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Evaluation of the Completeness of Spatial Data Infrastructure in the Context of Cadastral Data Sharing

Agnieszka Trystuła *, Małgorzata Dudzińska and Ryszard Źróbek

Department of Land Management and Geographic Information Systems, Faculty of Geoengineering, University of Warmia and Mazury in Olsztyn, 10-720 Olsztyn, Poland; gosiadudzi@uwm.edu.pl (M.D.); zrobek@uwm.edu.pl (R.Z.)
* Correspondence: agnieszka.trystula@uwm.edu.pl

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Abstract: The idea behind the Infrastructure for Spatial Information in Europe (INSPIRE) project was to provide EU citizens with access to various types of information, including environmental protection and spatial management data. These resources can be viewed (Web Map Service—WMS) and downloaded (Web Feature Service—WFS) online. Cadastral datasets represent one of the 34 spatial data themes in the spatial data infrastructure (SDI). The functionality of the SDI has not yet been fully achieved due to the failure of the WMS and WFS network services. The aim of this article was to assess the completeness of the SDI containing cadastral datasets. The present study has practical implications. The proposed diagnostic tool supports an assessment of the completeness of SDI resources in seven diagnostic groups (technical and legal identifiers, the cadastral information profile, the WMS network service, the WFS network service, source cadastral databases, data validity, and WMS and WFS standardization). The developed assessment methodology enables the identification of websites that publish cadastral data through INSPIRE network services, as well as problematic websites, and it has high development potential. The results of the assessment should be used in the ongoing construction of the SDI. They can also be used to improve the quality of network services and their availability for end users.

Keywords: cadastral data; spatial data infrastructure; websites publishing cadastral data; INSPIRE network services; evaluation

1. Introduction

Infrastructure for Spatial Information in Europe (INSPIRE) network services are widely applied in decision-making processes relating to responsible spatial management. Network services such as the Web Map Service (WMS), Web Map Tile Service (WMTS), Web Feature Service (WFS), Web Coverage Service (WCS) and Catalogue Service for Web (CSW) have been developed by the Open Geospatial Consortium (OGC), and they can be applied to develop dispersed systems and web applications that communicate across the network through appropriate HTTP protocols [1]. Network services speed up access to spatial data dispersed across multiple databases if they have been developed in accordance with OGC standards that guarantee proper service operation. WMS and WFS standards are used to develop spatial data infrastructure (SDI) according to selected EU and international standards [2–6].

The SDI was developed to facilitate the implementation of EU environmental policies and activities. The primary tasks of the SDI are to enable the exchange of spatial data between public sector organizations and to facilitate access to these data across the EU [7]. In every European country, the SDI can be implemented in a manner that promotes the development and improves the quality of European

initiatives such as e-administration and the European Interoperability Framework. One of the greatest advantages of the European SDI is that it improves the functioning of public administration at all levels by facilitating access to geospatial information [8]. Under the INSPIRE Directive, the public administration authorities of the EU member states are under obligation to integrate data from various thematic fields and to provide access to such information through web service modules that support the online viewing, searching, and downloading of spatial data.

The cadaster is one of the sources of spatial information for developing thematic datasets in line with the INSPIRE Directive. The cadaster aggregates spatial information that significantly influences economic processes and economic growth. The current status and functionality of the cadaster have been shaped by historical, political, and legal factors, as well as the dynamics of Poland's socioeconomic development. The cadastral system provides access to information on land parcels, buildings, premises, and entities who hold various legal titles to the listed property. Contemporary cadastral databases should be simple, effective, and reliable [9] in order to improve the functioning of organizations that are responsible for real estate management. Cadastral data are used to resolve decision-making problems in the process of achieving environmental, social, economic, legal, and tax policy objectives [10–13]. These objectives cannot be achieved without access to cadastral data. Cadastral data should be made available through network services [14–16] in line with national regulations on open access to public data. Public access to data is an essential instrument of social control over state administration, and it increases the responsibility and transparency of government activities. The relevant data are provided in the form of cadastral maps by the Head Office of Geodesy and Cartography [17].

The aim of this article was to assess the progress made in the development of the SDI, which is based on websites publishing cadastral data that have been submitted to the register of spatial datasets and services under the SDI. The present study has practical implications, and it proposes a tool for validating the progress in SDI development in seven diagnostic groups: technical and legal identifiers, the cadastral information profile, the WMS network service, the WFS network service, INSPIRE theme 1.6 and 3.2 source databases, data validity, and WMS and WFS standardization. The aim of the assessment was to diagnose the current status of SDI development, to identify the strengths and weaknesses related to the quality of publicly available cadastral data, and to formulate recommendations for further activities with the aim of improving their effectiveness in various decision-making processes.

Nearly 400 websites publishing cadastral data (county (powiat) cadastral databases) in Poland need to be consolidated, and the relevant data resources have to be standardized. The article evaluates websites publishing cadastral data to assess the progress made in the implementation of network service solutions as one of the key features of the SDI. The proposed procedure for evaluating websites publishing cadastral data involved the following stages:

- The determination of the main objective of service evaluation.
- The description of the criteria for diagnosing the functionality of websites publishing cadastral data and access to cadastral data (legal, organizational, and technical aspects).
- The development of indicators for evaluating selected diagnostic criteria.
- The interpretation of the results of cadastral service evaluation.

2. Background

The aim of the INSPIRE concept was to establish a framework for improving the availability, relevance and interoperability of spatial data for environmental policy-making and activities that exert a direct or an indirect impact on the environment [2,18–21]. An interoperable SDI is an institutional concept that aims to better respond to the public demand for geographic data in a wide range of thematic domains. This concept continues to evolve, and it has emerged as the main SDI that supports social and economic policy-making around the world [8,22]. The purpose of the SDI is to store,

share, and maintain spatial data and metadata at an appropriate level. The main features of the SDI are presented in Figure 1.

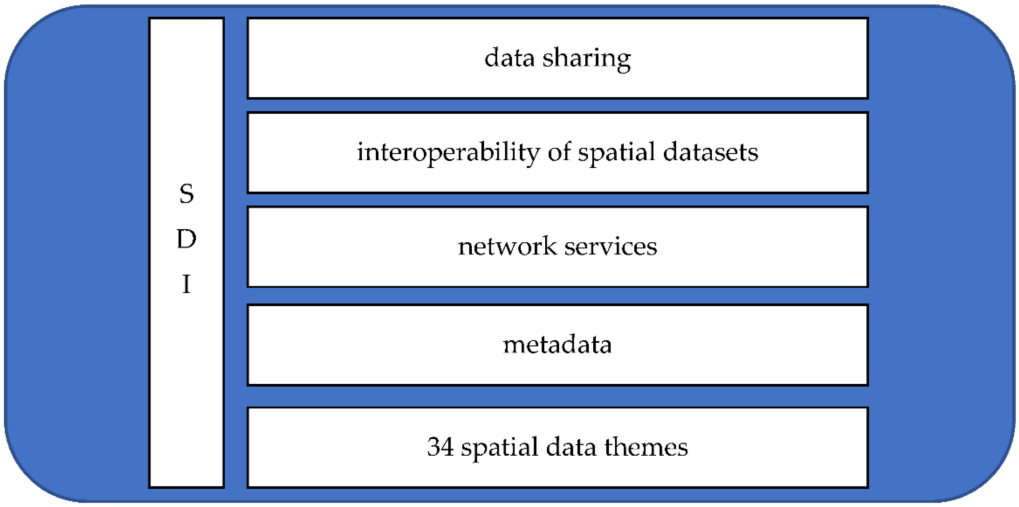

Figure 1. Spatial data infrastructure (SDI) features. Source: [2].

Network services pose one of the greatest challenges to the development of the SDI in Europe. These services create access to spatial data, including cadastral parcels, at both the national and European levels [2,23,24]. The spatial data themes referred to in the INSPIRE Directive include cadastral parcels and buildings [2]. Cadastral parcels are listed in Annex I, and they are considered reference data, i.e., data that constitute the spatial framework for linking and/or identifying other types of information in various thematic fields, such as buildings, the environment, soil use, and land use. The INSPIRE Directive focuses on the geographic attributes of cadastral data. In the context of the INSPIRE Directive, cadastral parcels mainly serve as locators of general geo-information, including environmental data. According to the technical standards laid down by the INSPIRE Directive [25], cadastral parcels fall under the scope of one or more INSPIRE themes if they are defined by cadastral or equivalent registers, as well as if they have uniform legal status and are available as vector data. From the perspective of the implemented directive, the INSPIRE model of cadastral data only covers the geometric part of the cadastral system. Legal aspects and ownership data are not taken into consideration even if they are part of the dataset because the member states have the right to limit public access to spatial data and services [2]. In view of the above, the cadastral data model is simple and highly compatible with other INSPIRE databases, such as databases of buildings whose specifications are based on geographic location in line with the developed guidelines [26].

The technical implementation of network services falls subject to the technical specifications developed by the OGC. The member states are under obligation to establish and operate a network of the following spatial data services:

- Discovery services that support the search for spatial datasets and services based on the content of the corresponding metadata, as well as enabling users to display metadata content.
- View services that, as a minimum, enable users to display, navigate, zoom in/out, pan, or overlay viewable spatial datasets, as well as to display legend information and any relevant metadata content.
- Download services that enable users to copy, download, and, where practicable, directly access spatial datasets or parts of such sets.
- Transformation services that enable users to transform spatial datasets with a view to achieving interoperability.
- Services that enable users to invoke spatial data services.

These services have to account for specific user requirements, and they have to be easy to use, available to the public, and accessible via the internet or any other appropriate means of telecommunication [2]. Cadastral data published via network services can be viewed (OGC WMS) and downloaded (OGC WFS) [25]. In line with the INSPIRE Directive, the INSPIRE geoportal is the main European spatial database that integrates spatial data resources and enables the member states to view (OGC WMS) and download (OGC WFS) spatial data. The geoportal also supports measures aiming to monitor the entire INSPIRE data collection. The WMS is based on the HTTP interface, and it enables users to view and integrate maps with other spatial data from the INSPIRE geoportal. Three functions have been identified in line with OGC standards: GetCapabilities for acquiring detailed descriptions of maps available on the server, GetMap for downloading maps, and GetFeatureInfo for requesting information about the objects displayed on the map. GetCapabilities and GetMap are obligatory functions that have to be implemented in every WMS [4]. The WFS is an internet service that provides access to geographic objects and enables users to download and edit objects in the database. The service also contains tools for creating, storing, and parameterizing server queries [5].

The INSPIRE concept promotes access to knowledge about European resources at the national, regional, and local levels. Modern societies have a vast need for a broad spectrum of information relating to environmental protection, cultural heritage protection, spatial management, investments, internal and external security, the development of a knowledge-based economy, e-administration, e-society, and, consequently, civil society [27]. Poland has developed the relevant legal tools [28] for implementing the provisions of the INSPIRE Directive. According to [1,29], the cadaster plays an important role in the Polish SDI as a reference for other spatial data themes covered by the INSPIRE Directive.

The cadaster provides access to the spatial data themes referred to in the INSPIRE cadastral model. The data pertaining to cadastral parcels (Annex I to the INSPIRE Directive, theme 6) can be compatible with other INSPIRE spatial data themes, such as buildings (Annex III, theme 2). The geoportal.gov.pl web service is being developed with the use of the open source technology, and it is operated by the Chief Surveyor General of Poland (CSG) in line with EU and national regulations [25,28] to provide access to SDI resources in Poland. The CSG is also responsible for 15 INSPIRE data themes, including cadastral parcels and buildings. The data relating to cadastral parcels (Annex I, theme 6) and buildings (Annex III, theme 2) are published by two groups of network services. The first group is based on the WMS, and it enables users to view data layers relating to cadastral parcel boundaries, parcel numbers, and buildings. In Poland, access to cadastral data was created by harmonizing the resources of the Land Parcel Identification System (LPIS), which supports direct payments to farmers under the Common Agricultural Policy. The boundaries of cadastral parcels are determined based on cadastral system data. The second group of web services involves the WMS and the WFS, which publish cadastral data that are available in county centers for geodetic and cartographic documentation (county cadastral databases) and have been previously notified in the geoportal's service repository.

According to [14], the WMS specifications for the cadastral data distributed by Polish counties include the following functions:

1. GetMap—for viewing cadastral maps in the PNG format.
2. GetFeatureInfo—for accessing information such as cadastral parcel ID, parcel number, the territorial unit for which the cadastral database is kept, the number of the land and mortgage register, and the date on which cadastral data were last updated.
3. GetCapabilities for accessing data layers via the WMS and basic layer parameters such as coordinate systems, graphic formats, and accessible data themes.

A cadastral parcel can be localized (its geometric parameters can be downloaded) using a service based on the OGC WFS standard. All WFS-based applications should have the following functionalities:

1. GetCapabilities, which returns metadata.
2. DescribeFeatureType, which returns a description of feature types from the cadastral parcel layer.

3. GetFeature, which returns the cadastral parcel, its geometry and features based on the legal definition, parcel identification data, or coordinates.

3. Materials and Methods

3.1. Study Area

In the geographic sense, the analyzed county cadastral databases are located in the Eastern Poland macroregion, which is one of the least economically developed regions of the EU [30]. This fact was one of the key arguments for selecting the study area. Eastern Poland is a peripheral macroregion that occupies an area of nearly 99,000 km^2 and accounts for 32% of Poland's territory. Its eastern border marks the eastern border of Poland and the eastern border of the EU (Figure 2). Websites that are tasked with providing valid cadastral data as reference data for the SDI under the Act on Spatial Data Infrastructure were analyzed and evaluated in 14 counties of Świętokrzyskie Voivodeship [28].

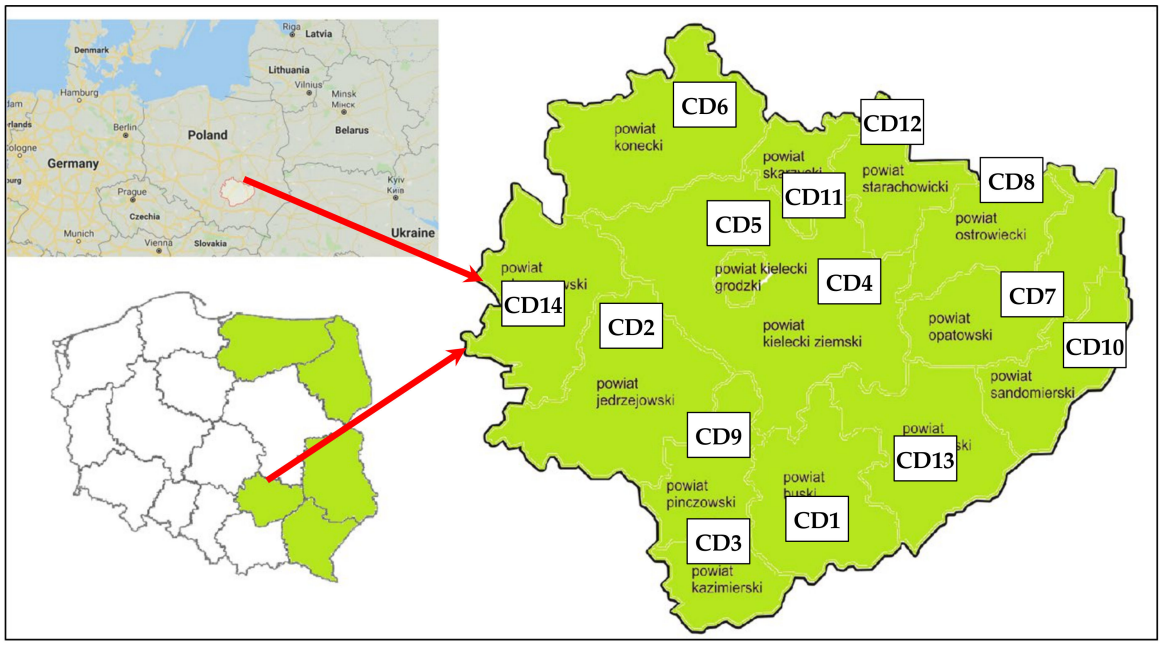

Figure 2. General location of Świętokrzyskie Voivodeship. Source: Own study.

County governors are responsible for maintaining and updating Polish cadastral systems. The analyzed county databases provide access to cadastral data, and they are partly integrated with the National Integration of Land Registers (NILR) service that groups the county WMS under a single URL address. The NILR is a tool that supports the national geoportal by facilitating the presentation of cadastral data directly acquired from public organizations that are responsible for integrating and updating cadastral data. Counties that are only partly integrated with the NILR rely on network services based on the cadastral resources of the LPIS that are not regularly updated. According to [31], county databases differ in the accuracy with which the boundary points of cadastral parcels have been mapped, and they contain discrepant information on the area of cadastral parcels, as well as errors relating to the classification of land-use types. Regardless of the manner in which spatial infrastructure nodes at the county level have been integrated with the NILR, cadastral data should be prepared in line with the EU model described in [25]. In the period covered by this study, the largest number of counties that published cadastral data based on LPIS resources were located in Świętokrzyskie Voivodeship (Figure 3).

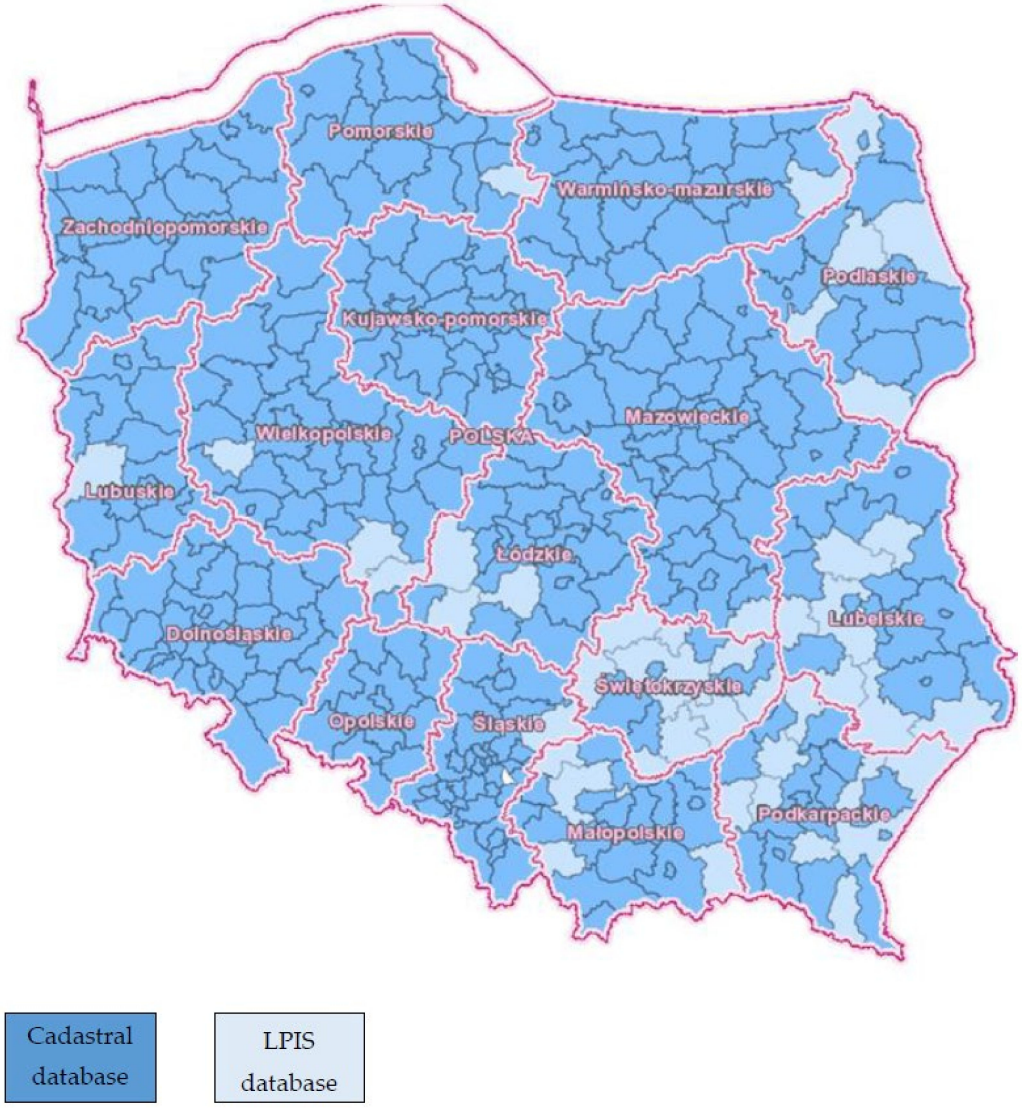

Figure 3. County infrastructure nodes in the National Integration of Land Registers (NILR) service. Source: https://geoportal.gov.pl/.

Nearly 90% of Polish counties are fully integrated with the NILR service (cadastral data are regularly updated). In Świętokrzyskie Voivodeship, cadastral databases were fully integrated with the NILR in 5 counties, i.e., in 36% of public administration units in that voivodeship. The remaining nine counties published cadastral data based on LPIS resources. As a result, Świętokrzyskie Voivodeship ranks last on the list of Polish voivodeships that publish valid cadastral data. This study covered all counties of Świętokrzyskie Voivodeship regardless of their integration status with the NILR

3.2. *Methodology*

According to [32], an evaluation is a process of collecting and analyzing data to identify the strengths and weaknesses of programs, policies, and organizations with the aim of improving their effectiveness. Evaluations have three objectives, which are to measure impacts, understand the causal path, and engage stakeholders in learning processes. The present study evaluated the progress made in the harmonization of Polish legal acts relating to the development of the SDI at the local level with the EU regulations.

The deployed methodology involved three research stages (Figure 4) that were developed by merging several approaches [33], including:

1. A review of the literature addressing the problem, with the main focus on selected legal, organizational, and technical aspects related to the publication of cadastral data using network services such as the WMS and the WFS.
2. Research into the usability of websites publishing cadastral data combined with an expert interview.
3. An analysis of the register of spatial datasets and services with the aim of exploring its structure and operating principles.
4. Evaluations involving the identification of success or failure criteria for the online publication of cadastral data.
5. Inference aiming to formulate, in a clear and unambiguous manner, the crucial results of the evaluation of selected websites that publish cadastral data.

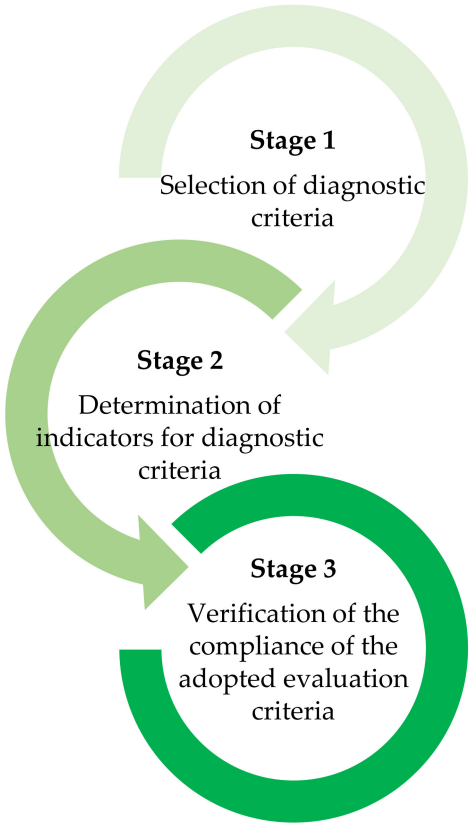

Figure 4. Research plan. Source: own study.

The adopted approach supported an analysis and evaluation of selected processes relating to the development of cadastral systems in line with the EU solutions.

The analyzed websites that publish cadastral databases should make the collected data available through network services. To verify the websites' compliance with the provisions of the INSPIRE Directive, complex phenomena with varied origin were analyzed with the use of a qualitative method.

Diagnostic criteria for evaluating cadastral systems that publish cadastral data via network services (the WMS and the WFS) and that determine the overall validity of the performed analysis were selected in the first stage of research. In the second stage, indicators were assigned to selected diagnostic criteria for evaluating network services. The anticipated compliance of the assigned indicators was determined.

Stage one: The identification of the diagnostic criteria for evaluating websites publishing cadastral data via the WMS and WFS services

The developed indicators were used to monitor the development of cadastral systems [11,34–36]. Diagnostic criteria and the relevant indicators were identified based on the provisions of:

1. Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 Establishing an Infrastructure for Spatial Information in the European Community [2].
2. Act on Spatial Data Infrastructure of 4 March 2010 [28].
3. Geodetic and Cartographic Law of 17 May 1989 [37].
4. Regulation of the Minister of Regional Development and Construction of 29 March 2001 on land and building registers [38].
5. ISO 19128 [4].
6. ISO 19142 [5].
7. Technical specifications for county-level WMSs relating to land and building registers.
8. Interviews with the experts employed by the County Centre for Geodetic and Cadastral Documentation in Świętokrzyskie Voivodeship.
9. Analysis of the structure and operating principles of the register of spatial datasets and spatial data services kept by the Head Office of Geodesy and Cartography (HOGC).

The adopted indicators for evaluating cadastral systems that publish spatial data combine the diagnostic criteria associated with the studied objects, including spatial data themes, cadastral parcel identifiers, the availability and standardization of network services, and the validity of published cadastral data.

Network services are among the identifiable features of the SDI. The criteria for evaluating systems that publish information about cadastral parcels and buildings via network services were selected based on European and Polish trends that account for local environmental needs. Seven diagnostic criteria (A–G) for evaluating equivalent cadastral systems are presented in Table 1. In systems that meet all criteria, SDIs were regarded as complete at both the local and national levels.

Table 1. Selected Diagnostic Criteria for Evaluating Cadastral Systems. WMS: Web Map Service; WFS: Web Feature Service.

Symbol	Diagnostic Criteria
A	Technical and legal identifiers
B	Cadastral data profile
C	WMS network service
D	WFS network service
E	Sources of data for databases of cadastral parcels (Annex I, theme 1.6) and buildings (Annex III, theme 3.2)
F	Standardization of WMS and WFS
G	Data validity

Source: Own study.

Stage two: The description of the diagnostic features of selected evaluation criteria, including the degree of criteria fulfilment

The indicators assigned to each diagnostic criterion for evaluating cadastral systems are presented in Tables 2–8.

Table 2. Technical and Legal Identifiers.

Diagnostic Criterion	Indicator	Symbol	Validity (0–1)
A	Ordinal number of cadastral dataset	A_1	0–1
	Publication date of cadastral dataset	A_2	
	Notification date of cadastral dataset	A_3	
	Notifying entity	A_4	
	Identifier of cadastral dataset	A_5	
	Name of cadastral dataset	A_6	
	Code of cadastral dataset	A_7	
	Legal regulations	A_8	

Source: own study.

Table 3. Cadastral Data Profile.

Diagnostic Criterion	Indicator	Symbol	Validity (0–1)
B	Annex I, theme1.6 * ° cadastral parcels ° cadastral parcel labels	B_1	0–1
	Annex III, theme 3.2 * ° buildings ° building labels	B_2	

*—The criterion is fulfilled when all data are visible or when all data have been returned by the function. Source: own study.

Table 4. WMS Network Service.

Diagnostic Criterion	Indicator	Symbol	Validity (0–1)
C	WMS availability	C_1	0–1
	WMS address	C_2	
	WMS indicator at county level: $P_{WMS} = \frac{N_{WMS}}{N_{US}} \cdot 100\%$	C_3	N_{WMS} (0–1) N_{us} (0–5) ** 0–100% 0—When 0% 1—When 20–100%

**—The indicated range covers 5 INSPIRE network services (WMS, WFS, Catalogue Service for Web (CSW), Web Coverage Service (WCS), and WCTS). Source: Own study.

Table 5. WFS Network Service.

Diagnostic Criterion	Indicator	Symbol	Validity (0–1)
D	WFS availability	D_1	0—Not available 1—Available
	WFS address	D_2	
	WFS indicator at county level: $P_{WFS} = \frac{N_{WFS}}{N_{US}} \cdot 100\%$	D_3	N_{WFS} (0–1) N_{us} (0–5) 0–100% 0—When 0% 1—When 20–100%

Source: own study.

Table 6. Sources of Data for Databases of Cadastral Parcels and Buildings. LPIS: Land Parcel Identification System.

Diagnostic Criterion.	Indicator	Symbol	Validity (0–1)
E	Land and building register	E_1	0—LPIS 1—Cadastral database

Source: own study.

Table 7. Standardization of WMS and WFS.

Diagnostic Criterion	Indicator	Symbol	Validity (0–1)
F	GetMap function	F_1	0–1
	GetFeatureInfo function *: ° cadastral parcel ID ° cadastral parcel number ° territorial unit for which the cadastral database is kept ° number of the land and mortgage register	F_2	
	GetCapabilities function *: ° cadastral parcel layer ° number of cadastral parcel ° building layer	F_3	
	HTTP protocol	F_4	
	GetFeature function based on parcel ID	F_5	
	Function based on x and y coordinates	F_6	

*—The criterion is fulfilled when all data are visible or when all data have been returned by the function. Source: own study.

Table 8. Data Validity.

Diagnostic Criterion	Indicator	Symbol	Validity (0–1)
G	Date of last cadastral data update	G_1	0—No date 1—Date of last update

Source: own study.

Stage three: The evaluation of selected systems publishing cadastral data based on the indicated criteria and their diagnostic features

Selected cadastral systems that publish spatial data based on the selected diagnostic criteria and indicators were evaluated in the third stage of the study. The criteria responsible for the success or failure of network services that publish cadastral data were identified. The results of the evaluation were used to formulate clear conclusions regarding the analyzed network systems that publish cadastral data. The trends and prospects relating to the development of cadastral systems that publish data via INSPIRE network services were verified based on the extent to which the selected equivalent systems met the diagnostic criteria. Each of the seven diagnostic criteria were evaluated on a two-point grading scale: 0 for when at least one diagnostic criterion was not met, and 1 for when all diagnostic criteria were met. The following key was used to evaluate the completeness of the Polish SDI based on the available network services, the associated spatial data themes, and their variability over time (data validity):

- Excellent (EXC)—100% of possible points for every adopted criterion; the evaluated SDI is fully complete.
- Above Average (AAVG)—More than 60% of possible points for every adopted criterion; the evaluated SDI is characterized by above-average completeness.
- Average (AVG)—More than 40% of possible points for every adopted criterion; the evaluated SDI is characterized by average completeness.
- Below Average (BAVG)—More than 20% of possible points for every adopted criterion; the evaluated SDI is characterized by below-average completeness.
- Negative (NEG)—0–20% of possible points for every adopted criterion; the evaluated SDI is characterized by critical-level completeness.

The proposed diagnostic criteria (A–G) for evaluating cadastral systems that publish data via network services were verified based on HOGC data [39]. The results of the verification process are presented in Tables 9–15.

Table 9. Evaluation of Cadastral Databases Based on Criterion A.

Diagnostic Criterion	Indicator	Cadastral Database (CD)														Fulfilment of Criterion (Counties)	Fulfilment of Criterion (Voivodeship)
		CD1	CD2	CD3	CD4	CD5	CD6	CD7	CD8	CD9	CD10	CD11	CD12	CD13	CD14		
Technical and legal identifiers																	
A	A_1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	93%	93%
	A_2	1	1	1	1	1	1	1	1	1	1	1	1	1	0	93%	
	A_3	1	1	1	1	1	1	1	1	1	1	1	1	1	0	93%	
	A_4	1	1	1	1	1	1	1	1	1	1	1	1	1	0	93%	
	A_5	1	1	1	1	1	1	1	1	1	1	1	1	1	0	93%	
	A_6	1	1	1	1	1	1	1	1	1	1	1	1	1	0	93%	
	A_7	1	1	1	1	1	1	1	1	1	1	1	1	1	0	93%	
	A_8	1	1	1	1	1	1	1	1	1	1	1	1	1	0	93%	

Source: own study.

Table 10. Evaluation of Cadastral Databases Based on Criterion B.

Diagnostic Criterion	Indicator	Cadastral Database (CD)														Fulfilment of Criterion (Counties)	Fulfilment of Criterion (Voivodeship)
		CD1	CD2	CD3	CD4	CD5	CD6	CD7	CD8	CD9	CD10	CD11	CD12	CD13	CD14		
Cadastral data profile																	
B	B_1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	93%	21%
	B_2	0	0	1	0	1	0	0	0	1	0	0	0	0	0	21%	

Source: own study.

Table 11. Evaluation of Cadastral Databases Based on Criterion C.

Diagnostic Criterion	Indicator	Cadastral Database (CD)														Fulfilment of Criterion (Counties)	Fulfilment of Criterion (Voivodeship)
		CD1	CD2	CD3	CD4	CD5	CD6	CD7	CD8	CD9	CD10	CD11	CD12	CD13	CD14		
WMS network service																	
C	C_1	1	1	1	1	1	0	1	1	1	0	0	1	0	0	64%	57%
	C_2	1	1	1	1	1	0	1	1	0	0	0	1	0	0	57%	
	C_3	1	1	1	1	1	0	1	1	1	0	0	1	0	0	64%	

Source: own study.

Table 12. Evaluation of Cadastral Databases Based on Criterion D.

Diagnostic Criterion	Indicator	Cadastral Database (CD)														Fulfilment of Criterion (Counties)	Fulfilment of Criterion (Voivodeship)
		CD1	CD2	CD3	CD4	CD5	CD6	CD7	CD8	CD9	CD10	CD11	CD12	CD13	CD14		
WFS network service																	
D	D_1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%	0%
	D_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%	
	D_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%	

Source: own study.

Table 13. Evaluation of Cadastral Databases Based on Criterion E.

Diagnostic Criterion	Indicator	Cadastral Database (CD)														Fulfilment of Criterion (Counties)	Fulfilment of Criterion (Voivodeship)
		CD1	CD2	CD3	CD4	CD5	CD6	CD7	CD8	CD9	CD10	CD11	CD12	CD13	CD14		
Sources of data for databases of cadastral parcels and buildings																	
E	E_1	0	1	0	0	1	0	1	0	1	0	0	1	0	0	36%	36%

Source: own study.

Table 14. Evaluation of Cadastral Databases Based on Criterion F.

Diagnostic Criterion	Indicator	Cadastral Database (CD)														Fulfilment of Criterion (Counties)	Fulfilment of Criterion (Voivodeship)
		CD1	CD2	CD3	CD4	CD5	CD6	CD7	CD8	CD9	CD10	CD11	CD12	CD13	CD14		
F	F_1	0	1	1	1	0	0	1	1	0	0	0	1	0	0	43%	36%
	F_2	0	1	0	1	0	0	1	1	0	0	0	1	0	0	36%	
	F_3	0	1	1	1	1	0	1	1	0	0	0	1	0	0	50%	
	F_4	0	1	0	1	0	0	1	1	0	0	0	1	0	0	36%	
	F_5	0	1	0	1	0	0	1	1	0	0	0	1	0	0	36%	
	F_6	0	1	0	1	0	0	1	1	0	0	0	1	0	0	36%	

Source: own study.

Table 15. Evaluation of Cadastral Databases Based on Criterion G.

Diagnostic Criterion	Indicator	Cadastral Database (CD)														Fulfilment of Criterion (Counties)	Fulfilment of Criterion (Voivodeship)
		CD1	CD2	CD3	CD4	CD5	CD6	CD7	CD8	CD9	CD10	CD11	CD12	CD13	CD14		
		Data validity															
G	G_1	0	1	0	1	0	0	1	1	0	0	0	1	0	0	36%	36%

Source: own study.

The criterion denoting compliance with technical and legal indicators (diagnostic criterion A) was met by 13 out of the 14 analyzed cadastral systems in the evaluated area. One cadastral system was not notified to the register of datasets and data services, and it was classified as not fulfilling criterion A.

The spatial data themes (diagnostic criterion B) relating to cadastral parcels and buildings were present in three databases. The remaining 11 databases had an incomplete data profile. One database with a complete data profile contained additional INSPIRE themes such as soil (Annex III, theme 3.3) and addresses (Annex I, theme 1.5).

The WMS (diagnostic criterion C) was evaluated based on the availability of an HTTP address. Nine of the analyzed databases published data via the WMS, and the HTTP address of one database was not available.

The WFS (diagnostic criterion D) was not available in any of the examined cadastral databases. This non-public service can only be accessed by authorized users, but this fact did not influence the evaluation results.

Two sources of cadastral data themes were evaluated (diagnostic criterion E). Only five databases contained cadastral data themes that were acquired from the cadaster.

The technical specifications relating to the publication of cadastral data via the WMS and the WFS were evaluated based on standards [4,5]. The WMS specifications were fully compliant in five databases (diagnostic criterion F). Validity was defined as data compliance with the present status of cadastral objects. This criterion is significantly influenced by time, which induces various changes in cadastral parcels and buildings. Criterion G denoted the date of the last cadastral data update, and it was fulfilled by five databases that publish cadastral data via network services.

A ranking of the examined databases based on the total number of scored points is presented in Figure 5.

The results of the evaluation based on the adopted diagnostic criteria were used to analyze the current status of the SDI, with special emphasis on the WMS and the WFS that publish cadastral data. In the EU, numerous legal, administrative, and technical obstacles had to be overcome in the process of SDI implementation [22,34,40]. The SDI was not complete in any of the examined cadastral databases, but infrastructure completeness was above average in 21% of the analyzed territorial units. An average completeness was noted in 36% of the studied cases, and a below-average completeness was found in one database (7% of the analyzed cases). Infrastructure completeness did not exceed 20% in 36% of the studied objects.

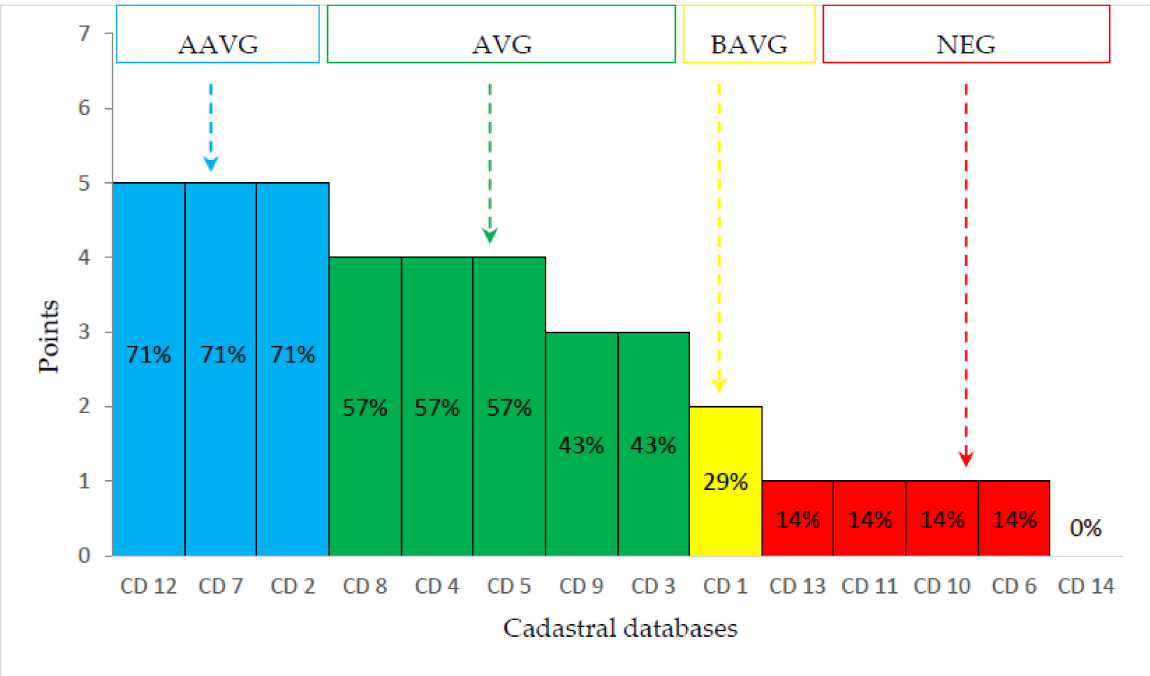

Figure 5. Total number of points scored by local cadastral databases. Source: own study.

4. Discussion

The proposed tool for verifying the completeness of the SDI supports an evaluation of websites that publish cadastral data in seven diagnostic groups to determine whether, or to what extent, this goal has been met (technical and legal indicators; cadastral data profile; the WMS; the WFS; sources of data for spatial data themes indicated in Annex I, theme 6; Annex III, theme 2; data validity; and the standardization of the WMS and the WFS). The adopted criteria support an evaluation of the factors and variables that play a key role in SDI development, and they reflect the strengths of the developed infrastructures.

The described methodology can be used to identify both cadastral web applications with high development potential (36% of the evaluated databases) and problematic services (64% of the examined cases). The analyzed territorial units differed in the level of SDI development. In view of previous studies that investigated the evolution of the SDI based on the availability of network services in Poland [14,29,41] and the EU [8,18,42–44], the evaluated territorial units have made strong and continued progress towards the achievement of a robust SDI.

In the presented evaluation, the main emphasis was placed on legal and technical aspects, the scope of cadastral data, the WMS, the WFS, and the standardization of network services. The fulfilment of seven diagnostic criteria based on the relevant indicator values is presented in Figure 6.

Diagnostic criterion A was the only parameter where the relevant indicator was fulfilled in more than 90% in the analyzed territorial units. This result validates the results of Izdebski [1], who observed that the fundamental sets of cadastral data had not been fully implemented and were not fully operational in Poland despite the fact that the SDI should be developed in line with the roadmap accepted by all EU member states. The above observation also indicates that not all cadastral datasets that are nearly fully compliant with Polish and EU regulations are fully operational. The developed cadastral system is theoretically compatible with EU requirements, but its operability continues to be limited in practice. However, the existing obstacles will most likely be overcome in the near future due either to support from EU funds that promote the implementation of central and local government initiatives in the field of the SDI or the dynamic development and dissemination of technologies for the acquisition, processing, and use of spatial data [28].

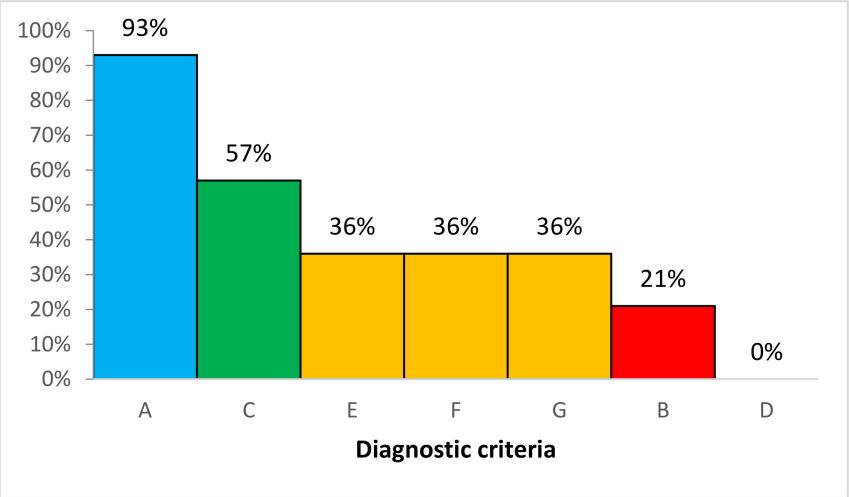

Figure 6. The fulfilment of diagnostic criteria based on the relevant indicator values in the analyzed territorial units. Source: own study.

Cadastral databases and the associated public (WMS) and non-public (WFS) services have been modernized with the support of EU funds. As demonstrated by several researchers, including those of [45], these databases have also been upgraded for compliance with Polish and EU standards. Polish counties have undertaken collaborative measures to develop and implement regional and local spatial databases as elements of the SDI, and these efforts promote problem solving, the sharing of experiences, and the achievement of strategic goals of the INSPIRE Directive.

In line with the provisions of the INSPIRE Directive, websites that publish cadastral data do not only have to be complete (diagnostic criterion B); they should also meet user expectations. Spatial data themes relating to cadastral parcels and buildings play a pivotal role in the SDI. Cadastral parcel identifiers contain information about land ownership, and cadastral parcels are also among the key reference objects for localizing other objects in spatial databases [14,25,46]. Buildings are equally important objects in cadasters, and they are linked with cadastral parcels by virtue of their legal status, attributes, and condition. Building identifiers are always linked to cadastral parcels. According to the roadmap for SDI implementation, datasets of cadastral parcels (Annex I, theme 6) should be implemented before datasets of buildings. The implementation of building data should be completed by the end of October 2020. The results of the presented analysis and previous research findings have indicated that the spatial data theme relating to cadastral parcels has been fully implemented in all datasets notified to the registers of spatial data that are covered by the Polish SDI.

The viewing of WMS data (diagnostic criterion C) and the downloading of WFS data (diagnostic criterion D) were evaluated based on the availability of these network services. The relevant criteria were not met when service addresses had not been notified or were absent. More than 64% of the examined cadastral web applications in Świętokrzyskie Voivodeship notified their data to the NILR service via the WMS. An analysis of the HOGC data archive for 2014 revealed that the relevant result had improved by more than 100% in the last five years. If the current growth trend is maintained, the WMS should be implemented in all of the examined databases in the next five years. The WFS had not been notified to the register of spatial datasets and spatial services by any of the analyzed territorial units that keep cadastral databases, which constitutes a breach of the respective legal provisions [28]. In Poland, the availability of the WFS is generally low. Only 6% of 380 county cadastral databases publish their data via the WFS, which stands in violation of the SDI strategy in the INSPIRE Directive, in particular in the context of obligatory network services. The above could be partly attributed to the misconception that data can be downloaded without transfer fees or authorization. In practice, the operators who publish cadastral data via the WFS monitor the users of data and the purpose for which the published data are used, and they set transfer fees for private users and public administration.

The responsible entities should develop principles for modelling network service processes that are compliant with SDI objectives. A dedicated data management module and mechanisms protecting datasets against unauthorized access and modification should be implemented.

The cadaster is the key component of the SDI in many EU countries [22,47]. The cadaster was not the primary source of cadastral data for the implemented SDI (diagnostic criterion E) in 64% of the analyzed databases. Cadastral parcel identifiers constitute the main reference data for many objects in INSPIRE datasets. However, temporary datasets that rely on other sources, such as the NILR service where data are not regularly updated, can be created in the process of SDI development.

The evaluation of the availability of network services in territorial units that keep cadasters in Świętokrzyskie Voivodeship (diagnostic criterion F) revealed that both the WMS (graphic presentation of cadastral data) and the WFS (search for and identification of cadastral parcels) should be harmonized with ISO standards. Only 36% of the analyzed county nodes published cadastral data via network services that were compliant with the EU standards. The first standardization efforts were undertaken in Poland already in 2007, and they led to the development of guidelines for the graphic presentation of thematic data layers in the WMS. Thematic data layers developed in county cadasters at the time were based on NILR data that were largely invalid, incomplete, and unfit for practical use, which was one of the main obstacles to the effective integration of county network services. Central administration authorities manage nearly 400 county cadastral databases with the involvement of diverse technical and organizational solutions, as well as various data visualization methods, a process that also obstructs the publication of cadastral data via network services. Before 2017, 30% of county cadastral nodes published data via WMSs. The implementation of the NILR service has radically improved the availability of cadastral data via network services [14]. The vast majority of the analyzed county databases that are fully integrated with the NILR publish cadastral data via WMSs that meet the requirements of the INSPIRE Directive and are compliant with ISO standards.

The validity of cadastral data (diagnostic criterion G) was largely determined by the register publishing such data. The above can be attributed to staffing shortages and a lack of adequate financial resources in Świętokrzyskie Voivodeship, which is one of the least economically developed regions in the EU. These problems could be resolved through financial aid from the state budget, support for human resources, the exchange of experiences, effective information flow, and assistance in SDI development.

5. Conclusions

The results of the evaluation of local network services that publish cadastral data at the county level were analyzed and interpreted to determine the progress made in the development of the Polish SDI based on a set of diagnostic criteria compliant with INSPIRE standards. This study demonstrated that the Polish SDI has been designed in line with the EU requirements, but it has not yet achieved full functionality. Considerable progress has been made since the INSPIRE Directive was transposed into Polish law, but the development of the SDI continues to face numerous obstacles. The implementation of the Polish SDI is delayed by the economic disparities between Polish regions and the existence of hundreds of county databases that publish cadastral data via network services such as the WMS and the WFS that are not always fully compliant with EU standards. The strengths and weaknesses of legal, organizational, and technical solutions adopted during the evolution of the Polish SDI were identified in the present study. The results of the evaluation constitute valuable inputs for developing the Polish SDI and network services. These results can also be used to improve the quality of the implemented network services and their availability for end users.

Territorial units, in particular counties, participate in the development of the Polish SDI pursuant to the provisions of the Act on Spatial Data Infrastructure [28]. These units are tasked with harmonizing cadastral data and ensuring the interoperability of datasets and infrastructure services. Therefore, further research is needed to identify the most effective technical solutions and legal instruments for adapting the existing spatial databases to INSPIRE requirements and other challenges of the

modern world. The resulting measures would substantially support and accelerate the development of local SDIs.

The INSPIRE Directive does not cover all spatial data themes that play a very important role in local, regional, and national development. Regional geoportals rely on own guidelines and technical solutions to publish data that are not addressed by INSPIRE themes, which runs counter to the objectives of the INSPIRE Directive. In many cases, data are acquired from reliable state-run databases, but not all of these sources comply with EU requirements. Therefore, the possibility of expanding the thematic scope of European SDIs should be further investigated to guarantee that the adopted solutions promote effective spatial management.

Spatial data infrastructures will be fully compliant with the provisions of the INSPIRE Directive when the responsible entities at every level of governance actively participate in the process of SDI development. Financial support from the state and the EU is also needed to speed up the implementation of INSPIRE solutions in regions where the development of the SDI is delayed due to a lack of tools with the required functionality.

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