needs of the local community (Szanyi-Gyenes, 2019). An example of this is the proposal of the 'smart tourist village' concept as a modern form of rural development, focusing on utilizing rural resources and building tourism infrastructure to attract tourists and boost the local economy through sustainable use of local resources and attractions (Aziiza & Susanto, 2020; Ciolac *et al.*, 2022).

The development of smart villages significantly impacts entrepreneurial activities. Primarily, smart rural development can substantially reduce the migration of people from rural areas to cities and counteract economic threats by rejuvenating rural infrastructure and creating new economic opportunities (Mohanty

et al., 2020). This creates broad opportunities for entrepreneurship, particularly in areas such as precision agriculture, energy diversification, tourism, and innovative enterprises (Visvizi *et al.*, 2019). The implementation of IoT-based smart village initiatives aims to improve residents' quality of life, promote sustainable development, and address socio-economic challenges in rural areas (Bhosale *et al.*, 2023).

Today, new opportunities for entrepreneurial development in rural areas are emerging based on modern technologies, innovations, and new business models, such as those related to circular economy, sharing economy, or bioeconomy. Companies in the ICT sector play a crucial role in this process as carriers of these modern solutions. Importantly, the management of biomass, as well as residues and waste generated in rural areas, creates new locational opportunities for enterprises due to the local nature of their processing (often due to their large volume, *e.g.*, biomass, transport costs, and associated environmental pollution) (Johnson & Altman, 2014).

The challenges and opportunities for entrepreneurs in smart villages are diverse. Challenges include financial constraints, the size of the informal economy, and management issues that limit government aspirations for smart village concepts (Utamajaya *et al.*, 2023). On the other hand, opportunities lie in utilizing digital transformation to modernize traditional aspects of rural areas, especially in agriculture, healthcare, and energy management (Gorain, 2022). Creating a startup ecosystem in smart villages can promote entrepreneurship and economic growth but requires interventions such as new programs and institutional reforms (Mitra *et al.*, 2023).

The role of technology in shaping entrepreneurship in smart villages is crucial. Digital and telecommunication technologies, bioenergy, and the Internet of Things play key roles in driving strategic breakthroughs in rural communities and promoting entrepreneurial activities (Atkočiūnienė & Vaznonienė, 2019; Babin *et al.*, 2022). The use of digital technologies may not always be an essential prerequisite for smart villages, but it can significantly contribute to the sustainable digital transformation of rural areas (Rwakihembo *et al.*, 2024). New digital technologies, such as cloud computing, blockchain, robotics, data analytics, artificial intelligence (AI), IoT, and 5G, create significant opportunities for improving the life quality in smart villages (Gorain, 2022). They enable innovative solutions in areas such as agriculture, healthcare, and infrastructure, which in turn fosters entrepreneurship in rural areas.

In the context of smart villages, entrepreneurship has become a significant research area as technological advancements and innovative approaches to rural space management contribute to transforming traditional communities and local economies. We attempted to identify and analyse the key features of entrepreneurship in smart villages, considering the impact of information technology development on entrepreneurial activities. We analysed both the challenges and opportunities that entrepreneurs face in the context of smart villages, as well as the role of technology in shaping new models of entrepreneurship and development opportunities. The study provides a better understanding of how the integration of modern technologies and innovative solutions can support entrepreneurial development in rural areas, contributing to their sustainable development and increased competitiveness.

In summary, smart village entrepreneurship focuses on improving rural infrastructure, utilizing digital technologies, and supporting local development. Smart rural development can prevent migration from rural areas to cities, create economic opportunities, and address socio-economic challenges. However, it also comes with challenges related to financial constraints and management issues. Technology, particularly IoT and digital innovations, plays a key role in shaping entrepreneurship in smart villages by driving strategic changes and promoting sustainable development.

CONCLUSIONS

Primarily, this study aimed to illustrate the development process of smart villages from 1.0 to 4.0, analogous to the development process of smart cities, along with identifying the conditions influencing this process. The theoretical section indicated that we may consider the concept of smart villages as analogous to the concept of smart cities as an innovation that organizes spatial structures according to a new model. Despite the differences between developing smart cities and smart villages due to the varying specifics of these areas, there are many connections between them. Thus, we highlighted the possible evolution of smart villages from 1.0 to 4.0, similar to the evolution of smart cities. Moreover,

we outlined the conditions for the development of each phase of smart villages. We also emphasised the significant role of ICT enterprises in the development of smart villages, particularly at the smart villages 1.0 level. Furthermore, we identified connections between ICT enterprises and other sectors of economic activity, which was another goal of this study.

The analysis confirmed the hypothesis that the smartification of villages, considered a diffusion process, is reflected in a greater degree of specialization in services stimulated by entrepreneurship in ICT. The analysis revealed that the diffusion of innovations in the form of smart village creation is hierarchical in nature, reinforced by the developmental potential of major urban agglomerations in Poland. This conclusion stems from the spatial concentration of municipalities with the highest level of ICT entrepreneurship development. Complementation of it is the innovation diffusion driven by the above-average development of ICT in municipalities with strategic geopolitical locations (especially along the eastern border of Poland and the European Union). However, to see relatively greater ICT entrepreneurship activity in eastern provinces, which suggests a breaking of the long-term pattern of infectious innovation diffusion in Poland from the southwest to the northeast. We could explain this phenomenon by the impact of public aid for rural areas in eastern Poland, particularly in the field of digitalization. Nevertheless, given the significantly lower interest in the ICT sector in western Polish villages, this phenomenon requires further research.

Hypothetically, we may already be witnessing the effects of stimulating the economy in rural areas of eastern Poland due to the strengthening of geopolitical functions not only in border areas but also in somewhat more distant industrial and service centres supporting the military and defence sectors. Municipalities with the highest level of ICT development, located in border areas (mainly on the eastern border), showed a significantly higher proportion of sections responsible for administration and national defence (Section O), tourism (Section I), and agriculture and related sectors (Section A) compared to other types of municipalities. In this case, a smart village was a consequence of applying ICT technology for defence development and supporting multifunctional rural development. This may signal a process moving from a smart village to a smart city if, as a result of the growth in the economic base of local centres, urbanization increases not only in terms of professional urbanization but also in terms of landscape and static urbanization. Smart villages evolving towards smart cities could become the carriers of these changes.

In municipalities located in the immediate vicinity of large urban centres classified as ITIs (Integrated Territorial Investments), a different kind of stimulation occurs since suburban centres are an integral part of smart cities. Smart cities expand into their supply spheres, where urban functions are succeeded from the core of the agglomeration. We can hypothesize that in this case, we are likely dealing with further stages of smart village development, where subsequent versions 2.0, 3.0, or even 4.0 are possible. This is particularly evident in the ITI of Warsaw, where there is an exceptionally high concentration of rural municipalities with the highest level of ICT entrepreneurship development. High ICT entrepreneurship development is accompanied by significant activity in sectors M and Q, indicating substantial support from local governments in healthcare and social services, as well as in the business ecosystem for business services and scientific and technical activities.

In light of the research findings, we recommend several key actions to further develop the smart village concept:

- Strengthening connections between ICT entrepreneurship and other key areas for smart village processes, such as education, health, and transportation, to ensure better integration and effective implementation of innovations. Improving communication and coordination between these sectors create synergies that will enhance the effectiveness of smart village initiatives and accelerate their implementation in various rural areas.
- Expanding ICT infrastructure to enable extensive use of digital technologies in managing resources and public services. Investments in broadband internet, data management systems, and smart energy grids are crucial to support innovative solutions.

- Supporting local initiatives through funding and advisory services to develop specific, innovative projects tailored to local needs. Providing access to financial resources, expert knowledge, and tools supporting local entrepreneurship can contribute to the sustainable development of rural areas.
- Promoting education and training in new technologies for rural residents to increase their digital skills and prepare them for active participation in smart village initiatives. Educational programs can include courses on ICT management, project management, and entrepreneurship.
- Encouraging cross-sector collaboration by creating platforms for knowledge and experience exchange between local governments, non-governmental organizations, the private sector, and local communities. This approach enables sharing best practices and implementing proven solutions in various local contexts.

Implementing these actions can contribute to the dynamic development of the smart village concept, improving the life quality in rural areas and supporting their sustainable development. Entrepreneurship in smart villages focuses on improving rural infrastructure, utilizing digital technologies, and supporting local solutions to local problems through community participation and active citizen engagement. Smart rural development can prevent migration from villages to cities, provide economic opportunities, and address socio-economic challenges. However, it also involves challenges related to financial constraints and management issues. Technology, particularly IoT and digital innovations, plays a key role in shaping entrepreneurship in smart villages by driving strategic breakthroughs and promoting sustainable development.

Future research could examine the impact of ICT entrepreneurship on the development of smart village 1.0 in other countries, including the EU, along with identifying the connections between this type of entrepreneurship and other forms of economic activity. Moreover, it seems crucial to attempt to study the level of development of smart villages 2.0, 3.0, and 4.0 in Poland and other countries. This requires defining indicators for each stage of smart village development. A potential research limitation in this area could be the availability of statistical data in public statistics.

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