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# The Role of Geographic Information Systems in Environmental Management and the Development of Renewable Energy Sources—A Review Approach

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## Abstract

The article examines the role of Geographic Information Systems (GIS) as a tool for environmental management and for the planning and development of renewable energy sources (RES). Based on a review of the literature, it is demonstrated that GIS support key managerial functions, including planning, monitoring, decision-making, and communication, by enabling comprehensive spatial analysis and the integration of environmental data. The study emphasizes the importance of GIS in facilitating a systemic and interdisciplinary approach to environmental governance. The paper examines how GIS can help with environmental management, specifically in locating high-risk areas and strategically placing energy investments. Examining GIS's organizational, technological, and legal facets, it emphasizes how it is increasingly collaborating with cutting-edge decision-support technologies like artificial intelligence (AI), the Internet of Things (IoT), remote sensing, and big data. The analysis emphasizes how GIS help achieve sustainable development's objectives and tasks.

**Keywords:** Geographic Information Systems (GIS); Renewable Energy Sources (RES); spatial planning; management instrument; environmental management

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Academic Editors: Eugenio Meloni, Alberto-Jesus Perea-Moreno, José Carlos Magalhães Pires, Juri Belikov, Iva Ridjan Skov, Giorgio Vilardi and Antonio Zuorro

Received: 6 August 2025
Revised: 27 August 2025
Accepted: 3 September 2025
Published: 5 September 2025

**Citation:** Kochanek, A.; Generowicz, A.; Zacłona, T. The Role of Geographic Information Systems in Environmental Management and the Development of Renewable Energy Sources—A Review Approach. *Energies* **2025**, *18*, 4740. https://doi.org/10.3390/en18174740

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## 1. Introduction

In the face of escalating challenges related to climate change, environmental degradation, and the imperative to implement the principles of sustainable development, the importance of effective environmental management is growing across various levels of decision-making. Addressing these challenges requires the application of diverse and mutually reinforcing instruments, as many environmental problems are inherently complex and multidimensional [1]. The management perspective is frequently overlooked in the current academic discourse on sustainable development, renewable energy, and the circular economy, which focuses mostly on technological, environmental, political, regulatory, and economic aspects. [2]. Moreover, research in management and organization studies has for a long time evolved independently of sustainability concerns [3,4]. This underscores the need to deepen the reflection on environmental issues specifically from the standpoint of management sciences, taking into account the variety of management instruments and their integration.

Geographic information systems (GIS) deserve special attention as effective tools for spatial analysis, risk monitoring and investment planning. In the face of complex environmental challenges, the integration of GIS with other environmental management methods is becoming not only beneficial, but essential [5,6]. This, however, requires not only a discussion of the theoretical and technological aspects of GIS, but also their coherent integration with environmental management within the broader perspective of management sciences. It therefore becomes necessary to precisely position and classify GIS within management theory and to identify the functions that can be effectively implemented with its involvement.

Based on a review of the scientific literature, this article examines the role of GIS in environmental management and the development of renewable energy sources (RES). The review brings new knowledge by showing the links between GIS and management functions, compiling GIS applications for locating RES into four technologies, and developing a regulatory matrix that puts these applications into context. Based on a review of the scientific literature, this article examines the role of GIS in environmental management and the development of renewable energy sources (RES). The review brings new knowledge by showing the links between GIS and management functions, compiling GIS applications for locating RES into four technologies, and developing a regulatory matrix that puts these applications into context. At the same time, it makes it possible to trace the evolution of environmental management concepts and to capture the ways in which they have been defined and interpreted in the literature. This provides a framework for understanding this dynamically developing field of management and for identifying the place of renewable energy within it. The literature review also allows for a synthetic account of the evolution of geographic information systems, whose definitions and applications have gradually expanded. It further enables the identification and systematization of the main functions of contemporary GIS, their precise positioning within the structure of management sciences, and the managerial functions that can be effectively carried out with their involvement. Moreover, the review highlights the current state of knowledge on the use of GIS in the development and siting of renewable energy sources, including wind farms, solar farms, biogas plants, and hydropower facilities, as well as the regulatory frameworks governing the application of Geographic Information Systems. Such a review provides not only a foundation but also a necessary condition for further scientific inquiry, enabling the systematization of existing knowledge, the identification of research gaps requiring in-depth analysis, and the development of empirical studies that advance understanding of the role of GIS in the energy transition.

## 2. Environmental Management and the Development of Renewable Energy Sources

Environmental Management (EM) has emerged as a subdiscipline within the management sciences, developed in response to the mainstream neglect of the environmental impacts of business and organizational activities [7]. EM is the term used to describe a systematic series of activities that societies, different groups, or organizations take to preserve or enhance the quality of the environment. It entails creating plans, identifying environmental harm-causing factors, evaluating damage, putting control measures in place, and regularly reviewing these efforts [8]. Environmental management is also understood as an operational concept in which decision-makers deliberately and systematically seek to understand how their actions affect the environment and how environmental considerations can influence their decisions [8].

Enterprise environmental management entails coordinated efforts to lessen operations' detrimental effects on the environment. It involves monitoring environmental conditions,

creating and implementing solutions in accordance with legal requirements, and carrying out internal training and communication. Collaboration between different organizational departments and the fusion of environmental objectives with more general business priorities are necessary for effective implementation of EM. The resources allocated to EM determine how effective it is, and its effects on a business's operational performance can differ greatly [9]. Seifert et al. distinguish five basic elements of environmental management in an organization: policies, objectives, processes, organizational structure and monitoring systems. Their coordinated application is expected to improve environmental performance in areas such as raw material, energy and water consumption, waste management, air emissions and wastewater discharge, with the goal of improving an organization's overall environmental performance [10].

Environmental management (EM) is now a well-established and widely implemented concept with an increasingly strong presence in mainstream management. Its importance is growing in both public policy and organizational operations, as a result of the recognition of environmental issues as an integral part of socioeconomic policy [11]. The growing significance of environmental management at the organizational level is closely linked to the growing importance of corporate governance practices (ESG), social responsibility, and environmental protection, all of which are now essential elements of modern business management. This trend is driven by increasing pressures related to CSR as well as by the influence of ESG (Environmental, Social, and Governance) practices on corporate financial performance (CFP) [12]. The growing practical relevance of environmental management is reflected in the rising number of ISO 14001 certifications [13]. The International Organization for Standardization (ISO) reports that over 500,000 organizations in more than 180 countries have earned certification under this standard. This demonstrates unequivocally that environmental management is now a commonly accepted global practice rather than a specialized managerial approach [14].

Companies may choose to implement environmental management internally as part of their own strategy or externally in response to external factors like international environmental commitments, market pressure, social expectations, or legal requirements [15]. It involves diverse activities, responsibilities, systems, and tools that support environmental protection and sustainable development within the organization [16]. Examples of such actions include:

- activities that impact the environment (e.g., emissions, energy consumption, waste generation) [17], as well as systematic evaluation of compliance with legal requirements and the organization's environmental policy;
- definition of measurable environmental objectives along with related programs and tasks for their implementation [17–19];
- implementation of an Environmental Management System (EMS) that includes planning, responsibilities, practices, procedures, processes, and resources aligned with the environmental policy [16];
- ongoing monitoring and measurement of environmental impact, such as tracking emissions, resource use, and noise levels [20];
- response to emergency situations, including the preparation of contingency plans for incidents that may have a negative environmental impact [21];
- environmental reporting, for example, through sustainability or CSR/ESG reports, disclosing the organization's environmental performance [22];
- training and employee awareness, aimed at increasing knowledge and engagement in environmentally responsible practices [23];
- internal and external communication, involving the dissemination of information regarding environmental policies, actions, and performance to stakeholders [24];

– continuous improvement, for example, through application of the "plan–do–check–act" (PDCA) cycle [16].

More broadly, environmental governance encompasses national strategies, public policies, actions by international institutions, legal regulations, and local agreements and initiatives [25]. As Mohamed et al. note, decarbonization has become a priority for global environmental management, and the development of renewable energy is one of the key strategies [26]. In the scientific literature, $CO_2$ emissions reduction and renewable energy development are considered essential tools for long-term, sustainable environmental management [26–28].

The development of renewable energy sources (RES) plays an important role in environmental protection by reducing air pollution and improving air quality [27,29]. Compared to traditional energy sources, RES have significantly lower environmental impacts, help reduce greenhouse gas emissions and slow down the degradation of ecosystems [30]. Furthermore, the development of RES enhances energy security by diversifying energy supply sources and decreasing dependency on fossil fuels [31–33]. Additionally, the development of green jobs and the promotion of technological innovation in the energy sector are greatly aided by renewable energy [34]. Its application can aid in the development of local communities [35], lessen energy poverty [36], and aid in the building of low-emission, resilient energy systems that support long-term economic growth and climate stability [37].

As shown in Figure 1, contemporary environmental management is based on a series of interrelated areas of action—ranging from the identification of environmental aspects to setting objectives, responding to emergencies, monitoring, implementing EMS, reporting, education and communication, and continuous improvement.

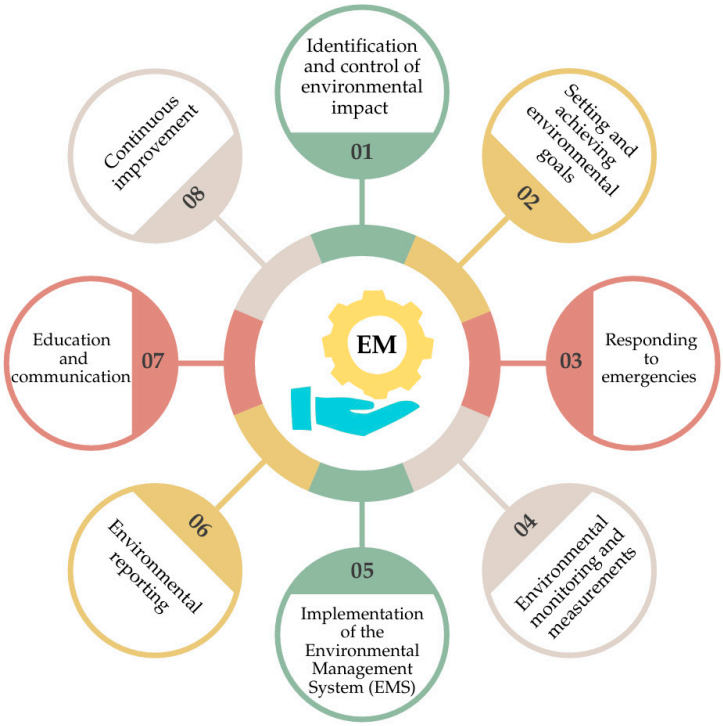


**Figure 1.** Basic components of environmental management [16–24].

In practice, this means that organizations not only ensure compliance with regulations, but also systematically learn to understand their impact on the environment and seek ways to mitigate the negative effects of their activities. Over the years, the concept of environmental management has expanded beyond a narrow set of technical tools and has become an integral part of business strategies, closely linked to CSR and ESG, as confirmed

by the widespread certification of ISO 14001. At the same time, environmental management has acquired a global dimension, as public policies increasingly emphasize decarbonization and the development of renewable energy sources as a means to improve air quality, reduce greenhouse gas emissions, and build resilient, low-carbon economies.

## 3. Theoretical and Technological Foundations of Geographic Information Systems

### *3.1. Definition and Functions of Geographic Information Systems*

GIS constitute a cohesive framework of instruments, data, technology, and personnel that facilitate location-based decision-making. They enable the collection, storage, analysis, transformation, and presentation of geographically referenced data. Over the decades, their definition has broadened to encompass a diverse range of activities and applications (Figure 2).

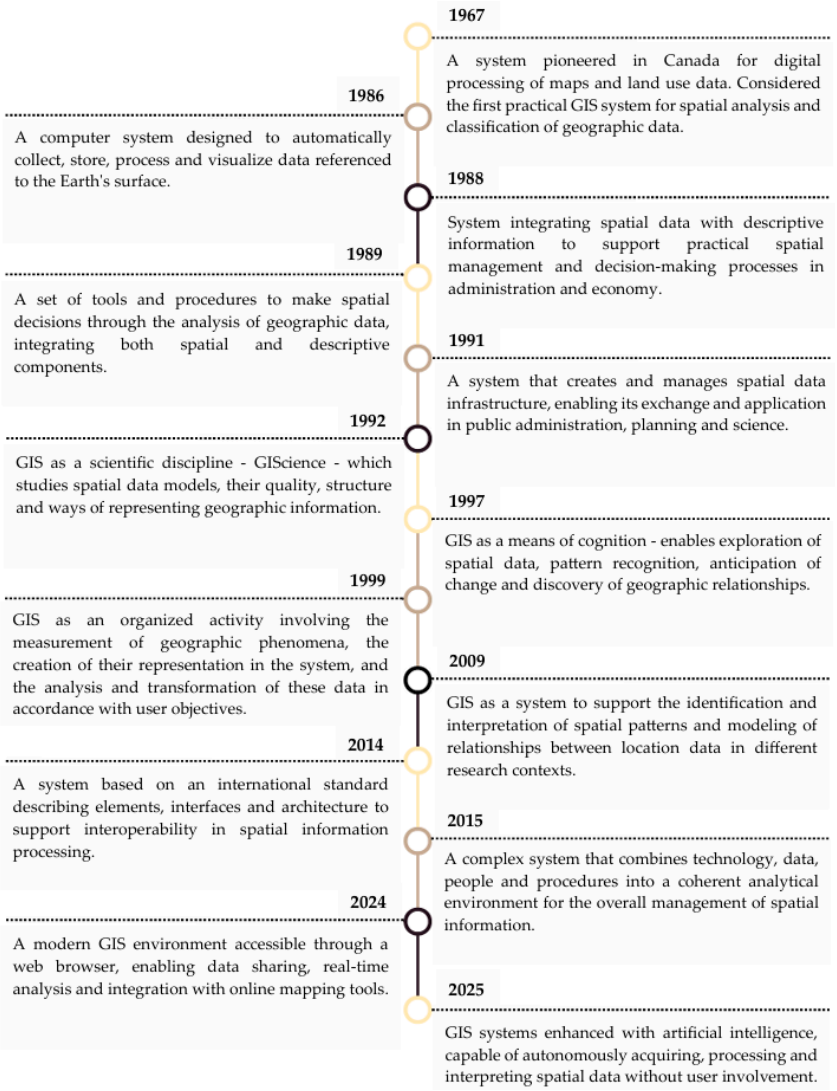


**Figure 2.** The Evolution of Definitions and Functions of Geographic Information Systems, 1967–2025 [38–52].

Modern GIS offer a wide range of advanced functions that support comprehensive spatial data management, analysis, visualization, and integration with emerging technologies. Table 1 presents the main functional areas of contemporary GIS along with their characteristics.

**Table 1.** Key Functionalities of Modern Geographic Information Systems.

| Functional Area | Description | Refs. |
| --- | --- | --- |
| Data Acquisition and Integration | Consolidation of data from Internet of Things (IoT) sensors, satellite photography, Laser Imaging Detection and Ranging (LiDAR), drones, Volunteered Geographic Information (VGI), and real-time data streams. | [53,54] |
| Spatial Data Management | Handling of distributed, dynamic, and heterogeneous datasets; cataloging, validation, versioning, archiving, metadata standards, and source synchronization. | [55] |
| Spatial Analysis | Classical and advanced spatial analyses: accessibility, natural hazards, ecosystem services, environmental assessments, and predictive models. | [56] |
| Modeling and Simulation | Land use change scenarios, hazard simulations (e.g., floods), disease spread, climate phenomena; includes agent-based and hybrid models. | [57] |
| Visualization and Data Communication | Dynamic 2D/3D maps, spatiotemporal visualizations, dashboards, and urban digital twins facilitate participatory planning and public involvement. | [58] |
| Collaboration and Data Sharing | Collaboration across sectors, data exchange through APIs, GeoNode platforms, WMS/WFS standards, and Spatial Data Infrastructure (SDI). | [59] |
| Artificial Intelligence (AI) Integration and Automation | Use of AI, deep learning, object detection, semantic segmentation; development of self-learning systems based on spatial data. | [60] |
| Monitoring and Spatial Alerts | Environmental monitoring, crisis management, location-based early warning systems, anomaly detection and automated alerts via cloud processing. | [61] |
| Mobile Integration | Collection of field data, mapping applications, geolocation instruments, and the application of augmented reality (AR) on mobile devices. | [62] |
| Multi-Criteria Decision Analysis (MCDA) | Support for urban, environmental, and infrastructure-related decision-making using Multi-Criteria Decision Analysis methods and sustainability indicators. | [63] |

### *3.2. Core Components of GIS Technology*

Data constitutes the foundation of a Geographic Information System, providing information about the spatial location of objects. It is available in vector format (points, lines, and polygons), raster format (such as satellite imagery and elevation data), as well as in three-dimensional forms like LiDAR point clouds. Attribute data, which describes the characteristics of objects, complements these spatial datasets and enables semantic and statistical analysis [64].

Satellite systems (Sentinel, Landsat), data from unmanned aerial vehicles, IoT sensors, topographic maps, public registries, crowdsourced data (VGI), and the INSPIRE and Copernicus frameworks are all modern sources of GIS data [65]. Spatiotemporal data are becoming more and more important, especially for watching how the environment changes [66].

The standardization of spatial data, encompassing adherence to ISO 19115 [67], INSPIRE, and the Open Geospatial Consortium (OGC), influences the quality of analysis, interoperability, and reusability of geoinformation resources [68,69].

GIS software facilitates the loading, processing, analysis, and visualization of data. Presently, two primary methodologies prevail: desktop applications (e.g., ArcGIS Pro 3.5,

QGIS 3.44.1-Solothurn) and web-based platforms (e.g., Google Earth Engine, WebGIS, MapLibre). Contemporary applications employ 3D rendering engines, facilitate interactive dashboards, and incorporate scripting languages including Python 3.11.13, R 4.4.1, and JavaScript ES2023 [70,71].

From an infrastructural standpoint, GIS depend on cloud-based and hybrid settings (AWS, Azure, GEE), facilitating resource scalability and extensive data processing. Hardware components comprise workstations, servers, GNSS devices, drones, and remote sensing sensors [72]. Elevated computing performance and parallel processing (GPU/Cloud HPC) facilitate real-time analyses and spatial simulations [73].

GIS are socio-technical systems that function through the interaction between technology and users. Users generate, alter, examine, and elucidate spatial data across many contexts: administrative, environmental, urban, infrastructural, and educational [74].

User classifications encompass data operators (such as surveyors and GIS technicians), spatial analysts, urban planners, scientists, and citizens engaged in participatory processes (PGIS). User roles are contingent upon system access levels, competences, and analytical objectives [75–77].

GIS processes encompass defined actions, including geodatabase generation, quality control, analytical workflows, data audits, MCDA techniques, and metadata documentation. Process-based modeling, which incorporates automation and artificial intelligence algorithms, is gaining prevalence.

### *3.3. Key Spatial Analysis Methods Include Multi-Criteria Analysis, Modeling, and Geostatistics*

MCDA is a set of methods that help people make decisions by looking at a number of criteria that may not agree with each other. It is widely used in GIS for spatial planning, site selection, risk assessment, and environmental conflict analysis [78]. Modern methods combine MCDA with spatial analyses using tools like AHP (Analytic Hierarchy Process), fuzzy logic, TOPSIS, ELECTRE, and raster-based methods. Recent changes also include combining MCDA with spatiotemporal simulations and participatory processes [79]. Open-source tools and web platforms make MCDA-based decision-making even more open and encourage people to get involved [80].

Modeling in GIS enables the representation, simulation, and prediction of geographic phenomena. It includes deterministic, probabilistic, agent-based, cellular automata, land change, hybrid, and urban simulation models [81]. People use these models to predict changes in land use, urban growth, flood risk, population movement, and the distribution of public services. More and more, models use real-time data and predictive interfaces [82]. They are based on ideas from complex systems, policy and economic scenarios, and data from sensors and crowdsourcing [83].

Geostatistics provides statistical tools for analyzing spatial phenomena while accounting for spatial autocorrelation. Some of the most important methods are interpolation (like Kriging and IDW), variogram analysis, spatial regression, uncertainty modeling, and hypothesis testing [84]. Bayesian geostatistics, spatial autoregressive models (SAR), point pattern and network models, and multiscale techniques used in environmental and epidemiological research are some of the modern methods used [85]. People use geostatistical tools in GIS a lot for making maps that predict the future, keeping an eye on the environment, studying pollution, managing natural resources, and studying public health [86].

### *3.4. Integration of GIS with Modern Technologies*

Geographic Information Systems can work with a lot of different technologies, which makes them much more useful for spatial analysis. Remote sensing obtains raster data

from satellites, planes, and unmanned aerial vehicles (UAVs). These data are widely used for environmental monitoring, mapping land use, finding changes, and classifying land cover. GIS make it easier to process, classify, calibrate, and combine these data with other spatial layers [87].

Modern analytical methods apply advanced GIS techniques in combination with multispectral, hyperspectral, and synthetic aperture radar (SAR) data. This integration enables automated change detection, environmental modeling, and crop monitoring [88].

The Internet of Things (IoT) enables the collection of data from thousands of sensors deployed in natural environments, urban areas, and vehicles. Integrating IoT data with GIS allows for real-time data analysis, spatial modeling, and support for operational decision-making [89]. Combined GIS-IoT systems contribute to traffic management, environmental monitoring, emergency response, and the development of intelligent transportation systems (ITS) [90].

In the context of Big Data, GIS process vast volumes of spatial information originating from social networks, sensors, mobile devices, and satellite archives. Efficient handling of such data requires distributed analytics platforms, cloud-based solutions, and optimized data structures [91]. Applications include mobility analysis, monitoring of extreme events, consumer behavior studies, public health analysis, and the mapping of predicted spatial trends [92].

Combining GIS with Building Information Modeling (BIM) and Computer-Aided Design (CAD) systems is becoming more and more important. This makes it possible to fully manage space in 2D, 3D, and 4D, which helps with infrastructure management, urban planning, and spatial design [93]. GIS-BIM integration also makes it possible to make digital twins of cities and run simulations of how investments will affect the environment [94].

AI is becoming more and more important in GIS. Machine learning methods and deep neural networks (like CNNs and LSTMs) are used for things like classifying images, finding objects, making predictions, and improving transportation networks [95]. AI helps with automating spatial analysis, finding anomalies, providing personalized location-based services, and improving the accuracy of classification [96].

High-performance computing (HPC), parallel processing, and cloud-based services (like SaaS and PaaS models) are some of the ways that modern computational platforms can handle large amounts of geospatial data [97]. Some well-known examples are Google Earth Engine, Amazon AWS Lambda, and Microsoft Azure, which all make it easy to work with large spatial datasets by making sure they can be scaled and accessed easily [98].

In order to provide an in-depth analysis of the practical aspects of integrating GIS, artificial intelligence, and the Internet of Things, this article presents empirical examples of their applications. These examples are presented in Table 2.

**Table 2.** Empirical Examples of GIS–AI–IoT Integration.

| Application Area | Description & Benefits | GIS–AI–IoT Integration | Refs. |
| --- | --- | --- | --- |
| Smart city—waste management | Greater Chennai (India) deployed a ‘smart waste’ system that improved collection efficiency and reduced costs through real-time monitoring. | IoT (bin sensors) + AI (overflow prediction, route optimization) + GIS (central monitoring dashboard) | [99] |
| Smart city—public cleanliness | Madurai (India) implemented AI-based monitoring of overflowing bins and illegal dumping, which accelerated response times of sanitation services. | IoT (cameras, sensors) + AI (image recognition, overflow detection) + GIS (map-based alerts and dispatch) | [100] |

**Table 2.** *Cont.*

| Application Area | Description & Benefits | GIS–AI–IoT Integration | Refs. |
| --- | --- | --- | --- |
| Smart city—mobility | Google's Project Green Light reduced congestion, emissions, and fuel use by optimizing traffic signals in pilot cities. | IoT (traffic flow sensors) + AI (signal optimization) + GIS (integration with mapping data) | [101] |
| Crisis response—wildfires | In Serbia's Golija Park, an integrated system improved fire risk forecasts and optimized firefighting operations. | IoT (environmental sensors) + AI (risk analysis) + GIS (hazard mapping) | [102] |
| Crisis response—urban DSS | Pimpri-Chinchwad (India) introduced a 72 h DSS that supports decision-makers in managing multi-hazard risks. | IoT (weather/air quality stations) + AI (forecasting) + GIS (map-based decision support system) | [103] |
| Environmental monitoring—air (global framework) | The AQ Framework delivers real-time air quality forecasts, supporting public health risk assessment. | IoT (fixed and mobile sensors) + AI (AQI forecasting) + GIS (health risk mapping) | [104] |
| Environmental monitoring—air (urban) | Chicago's Project Eclipse enabled hyper-local mapping of air quality, revealing neighborhood-level disparities. | IoT (air quality sensors) + AI (ML with GSV data) + GIS (neighborhood maps) | [105] |
| Environmental monitoring—water | In Southern England, a system provides 30 min forecasts of bathing water quality for users and authorities. | IoT (water quality sensors) + AI (bacteria prediction) + GIS (public maps/app) | [106] |

## 4. Geographic Information Systems as a Management Instrument

In order to identify the role of Geographic Information Systems in environmental management and in the development of renewable energy sources, it is first necessary to determine how GIS can be classified within the framework of management theory and what functions it performs from a managerial perspective. As per management theory, GIS can be considered management instruments that facilitate various tasks related to sustainable development, including planning [107], monitoring [108], and optimizing [109]. The definition of management instruments from the standpoint of management sciences and the requirements they must fulfill to be accepted as such must be established in order to support this assertion.

The terms "management tools" and "management instruments" are frequently used interchangeably in the management literature [110,111]. However, this perspective is not universally accepted among scholars, some of whom argue that instruments should not be regarded as synonymous with tools. In this view, management tools are understood as specific technical or informational solutions used by managers as operational means to support the execution of managerial tasks [112]. These include, among others, operational reports, schedules, performance indicators, management accounting tools, and other systems that support planning, control, and decision-making. They all share a design that is focused on functionality and practical usability in order to accomplish organizational goals [112].

Aggeri and Labatut contend that management instruments are more complex than simple tools because they combine a conceptual dimension with a material component. They are the result of scholarly analysis that takes particular usage doctrines and action models into account. Furthermore, these instruments have an explicit or implicit component that shows up in organizational procedures and affects the actual way management is carried out [112].

A third perspective on how these two concepts relate to one another presupposes a hierarchical framework where tools are integrated and serve as parts of the larger category of instruments [113]. It is important to note that the type of activities that management instruments are involved in [112], specifically the execution of managerial functions [114], are what set them apart from other types of instruments, not their form or technical characteristics. This suggests that, as with GIS, a solution that was not initially intended for the managerial domain may become a management tool once it is integrated into the execution of managerial tasks [112].

Adopting a slightly different definitional perspective, management instruments may be understood as mechanisms that support the implementation of concepts and ideas by facilitating organizational processes that perform functions such as planning, organizing, leading, coordinating, controlling, staffing, budgeting, and reporting [115]. According to the definition put forth by Wereda and Zacłona [113], management instruments are defined in this article as organizational systems, modes of thinking and acting, methods, processes, tools, and techniques that facilitate the execution of managerial functions, as well as a variety of activities that help achieve organizational goals or ad-dress particular issues in both theoretical and practical dimensions.

In light of the above, it is reasonable to pose the question of which managerial functions are supported by Geographic Information Systems and to what extent these instruments can be utilized in managerial processes. A review of the scientific literature suggests that GIS may fulfill or support various management functions, including planning, decision-making, organizing, coordinating, and controlling. However, the scope and significance of GIS applications vary depending on the specific managerial function under consideration.

One of the key areas in which Geographic Information Systems find particular application is planning. This managerial function can be effectively supported through the use of these systems. GIS make it easier to objectivize and optimize planning tasks, particularly when dealing with environmental contexts [116,117]. Combining GIS with Multi-Criteria Decision Analysis allows the evaluation of alternative investment scenarios in addition to determining whether a particular area is suitable for particular actions related to environmental management or the development of renewable energy sources (RES). By enabling the comparison of planning options using uniformly defined criteria, this enables the proper distribution of spatial functions [118].

Additionally, GIS facilitate the creation of spatial plans that take into account environmental factors like noise levels [119], air quality [120], flood risk [121,122], and nature conservation [112]. This helps to make more sustainable and informed spatial decisions [122]. GIS are crucial management tools that support more efficient decision-making in the field of Environmental Management (EM), which seeks to reduce the adverse effects of human activity on the environment by facilitating spatial analysis and the integration of environmental data [123].

Additionally, it should be mentioned that GIS were initially created as tools for geographical research with the goal of assisting with spatial decision-making [124]. Because they directly affect land use and resource distribution, environmental management and the development of renewable energy sources are processes that are intrinsically linked to the requirement to make spatial decisions [125]. Owing to its ability to integrate various types of spatial data, such as terrain morphology, the availability of natural resources, and protected areas, among others, GIS facilitate comprehensive and well-justified decisions regarding the siting of renewable energy sources [126,127].

In addition to preventing spatial conflicts and lessening adverse effects on the environment, this enables the selection of the most effective and sustainable sites for environ-mental investments [128,129].

Monitoring and continuous control are additional tasks carried out by GIS.

Better identification and analysis of some risk types is made possible by Geographic Information Systems, which allow for efficient monitoring and evaluation of the current conditions in the area where particular activities are being conducted [123]. GIS facilitate real-time tracking of environmental changes, including changes in land cover, deforestation, urbanization, and pollution of the air, water, and soil, because of their capacity to integrate, process, and visualize environmental data in spatial terms [123,130,131].

The foundation for evaluating environmental conditions and identifying regions in need of intervention or special protection is provided by data gathered and analyzed using GIS within the framework of Environmental Management (EM) [132]. Additionally, this makes it possible to pinpoint the sources of environmental hazards and predict how they might affect nearby regions [133]. A crucial component of environmental risk management is the use of GIS to identify and evaluate areas at risk of, among other things, flooding [134], wildfires [135], or landslides [136]. Systems for environmental or crisis management then use these data to create plans for responses and strategies for reducing risks [137]. Thus, combining GIS and EM allows for better environmental threat preparedness and lessens the adverse effects of those threats.

Moreover, the implementation and visualization of GIS data within management processes significantly enhances communication and improves its effectiveness by eliminating informational and terminological barriers between various types of stakeholders. This enables the creation of a shared visual language that facilitates better understanding of the situation, clearer identification of priorities, and faster, more accurate decision-making [138].

As a result, it becomes possible to foster constructive dialogue among representatives of public administration, emergency services, technical experts, and local communities, leading to more coherent and coordinated actions in both crisis management and spatial planning processes [139–141].

In conclusion, Geographic Information Systems represent an important instrument that supports environmental management and the planning of renewable energy development. Their application enables comprehensive spatial analysis and strengthens strategic decision-making. However, fully unlocking the potential of GIS requires their integration with other analytical methods, management instruments, and conceptual approaches, which in turn allows for more effective implementation of sustainable development goals [142].

Geographic Information Systems are increasingly perceived not only as tools for spatial analysis, but also as fully fledged management instruments. Their value lies in the ability to integrate the technical and conceptual dimensions, supporting managers in performing the core management functions presented in Figure 3.

In practice, this means that GIS support planning processes by creating objective investment scenarios, facilitate decision-making through the integration of spatial data, help organize and coordinate activities to minimize spatial conflicts, strengthen control and monitoring of environmental changes, and improve communication among stakeholders through a shared visual language.

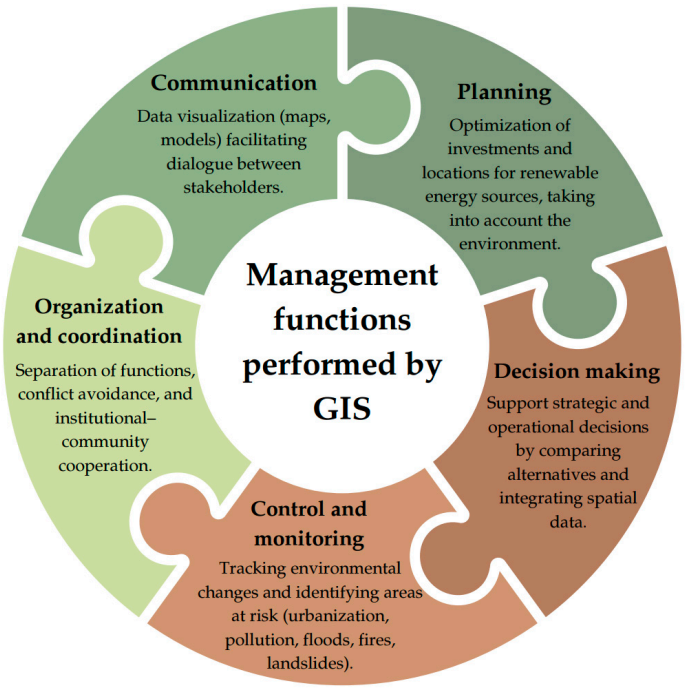


**Figure 3.** A GIS as a management instrument and implementing core management functions [123,124].

## 5. GIS in the Development and Siting of Renewable Energy Sources (RES)

Geographic Information Systems are essential for the planning, optimization, and assessment of renewable energy investments. GIS facilitate decision-making throughout all phases of renewable energy source project development by enabling the integration and analysis of various spatial data, including topography, land use, meteorological conditions, environmental constraints, and existing infrastructure. Figure 4 demonstrates that GIS are utilized in three primary domains: site selection, energy potential evaluation, and resource analysis. These functions improve project efficiency, reduce environmental impact, and promote the sustainable advancement of the energy industry.

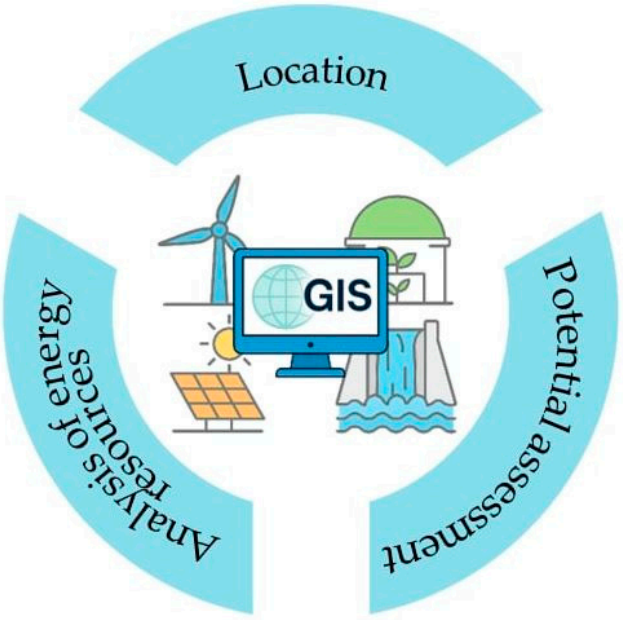


**Figure 4.** Main GIS applications in renewable energy: siting, resource analysis, and potential assessment.

### 5.1. GIS Applications in the Siting, Resource Analysis, and Potential Assessment of Wind Farms

#### 5.1.1. Wind Farm Siting

GIS facilitate the spatial integration of various datasets, including topography, land cover, transmission networks, roads, environmental constraints, and protection zones. Utilizing this information, suitability maps are created to pinpoint regions most conducive to wind turbine installation [143].

The prevalent methodology employed in practice entails the integration of multi-criteria decision analysis methods with geographic information systems. These methods facilitate the incorporation of both quantitative variables (e.g., proximity to power lines) and qualitative considerations (e.g., landscape impact). The models frequently utilize methodologies such as AHP, fuzzy logic, and TOPSIS, which facilitate the prioritization of criteria and the evaluation of alternative siting scenarios [144].

In Poland, GIS-MCDA methodologies integrate spatial data with expert assessment, facilitating the accurate identification of sites that satisfy environmental and technical criteria [145]. This method also enables the efficient exclusion of conflict-prone regions, including urban areas, protected zones, river valleys, or airport districts [146].

#### 5.1.2. Energy Resource Analysis

Geographic Information Systems are essential for evaluating wind conditions, a critical factor in assessing the economic feasibility of wind energy initiatives. Spatial meteorological data, including wind speed and direction, are acquired through satellite imagery, terrestrial measurements, and numerical atmospheric modeling. GIS facilitate the interpolation of data and the generation of energy resource maps at both local and regional levels [147].

When factors such as digital elevation models (DEMs), slope, aspect, surface roughness, and orographic shadowing are taken into account, airflows can be modeled more accurately, allowing for the identification of areas with the highest wind intensity. GIS-based models also incorporate information on temperature, humidity, and turbulence, which can influence turbine performance [148].

Location analyses may also look at the possibility of combining wind and solar power into hybrid energy systems. In these situations, GIS help with figuring out how well resources work together, how production changes with the seasons, and how spatial synergies might work [149].

#### 5.1.3. Wind Farm Potential Assessment

GIS help with a comprehensive assessment of an area's energy and investment potential, in addition to choosing a site and making sure there are enough resources. This includes evaluating system performance, estimating expected energy output, assessing infrastructure costs, determining project feasibility, and analyzing environmental impacts. Life cycle assessment (LCA) is being added to these models more and more. This lets us look at the emissions and total life-cycle costs of wind energy investments [150].

GIS make it easier to plan cable routes and figure out how much it will cost to connect to the grid in offshore wind projects. Least-cost path algorithms take into account bathymetric data, seabed features, ocean currents, protection zones, and existing infrastructure. This makes it possible to find the best energy transmission corridors [151,152].

The visual impact assessment is just as important. It is performed in GIS using viewshed analysis. It is possible to find out how far away turbines can be seen from certain viewpoints and residential areas by using digital elevation models and land cover data [153,154].

Advanced GIS tools also enable the execution of time-based investment simulations, phase analyses, and long-term assessments of social and spatial effects. The resulting

decision maps can serve as a foundation for public consultations and as strategic tools to support decision-making by local governments and investors [155,156].

### *5.2. GIS Applications in the Siting, Resource Analysis, and Potential Assessment of Solar Farms*

#### 5.2.1. Solar Farm Siting

Numerous spatial factors influence the best places to locate photovoltaic (PV) farms. Numerous factors, including solar exposure, land slope, land cover type, accessibility to power and road infrastructure, proximity to protected areas, and urban planning constraints, can be analyzed with GIS [157–159]. In order to support spatially informed decision processes, these analyses frequently use integrated decision-making models based on techniques like fuzzy logic, AHP, TOPSIS, or MIF [160–162].

Even in urbanized or mountainous areas, hybrid GIS-machine learning (GIS-ML) models enable the accurate identification of the optimal locations for PV installations [155,163–165]. Specialized applications, such as systems connected to railroads, aquaculture, or mobile urban infrastructure, may also be covered by sizing analyses [166–168].

Rooftop surfaces that can be modified for PV deployment in urban areas are evaluated using LiDAR data and 3D GIS tools [169–171].

#### 5.2.2. Energy Resource Analysis

GIS enable the creation of detailed models estimating the amount of solar radiation received by a specific area, based on its geographic location, orientation, and shading conditions. Models such as r.sun, PVGIS, and Solar Analyst are used to process satellite and meteorological data for this purpose [172–174].

An accurate estimate of energy output requires consideration of seasonal variations, topography, and local weather conditions [175–177]. GIS help find microclimatic niches with high photovoltaic potential in places with a lot of different types of terrain, like Nepal, Bangladesh, or Morocco [178–180].

Agrovoltaic and aquavoltaic systems need a lot of research on the site because of competition for land use and water resources [181,182]. GIS models also include information about shading, dust buildup, humidity, and solar reflectance, which helps make predictions about how well a PV system will work more accurate [183,184].

#### 5.2.3. Solar Farm Potential Assessment

GIS are very important for analyzing energy potential because they can model how much energy will be produced based on PV technology, the direction the installation faces, and the local environment [185–187]. GIS-MCDA models and techno-economic simulations can be used to assess investment profitability and estimate payback periods [188–190].

It takes a lot of work to model space and energy to combine PV with industrial, agricultural, and water infrastructure, as well as with making green hydrogen [191–193]. GIS can be used to evaluate planned PV projects in terms of their technical, environmental, and social impact [194–196].

Dynamic online GIS platforms enable real-time data analysis and the development of tools that support investment decision-making [197–199].

### *5.3. GIS Applications in the Siting, Resource Analysis, and Potential Assessment of Biogas Plants*

#### 5.3.1. Siting of Biogas Plants

Selecting suitable locations for biogas plants requires consideration of various spatial factors, including substrate availability, proximity to infrastructure such as roads and power grids, legal constraints, and social conditions. GIS enable the integration of these factors into multi-criteria decision models such as the Analytic Hierarchy Process (AHP) or the

Best-Worst Method, facilitating the objective identification of sites that are optimal from both economic and environmental perspectives [200–202].

GIS models also support the exclusion of unsuitable sites, such as those located too far from biomass sources or within protected areas. By considering the spatial structure of agricultural and livestock production, it is possible to identify locations that improve the efficiency of substrate logistics [203,204].

GIS also help create lists of existing and planned installations, which helps keep biogas facilities from clustering too much in one area [205]. Using GIS to choose where to put biogas plants in Poland takes into account a lot of complicated social and environmental factors and helps to follow the principles of sustainable development [206].

#### 5.3.2. Energy Resource Analysis

It is crucial to look at the biomass resources that are available while planning biogas facilities. GIS help create geographic databases that maintain track of the types and amounts of substrates, such as sewage sludge, slurry, and agricultural waste. These datasets can be integrated with statistical data, satellite imagery, and crop growth models [207–209].

Taking into account the seasonality of biomass production supports the modeling of substrate supply fluctuations and the development of storage solutions. Spatial models facilitate the assessment of collection logistics and the identification of local production clusters, which is crucial for enhancing the project's energy efficiency [210,211].

The use of GIS enables the integration of non-traditional biomass sources, including fruit and vegetable waste [212] and prickly pear cactus [213]. The combination of GIS tools and supply chain analysis allows for a comprehensive evaluation of substrate availability at both local and regional levels.

#### 5.3.3. Production and Investment Potential Assessment

Theoretical, technical, and financial estimates of biogas production potential are supported by GIS. This covers factors like substrate density, co-digestion potential, fermentation efficiency, and technology expenses [214].

GIS enable scenario modeling of plant development, profitability evaluations, and environmental impact assessments when combined with multi-criteria decision analysis. The feasibility of injecting biomethane into gas grids, water consumption, and greenhouse gas (GHG) emissions are given special consideration [215].

GIS models make it possible to optimize siting in the context of urbanization and industrialization by taking into account local energy demand, urban constraints, and the possibility of integrating with other systems like hydrogen and power-to-gas (P2G) [216,217].

GIS make it easier to locate biogas plants in developing nations based on municipal waste, promoting integrated waste management and decentralized energy systems [218,219]. Cluster models demonstrate how regional collaboration facilitated by GIS can improve system performance and aid in the creation of a circular economy [220].

In Europe, GIS contribute to the growth of decentralized energy models and microscale biogas plants targeted at local populations, which enhance regional energy independence [221,222]. In Poland, GIS help with local environmental assessments, registries, and agricultural investment planning [223].

### *5.4. GIS Applications in the Siting, Resource Analysis, and Potential Assessment of Hydropower Farms*

#### 5.4.1. Siting of Hydropower Farms

Selecting optimal sites for small hydropower plants, including run-of-river systems, requires consideration of factors such as elevation drop, water flow velocity, proximity to energy grids, accessibility of infrastructure, and environmental conditions. GIS make it

possible to combine topographic data (DEM), hydrological inputs, and protection zones, facilitating the creation of siting suitability maps [224].

GIS integrated with hydrological models is used to simulate river flows and estimate how much energy a site can produce, especially for run-of-river plants, by analyzing hydraulic and geometric parameters [225,226].

Multi-criteria decision analysis methods used in GIS help find the best places to build power plants by removing sites that have environmental or urban issues [227,228].

#### 5.4.2. Energy Resource Analysis

GIS enable the estimation of hydrological potential, including flow rates and elevation drops, through spatial analysis of watershed models. Algorithms find possible sites with the right flow patterns and head levels, which helps with evaluating energy potential [229].

Land cover maps and environmental constraints are combined with data on terrain slope (DEM), elevation points, and stream order (Strahler method) to leave out areas that are protected or geologically unstable [230,231].

OnSSET and other analytical frameworks can help find places where mini- and micro-hydropower installations can be built that will make money, taking into account the cost of the units and the availability of water resources [232,233].

In the context of the water-energy-food nexus, GIS also help with integrated water resource analyses that look at both environmental and social benefits at the same time [234].

#### 5.4.3. Production and Investment Potential Assessment

To determine the potential hydropower of a location, one must assess both its theoretical and technical capacities, including the water flow and elevation decrease. GIS integrate hydrological and economic data, enabling the estimation of potential energy production and investment feasibility [235].

GIS-based analyses enable the creation of energy suitability maps that quantify potential power generation in megawatts, contingent upon stream flow. These tools assist individuals in making informed decisions about site selection, cost estimation, and environmental impact when utilized in conjunction with multi-criteria decision analysis methodologies [236,237].

In poor nations, GIS are extensively utilized to facilitate the planning of decentralized energy systems and to identify small-scale hydropower installations [238].

### *5.5. Comparative Overview of GIS Methods for Renewable Energy Sources*

The application of GIS in assessing the potential of renewable energy sources is characterized by a wide diversity of technical pathways and unique challenges depending on the resource type. In hydropower, the focus is on hydrological modeling and watershed ecological protection, while in wind energy, wind speed simulation and the assessment of visual and acoustic impacts are of key importance. Photovoltaics requires detailed modeling of solar radiation balance and shading effects, biomass depends on supply seasonality and logistic constraints, and geothermal energy involves the interpretation of subsurface anomalies and structural uncertainties. Table 3 synthesizes these differences in GIS approaches, highlighting specific models, input data, environmental restrictions, and typical tools used in practice.

**Table 3.** Comparison of GIS approaches across renewable energy technologies.

| RES Type | Resource and Key GIS Layers (Description) | Limitations/Challenges | Typical Tools | Refs. |
|---|---|---|---|---|
| Hydropower | In hydropower, the resource is typically modelled using HEC-HMS or SWAT, which simulate rainfall–runoff processes; in GIS, the most important layers are DEMs, watershed boundaries, land cover, soils, and hydrometric data. | Key challenges include catchment ecology, minimum environmental flow requirements, and sedimentation. | HEC-HMS, SWAT/QSWAT, HEC-GeoHMS, ArcHydro | [239] |
| Wind | In wind energy, the resource is assessed via mesoscale datasets (WRF, reanalyses) that are downscaled in GIS to microscale with adjustments for terrain, surface roughness, infrastructure, and environmental receptors. | Main issues include visual impact, noise, shadow flicker, and wake losses. | WRF, CFD/wake models, viewshed tools, MCDA | [240] |
| Solar PV | In photovoltaics, solar resource is modelled with tools such as PVGIS; GIS analyses typically combine DSM/DTM, buildings, protected areas, power grid layers, hydrological features, and LiDAR for shading analysis. | Challenges include glare/glint impacts near airports and land use conflicts. | PVGIS, SGHAT/ForgeSolar, 3D GIS, MCDA | [241] |
| Biomass | In bioenergy, GIS support balancing the supply of agricultural and forestry residues, drawing on data about land use, crop yields, road networks, slope gradients, and protected areas. | Main difficulties include seasonal variability of supply and high feedstock transport costs. | Cost-distance modelling, MCDA, transport network analysis | [242] |
| Geothermal | In geothermal energy, GIS are used to integrate thermal anomalies and geological structures, including faults and hydrothermal indicators, with remote sensing datasets. | The biggest challenge is the uncertainty and low resolution of subsurface data. | GIS toolboxes for geothermal prospecting | [243] |

This comparative overview illustrates how GIS applications differ across renewable energy technologies and emphasizes their unique methodological difficulties. By explicitly contrasting hydropower, wind, solar, biomass, and geothermal approaches, the analysis directly addresses the need to refine and highlight the distinct GIS technical pathways for each RES, thereby enhancing the practical guidance of this study.

## 6. Geographic Information Systems—Legal Framework

### *6.1. International Frameworks and Technological Standards for Spatial Data*

Geographic Information Systems operate within a regulatory framework that includes national laws, European Union directives and international legal instruments. The regulatory framework for GIS mainly concerns data access, data sharing, privacy, interoperability, security and data reuse.

The Open Geospatial Consortium (OGC) has created specifications for Web Map Service (WMS), Web Feature Service (WFS) and modern OGC APIs for sharing spatial data and maps. These are some of the best-known technical standards that make GIS platforms work together worldwide. The ISO 191xx series of standards, particularly ISO 19115, which deals with the metadata needed to describe and organize spatial datasets, complements them. Systems and institutions can share, integrate, and reuse spatial data more easily thanks to these standards [67,244].

The technological foundations also support the Integrated Geospatial Information Framework (IGIF), a strategic document developed by the United Nations through the UN-GGIM (United Nations Committee of Experts on Global Geospatial Information Management). IGIF aids countries in establishing National Spatial Data Infrastructures (NSDI) and provides guidance on data governance, standardization, and sharing protocols. This

framework facilitates the development of integrated and efficient geospatial systems aimed at enhancing spatial planning, promoting sustainable development, and improving crisis response [245].

The Geospatial Data Act of 2018 in the United States enhanced the Federal Geographic Data Committee's (FGDC) role and mandated that federal agencies utilize GeoPlatform.gov as the primary instrument for the implementation of the National Spatial Data Infrastructure (NSDI) [246]. The OPEN Government Data Act mandates the publication of data in open formats, thereby promoting open access to information [247]. Both acts serve as significant reference points for global spatial data policies.

### 6.2. The Legal Framework of the European Union

In the European Union, a key foundation of spatial information infrastructure is the INSPIRE Directive (Infrastructure for Spatial Information in the European Community), which establishes principles for the harmonization of spatial datasets and network services such as discovery, view, download, and transformation. The implementing rules of the directive require, among other things, that View and Download services comply with the INSPIRE profile, which is based on OGC standards [248]. The goal of INSPIRE is to build a common spatial data infrastructure in the European Union, facilitate the development of environmental policies, and improve the exchange of spatial information between Member States.

Issues concerning open data are regulated by Directive (EU) 2019/1024 and Implementing Regulation 2023/138, which establish a list of so-called High-Value Datasets (HVD)—including spatial data—made available free of charge, in machine-readable format, and via APIs [249].

The protection of personal data (e.g., geolocation data) in the context of GIS is governed by the GDPR (General Data Protection Regulation) [250], while access to environmental information, often in the form of spatial data, is guaranteed by the Aarhus Convention and Directive 2003/4/EC [251].

Meanwhile, the cybersecurity of GIS services such as geoportals is regulated by the NIS2 Directive (2022/2555), which requires operators to manage risks and report incidents [252].

### 6.3. Polish Legislation and the Legislation of Other Countries

In Poland, the legal framework concerning spatial data is based on several legislative acts that regulate the spatial information infrastructure, data openness, access to public information, spatial planning, and geodesy. An overview of these regulations is presented in Table 4.

**Table 4.** Main legal acts concerning spatial data in Poland.

| Legal Act | Scope of Regulation | Refs. |
| --- | --- | --- |
| Act of 4 March 2010 on Spatial Information Infrastructure | Implementation of INSPIRE; defines authorities, datasets, services, and administrative cooperation | [253] |
| Geodesy and Cartography Law | Rules for maintaining the Land and Building Register (EGiB) and the State Geodetic and Cartographic Resource | [254] |
| Act of 11 August 2021 on Open Data | Implementation of Directive 2019/1024; re-use of public sector data | [255] |
| Act of 6 September 2001 on Access to Public Information | General access to public information, including spatial data | [256] |
| Amendment to the Spatial Planning Act of 7 July 2023 | Digitalisation of spatial planning, introduction of the Urban Planning Register | [257] |

Selected legal provisions and policies from various countries, which define how states collect, integrate, and share spatial data, are presented in Table 5. Despite the diversity of approaches adopted in individual countries, the overarching goal remains to ensure interoperability of spatial data originating from different institutions by implementing common standards and harmonized metadata.

**Table 5.** Examples of legal regulations and spatial data management strategies in selected countries.

| Country | Legal Act | Year | Scope of Regulation | Refs. |
|---|---|---|---|---|
| USA | Geospatial Data Act (GDA) | 2018 | Geospatial Data Governance Framework in the Federal Administration | [258] |
| USA | OPEN Government Data Act (Evidence Act, Title II) | 2019 | Default openness of government data, metadata catalog | [259,260] |
| Japan | Basic Act on the Advancement of Utilizing Geospatial Information (AUGI) | 2007 | NSDI Act: base plan, reference data, GIS policies. | [261,262] |
| South Korea | Act on the Establishment and Management of Spatial Data | 2014 | Creation, standardization, and sharing of spatial data | [263,264] |
| China | Surveying and Mapping Law (revised) | 2017 | Regulation of geodetic and cartographic activities and geographic information security. | [265,266] |
| Brazil | Decreto$^{o}$ 6.666/2008 (INDE) | 2008 | Establishment of the National Spatial Data Infrastructure (NSDI) | [267,268] |
| Mexico | Ley del Sistema Nacional de Información Estadística y Geográfica (SNIEG) | 2008 | Statistical-geographic system; INEGI's competences, geographic pillar | [269–271] |
| South Africa | Spatial Data Infrastructure Act (Act 54/2003) | 2003 | Establishment of SASDI, the Spatial Information Committee, and the metadata catalog. | [272–274] |
| Switzerland | Federal Geoinformation Act (GeoIG, SR 510.62) | 2007 | Provision of official geospatial data, quality standards, and metadata | [275,276] |
| Germany | Geodatenzugangsgesetz (GeoZG) | 2009 | Access to geospatial data at the federal level (INSPIRE transposition and national principles). | [277–279] |
| United Kingdom | The INSPIRE Regulations 2009 (SI 2009/3157) | 2009 | Implementation of the INSPIRE directive into UK law | [280–282] |
| Indonesia | Perpres No. 9/2016—One Map Policy | 2016 | One Map Policy: a single reference framework, standard, database, and geoportal. | [283–287] |

Equally important is the clear assignment of data responsibilities and the provision of simplified—and increasingly open—access to spatial data for both public authorities and citizens.

A clear evolution can also be observed over time: from technical solutions developed in the 1980s and 1990s to comprehensive legislation and national programs from the 2000s onward. The legal acts discussed do not constitute an exhaustive list of all regula-

tions, but they offer guidance and orientation while highlighting potential avenues for further research.

## 7. Conclusions and Directions for Further Research

Geographic Information Systems constitute an important instrument supporting environmental management and the planning of renewable energy development [288–290]. Their use facilitates strategic decision-making and allows for thorough spatial analysis [291]. However, fully realizing the potential of GIS requires their integration with complementary analytical methods [292], management instruments, and various conceptual and methodological approaches, thereby enabling more effective implementation of sustainable development goals.

Environmental Management (EM) is increasingly recognized today as a widely implemented management concept that integrates diverse organizational, operational, and social aspects related to human impact on the natural environment. It entails a comprehensive approach to environmental resources, taking into account their valuation, protection, allocation, development, exploitation, reclamation, remediation, and restoration to their original condition [293]. This concept is applied both in public policy and at the level of enterprises and non-governmental organizations. Its effectiveness increases through the combination of EM practices with certification systems (such as ISO 14001) and their growing integration with digital instruments.

In this context, GIS gain the status of fully recognized management instruments, supporting the implementation of key managerial functions such as planning, control, monitoring, decision-making, and communication [294–296]. Due to their ability to integrate, visualize, and analyze spatial data, GIS facilitate optimal location-based decisions for environmental and energy-related investments. GIS are also applied in the analysis and siting of wind, solar, and biogas farms, utilizing techniques such as MCDA, AHP, fuzzy logic, spatial modeling, and geostatistics.

The potential applications of artificial intelligence in environmental management and the development of renewable energy sources are very broad. They include event prediction, modeling and simulation of environmental processes, support for rapid geospatial data processing, and the integration of diverse sources of information. With the advancement of the Internet of Things (IoT), vast amounts of environmental data are being collected. However, this also generates challenges, particularly the need to decentralize decision-making processes, which addresses issues of scalability and the resilience of energy systems against failures or attacks. In this context, AI can play an important role by supporting decision-making at the local level, especially when communication with the central control center is disrupted. Complementing these solutions are GIS, which—through integration with modern technologies such as AI, remote sensing, Big Data, and BIM—gain the status of not only a technological platform but also a socio-organizational tool. They support stakeholder dialogue, participatory processes, and the implementation of climate and energy policies in an integrated and transparent manner, while also fitting into key regulatory frameworks, from EU directives on spatial data, security, and open data to the INSPIRE initiative and ISO 191xx standards.

The conducted analysis has demonstrated the potential of Geographic Information Systems as a multidimensional instrument supporting environmental management and the development of renewable energy sources. However, it should be emphasized that the content presented in this article does not exhaust the complexity of GIS-related issues in this field. A number of significant research directions remain that deserve further exploration, both theoretically and empirically.

It appears justified to expand the conceptual boundaries and theoretical reflection within environmental management by incorporating well-established management theories and emerging organizational concepts. These approaches may offer more comprehensive interpretive frameworks for understanding the complex phenomena occurring at the intersection of technology, the environment, and decision-making structures [297]. Research on the interdisciplinary integration of GIS with organization and management theory is especially crucial, with an emphasis on how these systems affect the dynamics and structure of decision-making processes in both public and private organizations. Future analysis should also focus on the automation and scalability of spatial decisions, including investigating how artificial intelligence (AI) can be used to process geospatial data automatically.

Another important area that needs to be looked into more closely is the social and moral effects of using GIS, especially when it comes to making plans to invest in renewable energy sources. This includes, among other things, assessing the impact of such projects on local communities, the potential for spatial conflicts, and the role of participatory tools such as PGIS (Participatory GIS) [298] in increasing the transparency of decision-making processes. It also highlights the need for research on the role of GIS within the framework of stakeholder theory, which emphasizes that sustainable development projects should take into account the interests of all groups that are or may be affected by their outcomes [299,300]. A vivid example is the current debate in Poland concerning the so-called "wind turbine act," in which the main point of contention is the definition of the minimum distance between wind turbines and residential buildings. Addressing this issue could be supported by studies integrating GIS with stakeholder theory. Such an approach could be based on the identification and mapping of stakeholders—including local governments, residents, investors, environmental organizations, and municipalities—and on the analysis of how GIS visualizations influence the strength of their arguments and their degree of involvement in the decision-making process. In this context, GIS could provide data on buffer distances between investments and residential areas (for example, 500 m versus 700 m), visibility and landscape exposure analyses (indicating which spatial points are affected by turbines), potential environmental conflicts (such as overlaps with Natura 2000 areas, reserves, or migration corridors), grid connection capacities, as well as suitability and risk maps. At the same time, it seems reasonable to do real-world research on how GIS affect the economic and environmental efficiency of investments in renewable energy, such as by lowering costs, improving return on investment indicators, and lowering different risks.

Using GIS to manage climate risks is especially important because they can help create integrated early warning systems and adaptive spatial planning strategies. Finally, one of the main areas of research that should be performed in the future is comparative legal analyses that look at how different legal systems affect the use of GIS in managing the environment and renewable energy.

**Author Contributions:** Conceptualization, A.K. and T.Z.; methodology, A.K. and T.Z.; software, T.Z.; validation, A.K., A.G. and T.Z.; formal analysis, A.K.; investigation, A.K., A.G. and T.Z.; resources, A.K., A.G. and T.Z.; data curation, A.K. and T.Z.; writing—original draft preparation, A.K.; writing—review and editing, A.K. and T.Z.; visualization, A.K.; supervision, A.K. and A.G.; project administration, A.K., A.G. and T.Z.; funding acquisition, A.G. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

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

## Abbreviations

The following abbreviations are used in this manuscript:

| Abbreviation | Definition |
|---|---|
| AHP | Analytic Hierarchy Process |
| AI | Artificial Intelligence |
| AR | Augmented Reality |
| BIM | Building Information Modeling |
| CAD | Computer-Aided Design |
| CFP | Corporate Financial Performance |
| CNN | Convolutional Neural Network |
| CSR | Corporate Social Responsibility |
| DEM | Digital Elevation Model |
| EM | Environmental Management |
| EMS | Environmental Management System |
| ESG | Environmental, Social and Governance |
| EU | European Union |
| GIS | Geographic Information System(s) |
| GNSS | Global Navigation Satellite System |
| HPC | High Performance Computing |
| IEA | International Energy Agency |
| INSPIRE | Infrastructure for Spatial Information in the European Community |
| ISO | International Organization for Standardization |
| ITS | Intelligent Transport Systems |
| IoT | Internet of Things |
| LCA | Life-Cycle Assessment |
| LSTM | Long Short-Term Memory |
| LiDAR | Laser Imaging Detection and Ranging |
| MCDA | Multi-Criteria Decision Analysis |
| OGC | Open Geospatial Consortium |
| PDCA | Plan–Do–Check–Act |
| PGIS | Participatory Geographic Information Systems |
| PV | Photovoltaics |
| PVGIS | Photovoltaic Geographical Information System |
| RES | Renewable Energy Sources |
| SAR | Synthetic Aperture Radar |
| SDI | Spatial Data Infrastructure |
| TOPSIS | Technique for Order Preference by Similarity to Ideal Solution |
| UAV | Unmanned Aerial Vehicle |
| VGI | Volunteered Geographic Information |

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