

Enhancing Higher Education Policy and Governance through Spatial Decision Support Systems: Evidence and Barriers

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Abstract

This article examines the potential, obstacles, and prospects for using Spatial Decision Support Systems (SDSS) as advanced educational technologies in higher education policy design. By emphasizing the spatial dimension, the study highlights how SDSS enable evidence-based decision-making on the distribution, evaluation, and sustainability of university institutions. A structured literature review is presented, thematically addressing the theoretical foundations and evolution of SDSS, their advantages and limitations, barriers to adoption by public authorities, and international examples of use in education policy. Synthesizing existing evidence, the review identifies critical gaps, particularly the limited integration of SDSS into higher education governance frameworks and underscores the distinct decision-making needs of this field. The contribution of this work lies in positioning SDSS not merely as geospatial tools, but as educational technologies capable of supporting spatial equity, strategic planning, and alignment with labor market demands. The findings reveal that, despite their potential, adoption remains restricted due to technical, institutional, and organizational barriers, calling for systematic and interdisciplinary action. Ultimately, the study argues for the development of SDSS tailored to educational governance, promoting transparency, participation, and socially meaningful outcomes. In this context, SDSS extend the role of data: beyond telling us “where”, they help us ask “for whom” and “to what end”, offering higher education interactive, open, and strategic maps to guide decision-making in the 21st century.

Keywords

Spatial Decision Support Systems (SDSS), Higher Education Governance, Geographic Information Systems (GIS), Spatial Planning, Educational Policy

1. Introduction

The formulation of educational policy at the level of higher education requires decisions that in many cases have spatial implications: the geographical location of institutions, access for different social groups, and the relationship between universities and the local economy and infrastructure are critical variables that are difficult to capture in numbers or indicators alone.

In this field, Spatial Decision Support Systems (SDSS) represent a set of tools with enhanced spatial analysis and decision-making capabilities: technologies that are not limited to monitoring, but actively support planning, focusing not only on “where” and “how much,” but also on “why,” “for whom,” and “at what cost/benefit.” Although SDSS have already been integrated into fields such as urban planning and natural resource management, their use in higher education remains fragmented, sporadic, and often disconnected from the decision-making process.

This study approaches the issue not only as a technological proposal, but also as a necessary intervention in the field of educational policy: How can spatial information acquire a regulatory and strategic function in the design of higher education? What are the examples of application, limitations, and possibilities that remain theoretically or practically unexploited for SDSS in the field of educational policy? And above all, how can an SDSS go beyond visualization tool and function as a platform for synthesizing policy options, empirical data, and social needs?

1.1. Significance of the Topic

Decision Support Systems (DSS) are the foundation of modern computer-based support for complex decision-making. These sophisticated tools do not merely manage data, but synthesize information, analytical models, and interactive interfaces to empower decision-makers, especially when the problem domain is ambiguous or unstructured [1].

The rapid advancement of geospatial technologies in recent decades has brought to the fore a new generation of DSS: Spatial Decision Support Systems (SDSS). In these systems, the geographical dimension is not just an additional feature but lies at the core of their design. SDSS combine spatial and non-spatial data, leverage the analytical and visualization capabilities of GIS, and incorporate specialized decision models for mapping, simulating, and evaluating alternative scenarios in problems with a strong spatial component [2].

Unlike traditional DSS, which draw mainly on internal organizational data, SDSS are dynamically linked to external sources, such as geospatial data from public agencies or demographic datasets, enabling a more multifaceted and richer representation of reality. The concept of SDSS was established in the late 1980s (Hopkins & Armstrong) and further consolidated with its inclusion in a landmark GIS collective work in 1991 [3]. Since then, technological advances and the increasing availability of data have contributed to the widespread adoption of SDSS.

The effectiveness of SDSS has been demonstrated in a wide range of applications: from urban planning and natural resource management to environmental

assessment, transportation, and operational research. At their core, they offer critical support for decisions where location plays a key role. For example, they are used for land use analysis, site selection, participatory planning, and consultation support through cartographic interfaces [3] [4].

Despite their proven value, SDSS remain limited in their application in education, particularly at the tertiary level. Educational administration relies mainly on EMIS systems, with an emphasis on quantitative data on enrollment, graduation, or performance [5]. Thus, the geographical dimension of planning, such as the distribution of institutions or accessibility, is often ignored or addressed in a fragmented manner. It is indicative that universities, unlike schools, were considered less “geographically located,” limiting the use of GIS in higher education [6].

In recent years, however, interest in spatial analysis in education has been rekindled. Advances in Web-GIS, the increasing availability of reliable geospatial data, and the pressure for evidence-based governance are highlighting the spatial dimension as a critical planning tool. Spatial intelligence is entering the core of educational strategy, signaling a shift toward more equitable, targeted, and participatory decisions [7].

Strategic decisions in higher education, including the location of institutions, the restructuring of the academic map, and the adaptation of curricula to the needs of local communities, have always had a strong spatial dimension. SDSS offer the possibility of integrating geographical, demographic, and socioeconomic data for the development of policies that respond to the local context, ensuring greater equity, better use of resources, and meaningful participation of stakeholders [8] [9].

1.2. Objectives of the Article

This article attempts a systematic review of the use of SDSS in higher education, focusing on mapping the research field, highlighting key applications, and analyzing the barriers that hinder their use by educators and public institutions. It aims to explore how SDSS can support the development of more targeted, evidence-based, and flexible educational policies, considering local and geographical specificities.

To this end, the study material is organized into four main axes:

- 1) the conceptual foundation of SDSS and their relationship with GIS/DSS,
- 2) empirical applications in educational policy and infrastructure planning, and
- 3) the limitations and challenges in their implementation.

At the same time, a comparative synthesis of the findings is attempted to identify the dominant scientific trends and to provide an analytical background for the development of effective spatial support tools for educational decision-making.

More specifically, the article presents the theoretical framework of SDSS, focusing on the spatial dimension of educational policy, conceptual differences from related tools, and the particular possibilities they offer to higher education (Section 2). Next, SDSS applications with a strategic focus on the spatial planning of higher ed-

education are presented and analyzed in terms of the distribution and origin of the student population, accessibility and spatial equity analysis, educational infrastructure planning, and the planning of study programs in relation to spatial and socio-economic needs (Section 3). This is followed by a systematic investigation of the technical, institutional, organizational, and cultural barriers that limit the dissemination of SDSS (Section 4), while the study concludes with a summary of the main findings and the identification of a multidimensional research gap that highlights the need for further study and institutional integration (Section 5).

1.3. Methodology: Structured Literature Review

This study adopts a structured literature review to map definitions, methods, applications, and adoption barriers of Spatial Decision Support Systems (SDSS) in higher education governance and planning. The evidence base was collected across the period 1988-2024, ensuring both historical depth (early SDSS conceptualization) and contemporary relevance to current geospatial and educational-governance practices.

Search strategy and sources. The search strategy combined peer-reviewed literature retrieval with targeted sourcing of contextual and implementation-oriented material relevant to higher education policy. The corpus included five complementary source types: (i) doctoral and master's theses (with emphasis on Greek universities), (ii) scientific books and edited volumes establishing theoretical and institutional foundations, (iii) conference proceedings, (iv) research reports and technical manuals documenting applied implementations, and (v) official documents, laws, and European strategies capturing the governance and regulatory context of decision-making in higher education.

Search strings were built around three concept clusters: (a) SDSS/DSS (e.g., "spatial decision support system", SDSS, "spatial DSS", "decision support system"), (b) GIS/geospatial analytics (GIS, "geographic information system", geospatial), and (c) higher education governance/planning (e.g., "higher education", university, campus, governance, "educational planning"), optionally expanded with method terms (MCDA, optimization, simulation, accessibility, location-allocation, scenario/what-if).

Inclusion/exclusion criteria. Source selection followed strict but flexible criteria to maximize scientific validity, thematic relevance, and applicability, particularly where insights translate to the Greek higher-education setting. Core inclusion required that a work (i) addressed DSS/GIS/SDSS concepts, architectures, or implementations relevant to governance/planning, and (ii) contained an explicit decision-support component beyond visualization (e.g., multi-criteria evaluation, suitability modeling, scenario simulation, optimization such as location-allocation). Sources were excluded when they were purely descriptive/visualization-only or lacked sufficient detail to evaluate the decision-support component.

Use of grey literature. The strategy allowed supplementary ("grey") literature or non-traditionally published material when it contributed useful empirical data,

implementation details, or illustrative examples not readily available in peer-reviewed sources. This was treated as supportive evidence rather than as the primary basis for claims, given the interdisciplinary and technologically complex nature of SDSS in higher education.

Screening and synthesis. Retrieved records were screened and then synthesized thematically and methodologically. Included studies were coded by: (a) higher-education governance use-case (e.g., student distribution/origins, accessibility/equity, infrastructure planning, program-labor market alignment), (b) decision-support method (e.g., MCDA, simulation, optimization), (c) data requirements (spatial/non-spatial; static/dynamic), and (d) adoption barriers (technical, organizational, institutional/regulatory). The synthesis is presented in the subsequent sections, organized around definitions and components of SDSS, application areas in higher education governance, and adoption barriers and future directions.

2. SDSS: Theoretical Framework and Role in Higher Education

In higher education, where strategic decisions are often made without spatial awareness, SDSS highlight space as a key variable in analysis and planning. Their use is not limited to technical innovations; they offer the possibility of developing more equitable, accessible, and informed policies. The following section explores this potential, focusing on the role of SDSS in supporting spatially sensitive decisions in the university context.

2.1. The Spatial Dimension in Education Policy

Decision-making in education policy inevitably has a spatial dimension: the question of “where and when to establish a new school or university” requires geographical analysis [10]. Spatial educational planning integrates data with a geographical background, allowing for the evaluation of alternative interventions in space [11]. Issues such as the establishment of new schools, the reallocation of resources, or access for remote communities require responses based on spatial data, demographic information, infrastructure, and socioeconomic indicators [12].

This approach promotes equality, the adaptation of policies to local needs, and the efficient use of resources. According to IIEP-UNESCO, linking educational and geospatial information enhances the accuracy and targeting of policies. At the international level, the use of GIS and geospatial data has been successfully implemented in countries such as Sierra Leone, India, and Nigeria, supporting staff allocation, demand forecasting, and the identification of excluded areas [13]. UNICEF is developing global school mapping using satellite data and machine learning algorithms [14]. In Greece, the need for spatial analysis is gradually being recognized in higher education. The Ministry of Education and Culture has highlighted the role of SDSS in the geographical distribution of universities, the establishment of new departments, and accessibility [15]. Tools such as interactive “what-if” scenarios will facilitate strategic planning. The integration of the geographical di-

mension transforms decision-making, making it more equitable, transparent, and effective, both technically and socially [16].

2.2. SDSS: Theoretical Foundation and Distinction from GIS and DSS

Spatial Decision Support Systems (SDSS) are technologically advanced tools that combine geographic information systems (GIS), decision-making models, and interactive interfaces to support decisions that include a spatial dimension [3] [4] [17]. Although there is no single, universally accepted definition of SDSS [18], the literature reveals recurring conceptual patterns that highlight the theoretical diversity and application flexibility of these systems. In order to clarify the different interpretative approaches, the main definitions found in the literature have been classified into four basic categories:

Technological definitions: which focus mainly on the GIS–DSS coupling. Armstrong, Densham, and others [17] [19] describe SDSS as an evolution of decision support systems, enhanced with geospatial information and corresponding processing capabilities.

Interactive definitions: which emphasize the importance of active user participation and the exploration of alternative solutions. Keen [20], Gray *et al.* [21], and Malczewski [3] define SDSS as tools for exploring and shaping options in an environment that supports dynamic visualization.

Organizational or institutional definitions: as formulated by Nyerges, Dueker, and Chrisman [22], approach SDSS as elements of a system in which technology, human actors, and institutional environments interact.

Analytical or functional definitions: based on spatial criteria, emphasize complex decision-making tools such as multi-criteria analysis, simulations, scenarios, and strategy selection based on spatial data. Typical examples are the definitions by Turban [23], Jankowski [8] and Sugumaran & DeGroot [4].

The contributions of Eldrandaly [24] and Andrienko [25], along with later Web-based SDSS studies, highlight the growing role of SDSS in supporting decisions on complex social and environmental issues. Fotheringham [18] aptly observes that the diversity of definitions is not a weakness, but a reflection of the breadth of applications and adaptability of SDSS to different institutional, geographical, and operational contexts.

For a better understanding of SDSS, it is necessary to distinguish between GIS, DSS, and SDSS. Although there is often overlap and ambiguity in the literature, SDSS are not simply a hybrid combination of GIS and DSS. Instead, they constitute a distinct category of systems with specialized functions, capabilities, and application areas [3] [4] [17].

The need for this distinction is twofold: on the one hand, it prevents confusion at the level of theoretical analysis, and on the other hand, it allows the formulation of technical and functional specifications when designing complex applications. As Sugumaran & DeGroot [4] point out, the introduction of spatial characteris-

tics into a decision support system fundamentally affects the way problems are formulated and analyzed. Similarly, Malczewski [3] emphasizes that the integration of multi-criteria tools into GIS leads to completely new questions and solutions, differing from traditional mapping tools.

To clarify the differences and similarities between the three types of systems, the following comparative table was created. The analysis allows for a thorough mapping of the purpose, data types, analytical capabilities, interfaces, and applications of each system, highlighting documented conclusions about the functionality and potential of SDSS in educational policy and spatial planning:

Table 1. Comparative overview of the main differences and complementary features between GIS, DSS, and SDSS in terms of purpose, data, analytical capabilities, interface, and applications.

Aspect	GIS	DSS	SDSS
Main purpose	Management and analysis of geographic data, mapping.	Support for decision-making through data analysis and models (general problems, non-spatial).	Support for spatial decision-making through a combination of spatial analyses and decision models.
Data	Spatial/geographic data (points, lines, polygons, rasters, etc.).	Numeric, alphanumeric, or other data (usually non-geographic).	Spatial and non-spatial data. Combination of geographic information and other relevant data.
Analytical capabilities	Spatial analyses: map overlay, spatial queries, distances, routing, etc.	Decision models: simulations, optimization, what-if analysis, multi-criteria evaluation.	Combination of GIS & DSS tools: suitability analysis, site selection, scenarios, optimization.
User interface	Cartographic interface, GIS tools.	Reporting and modeling interface (forms, tables, graphs).	Interactive maps and graphics. Allows parameter modification and immediate visual feedback.
Typical applications	E.g. resource allocation mapping, environmental maps, land registry.	E.g. financial analysis, business planning, logistics.	E.g. urban planning, environmental management, educational planning, routing.

Table 1 shows that SDSS are not a simple integration of GIS and DSS tools, but rather a synthetic evolution of these tools. While GIS focuses on geographic information and cartographic analysis and DSS on computational models for non-spatial problems, SDSS integrate both dimensions into a comprehensive and dynamic decision-making environment. From data management and analysis capabilities to interactive interfaces and a wide range of applications, SDSS provide a functional decision support space that allows the user or team to examine, compare, and select solutions with immediate geographic impact.

The contribution of SDSS is particularly critical in fields such as educational policy, urban planning, and regional development, where decisions require documentation, multi-criteria evaluation, and socially acceptable targeting. In this light, SDSS bridge the gap between geographical knowledge and operational strategy, enhancing the effectiveness of interventions in the field.

2.3. SDSS: Capabilities and Functions

Spatial Decision Support Systems (SDSS) are characterized by a set of properties that make them particularly suitable for informed decision-making in fields where spatial information is a critical factor [4] [26].

Focus on spatial information: A key feature of SDSS is their ability to process and analyze geographically referenced data, which sets them apart from traditional DSS [26] [27]. This allows, for example, the detection of geographical inequalities in the distribution of educational resources or the assessment of accessibility to university facilities [28] [29].

Support for complex decisions: The ability to perform multi-criteria and scenario analysis makes SDSS particularly useful for problems with conflicting criteria, such as selecting locations for new educational facilities [4] [27] [29] [30]. Through “what-if” policy simulation, SDSS allow experimentation with alternatives before final decisions are made [31].

Data integration: The ability to combine spatial and non-spatial data is a structural advantage of SDSS. By combining, for example, cartographic data with demographic and statistical records, “educational deserts” and areas with low accessibility can be identified [29] [32]. The general architecture of an SDSS is described in the literature as a set of core building blocks (data sources, analytical models, and interactive interfaces) linked through information flows that support spatial decision-making in educational policy design. Following the approach of Malczewski & Rinner (2015), this perspective emphasizes the need to integrate heterogeneous datasets with multicriteria analysis tools and user-centered, web-based GIS functionalities, in order to enhance transparency, stakeholder participation, and the scientific documentation of decisions.

Visualization and user-friendliness: Interactive data visualization through maps, charts, and dashboards makes SDSS particularly accessible to non-experts, facilitating participatory decision-making [4] [33]. The development of Web-GIS and cloud-based SDSS enhances collaboration and shared use [34].

Multi-scale operation: SDSS are flexible in terms of application scale, from national strategy to the level of a school unit [30] [31] [35]. Applications such as the redesign of school boundaries in Kansas demonstrate their value in managing population changes [35].

Interoperability and innovation: The integration of open data, sensors, and machine learning technologies enriches the functionality of SDSS, enhancing forecasting and automating complex analyses [28] [30]. Their connection to other information systems (e.g., EMIS) enhances transparency and reliability [4] [28].

2.4. SDSS in Education: Geospatial Intelligence for Targeted Policy

The integration of Spatial Decision Support Systems (SDSS) into education policy is a critical step toward modernizing planning and decision-making, enhancing transparency, accountability, and documentation [26] [36]. The ability of SDSS to integrate geospatial and administrative data, simulate scenarios, and visualize complex issues allows for the analysis and evaluation of policies in real time [37].

An SDSS can play a pivotal role in supporting critical decisions regarding the establishment or restructuring of universities, improving accessibility, optimizing the utilization of infrastructure, and strengthening institutional visibility through targeted strategies. Furthermore, SDSS make a substantial contribution to strategic planning, resource allocation, forecasting of future needs, and ensuring the alignment of educational provision with labor market requirements [28] [38].

At the same time, they offer tools for promoting spatial equity and social justice, such as through the mapping of “educational deserts” or the modeling of student accessibility [39] [40]. At the local level in Spain, the use of SDSS for the optimal allocation of school units has resulted in a reduction in total travel distance of approximately 8%, achieving better service for students and saving resources. In France, geospatial tools are used to select areas with low accessibility as potential sites for new university centers, promoting educational equality [41].

The use of innovative data analysis technologies, such as knowledge mining and machine learning, enables SDSS to identify patterns in academic and social variables, facilitating targeted interventions such as personalized study plans [42] [43]. Interactive dashboards, thematic maps, and simulation scenarios enable dynamic monitoring and evaluation of educational policy [44] [45]. The use of open technologies (e.g., open-source GIS, PostGIS, Python) makes SDSS accessible and sustainable even for institutions with limited resources [46].

Furthermore, SDSS link education to local development and the needs of regional economies: they map skill gaps, enhance strategic curriculum design, and strengthen the role of universities as development hubs. In Canada, for example, they have been used to design postgraduate programs aligned with the needs of the local labor market [38]. At the same time, they help combat brain drain, enhance transparency through open data for citizens, and enable institutions to communicate effectively with local communities [39] [40]. As promotional tools, SDSS can boost demand for studies and highlight the social role of institutions.

At the international level, organizations such as UNESCO and the OECD are promoting the use of open-access geospatial data for monitoring indicators of educational equality and sustainability [46]. Rapid advances in artificial intelligence, combined with the increasing availability of open data, are creating a dynamic ecosystem that enhances the ability of SDSS to provide real-time predictions, scenarios, and interactive support [28]. With the right investment in infrastructure and human resources, SDSS have the potential to transform educational policy design into a more equitable, adaptive, and scientifically informed process [26].

3. SDSS in Education: Applications and Spatial Planning

As higher education now operates in an environment of intense social, economic, and spatial change, the need for evidence-based planning is becoming imperative. Spatial Decision Support Systems (SDSS) introduce a new, geospatially sensitive approach to policy-making: they identify inequalities, support targeted interventions, and link university structures to the needs of local communities and the market.

Unlike Geographic Information Systems (GIS), which primarily support spatial visualization and descriptive analysis, Spatial Decision Support Systems (SDSS) integrate decision models, simulation techniques, and optimization algorithms to actively support policy formulation. Typical SDSS functionalities include scenario analysis, location-allocation models, and multi-criteria decision evaluation, enabling evidence-based and forward-looking decision-making. In this context, maps should be understood as a communication layer for model outputs, while the core SDSS contribution lies in the explicit decision logic used to generate, compare, and justify alternative policy options.

The following section presents examples and international comparisons, showing how SDSS can reshape the map of educational policy. **Figure 1** illustrates the main areas of application of SDSS in higher education. The four themes (infrastructure, accessibility, student population, and study programs) reflect the potential for spatially informed decisions with a social focus.

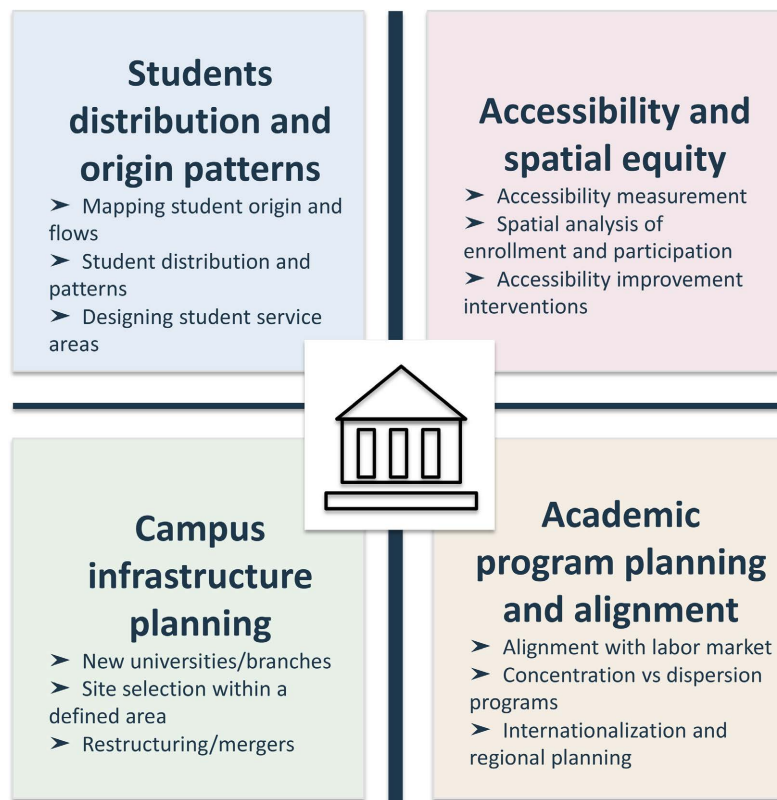


Figure 1. Main axes of application of Spatial Decision Support Systems in higher education.

3.1. Students Distribution and Origin Patterns

Understanding the geographical distribution of the student population, both potential (prospective students) and active (enrolled students), is a key component of strategic planning in higher education. Beyond visualization, SDSS support enrollment planning by combining origin-destination (OD) flow analysis, predictive modeling, and scenario testing to anticipate spatial shifts in demand and to guide recruitment, capacity planning, and academic offerings.

Mapping student origin and flows: One of the first steps taken by many universities often using basic GIS tools, is to map the geographical origins of their students [47]. Analyses typically use permanent addresses or schools attended to delineate feeder zones and detect spatial concentration versus long-range recruitment patterns. For example, an institution may observe that most enrollments originate from neighboring counties, while smaller shares come from more distant regions; such patterns directly inform recruitment strategy and outreach targeting.

SDSS extend this mapping through explicit OD flow modeling and predictive components. Geographic information is combined with demographic projections (e.g., expected changes in high-school graduates) to produce forecasted origin flows and to compare recruitment scenarios across territories [48]. As noted, CSU Dominguez Hills developed a system [49] that integrates school-level data, applications, and population trends to define “core service areas” and predict future student inflows over a 5-10-year horizon, using historical enrollment rates and projected cohort changes as model inputs.

Student distribution and spatial balance of supply and demand: At the national level, SDSS offer valuable tools for analyzing the relationship between student demand and available infrastructure [50]. A SDSS can map enrolled students by region and relate them to regions of origin, revealing net inflows/outflows and highlighting imbalance patterns [51]. Regions with low ratios of enrolled-to-graduating students may indicate leakage (insufficient local supply or mismatch with preferences), while regions with strong net inflows act as pull factors [52]. Greece’s Attica region is a typical example of such concentration. Methodologically, this is operationalized through flow-balance indicators and spatial interaction metrics derived from OD matrices, enabling systematic comparison across regions and time periods rather than descriptive mapping alone [53].

Designing student service areas based on geographical origin: The geographical origin of students also influences the operational needs of universities [54]. Institutions that attract students from distant areas need to invest more in student residences or housing programs. Conversely, in cases where students from the local area predominate (so-called commuters) priority is given to parking facilities or local transport [55]. In addition, students from different cultural or linguistic backgrounds may need special support to adapt. SDSS can formalize these decisions through catchment/service-area modeling and resource-allocation rules. For example, network-based service areas can delineate commuting catchments, while spatial clustering can detect concentrations of specific student groups; these out-

puts can then feed allocation decisions (e.g., prioritizing housing capacity or strengthening international relations offices on campuses with higher shares of international students) [27].

3.2. Accessibility and Spatial Equity

Accessibility to higher education, that is, the degree of ease or difficulty with which prospective students can enroll and study at a higher education institution (HEI), has strong geographical characteristics. This section examines how SDSS operationalize accessibility through network-based travel-time modeling, spatial equity indicators, and scenario testing, enabling evidence-based interventions to reduce spatial disparities [56].

Accessibility measurement: Traditionally, accessibility assessment was based on simple geometric approaches, such as the existence of HEIs within the same administrative unit or within a predetermined radius. However, such approaches ignore real travel conditions, terrain constraints, and network connectivity. Modern GIS supports the computation of isochrones (areas reachable within a given travel time) [57]. Within the UNESCO framework, an application [58] uses road-network data and pedestrian travel speeds to delineate realistic school catchments; the same network methodology applies to universities by mapping 30/60/90-minute travel-time catchments. When combined with the spatial distribution of the 18 - 22 population, these models estimate the share of youth with “effective access” to higher education and identify low-accessibility gaps where populations fall outside reasonable travel-time thresholds.

In SDSS terms, the core contribution is a network-based accessibility model coupled with scenario simulation. The system can test “what-if” alternatives, e.g., introducing a new learning hub (physical or blended) and recalculating catchments as a virtual change in supply, while also assessing transport upgrades (road improvements, new rail links) by recomputing travel times and quantifying accessibility gains for specific communities. Evidence from remote areas (e.g., Scotland and Sweden) shows how such outputs can support decisions on local provision or subsidized transport solutions.

Spatial analysis of enrollment and participation: An alternative approach focuses on actual participation rates in higher education. For each spatial unit (e.g., county, municipality, postal code), the percentage of high school graduates who go on to university can be calculated [59]. When these data are mapped, spatial patterns of inequality emerge: urban centers and more developed areas have higher participation rates, while rural or isolated areas have significantly lower rates [60]. Although these differences depend on a number of factors (socio-economic, cultural), geographical distance remains a major obstacle. Through an SDSS, it is possible to apply spatial statistical analysis to investigate the relationship between participation rates and distance from the nearest HEI. Numerous studies have confirmed the existence of a negative correlation: the greater the distance, the lower the likelihood of enrollment [61]. This phenomenon is a case in point of

“spatial bias” in access to education. Of course, there may be exceptions: for example, areas with high incomes or well-developed transport systems may maintain high participation rates despite the relative distance [62]. A robust SDSS integrates contextual variables (e.g., income and student housing availability) to more accurately isolate the geographical component [2].

Interventions to improve accessibility: Once areas with reduced accessibility have been identified, the responsible authorities can consider targeted interventions. These may include educational provision (e.g., establishing a lifelong learning center linked to a university or expanding digital study programs) [63], transport policy measures (e.g., subsidizing travel for students from remote areas) [61], and financial incentives (e.g., scholarships for geographically disadvantaged groups, housing allowances) [64]. SDSS can be used to assess the potential effectiveness of such interventions through policy scenario analysis: for example, by simulating the establishment of an educational center in a specific location and estimating the expected additional enrollments based on local population potential, modeled accessibility improvements, and participation–access response relationships [2].

3.3. Campus Infrastructure Location-Allocation

One of the most direct and critical applications of an SDSS in higher education concerns decisions about the establishment, expansion, or possible merger of university infrastructure. These are decisions of strategic importance, such as the creation of a new university in a region, the choice of location for a campus or educational building, or the reorganization of the national network of academic departments. Importantly, in these use-cases the SDSS contribution lies in the explicit decision logic (e.g., multi-criteria evaluation, location-allocation optimization, and scenario testing under constraints), rather than in map visualization alone.

Establishment of new universities/branches: During the 1990s and 2000s, many countries faced the need to expand higher education due to increased demand. The choice of locations for new institutions was often the result of political negotiations. SDSS offer an objective and multifactorial basis for evaluating candidate locations [65]. A case in point is Jordan, where a GIS-MCDA model [27] was developed to identify the optimal location for a new university in northern Jordan [66]. The model combined eight criteria, such as: distance from existing universities (the greater the better), proximity to large cities (for infrastructure and population base reasons), connection to road networks, availability of sufficient and flat land, distance from airports (to avoid noise pollution or hazards), and environmental indicators. The criteria were weighted using the AHP method (AHP-Analytic Hierarchy Process) and thematic suitability maps were produced. The final result, a spatial suitability map graded from “highly suitable” to “unsuitable” areas, provided decision-makers with a clear, evidence-based support tool. Indicatively, approximately 65% of the area under consideration was assessed as suitable, with a smaller percentage being classified as highly suitable, allowing for tar-

geted interventions. In decision-analytic terms, this corresponds to a weighted suitability (MCDA) evaluation that ranks candidate areas by aggregating criteria scores and weights, supporting transparent comparison of alternative locations.

Similar approaches have been used in other countries: in India, a spatial analysis was carried out to create new technology institutes based on distance from existing institutions, youth population density, and transport accessibility. In Egypt, GIS tools were used to map the carrying capacity of universities in relation to the local population, with the aim of identifying geographical mismatches and proposing new university campuses, even though such decisions often remain influenced by political expediency. Here, SDSS value is strengthened when mismatch mapping is coupled with explicit allocation/optimization or scenario rules (e.g., “add a campus here” vs “expand capacity there”) to compare policy alternatives under capacity and budget constraints.

Site selection within a defined area: When the decision on the location has already been made, but a specific site needs to be selected, SDSS utilize techniques from urban planning and urban logistics, such as location-allocation analysis [67] or the calculation of the “geographical center of gravity” of demand. If, for example, a country chooses to establish a university in a province, the SDSS can indicate which city or town best serves the student population. By combining the geographical distribution of high school graduates (potential demand) with travel times via road networks, each candidate location is evaluated in terms of the number of students within 30, 60, or 120 minutes of access. Similar studies have been reported in the US: although community colleges are designed to serve their “service areas,” exercises have been carried out to optimize their geographical location in order to minimize the average distance for the population. SDSS allow such scenarios to be evaluated, for example, slightly shifting a campus northward may increase the number of students within a 30-minute radius but reduce coverage of other areas. This is effectively an optimization/sensitivity exercise, where the objective (e.g., maximize covered demand within a threshold or minimize average travel time) is evaluated across alternative site configurations and constraints

Restructuring/mergers: An even more complex application involves decisions on mergers or closures of university units as part of the rationalization of the academic map. Some countries, such as Russia and France, have implemented policies to consolidate scattered institutions [68]. In such cases, SDSS can also be used retrospectively to assess the impact of interventions: for example, if branch A is closed and students are transferred to branch B, the change in the average travel distance per region can be calculated [41]. In the United Kingdom, maps have been produced showing the “supply shadow” of each institution, allowing the spatial gap left by its removal to be assessed [62]. A similar methodology is found in studies on school units, such as a UNESCO report that analyzed the impact of possible school closures in England: although it concerns lower levels, the methodological transfer to universities is entirely legitimate [69]. In SDSS terms, this corresponds to scenario simulation (“close/merge/transfer”) with quantified im-

pact indicators (e.g., changes in travel-time burden and coverage), enabling comparison of restructuring alternatives before implementation.

3.4. Academic Program Planning and Spatial-Socioeconomic Alignment

Effective policy-making in higher education is not limited to the quantitative adequacy of educational structures; it requires the spatial alignment of the supply of studies with the needs of both the local community and the national economy. In this context, Spatial Decision Support Systems (SDSS) offer advanced capabilities for combining education, labor market, and spatial dispersion data, enabling the formulation of evidence-based strategies. In these use-cases, SDSS go beyond descriptive mapping by embedding explicit decision logic (e.g., mismatch indicators, scenario evaluation, and spatial interaction modeling) to compare alternative policy configurations.

Alignment with the labor market: A key question for education policymakers is whether universities offer programs that meet the needs of the regional or national economy. In many cases, there is an imbalance: geographical areas with specialized productive potential lack corresponding academic programs. Through SDSS, “alignment maps” can be drawn up that illustrate the geographical relationship between thematic fields of study and sectors of the economy. A representative case is Romania, where mapping of university institutions in conjunction with industrial areas revealed critical gaps, leading to proposals for the establishment of new or decentralized educational structures in areas with high specialization but low local study offerings [70]. Methodologically, this corresponds to a spatial mismatch assessment in which demand-supply indicators are computed (e.g., sectoral employment/industry intensity versus program availability), producing ranked “gap” areas to prioritize program creation or decentralization options.

Spatial strategies of concentration or dispersion: The reorganization of the higher education map often involves the dilemma between concentrating study programs (and the resulting specialization per region) versus uniform dispersion [71]. SDSS can support such decisions through scenario modeling: for example, they can calculate the change in accessibility or student travel costs if polytechnic schools are concentrated in two urban centers instead of five [27]. Similar exercises have been used in Australia to optimize the spatial distribution of universities based on population density and inland access needs [72]. Here, the SDSS decision core is scenario-based evaluation (and, where applicable, optimization) that compares alternative program-location configurations against objectives such as minimizing aggregate travel cost and maximizing equitable coverage under capacity constraints.

Internationalization and regional planning: In an increasingly globalized educational landscape, several countries are seeking to develop into international “education hubs,” strategically leveraging their geographical location to attract foreign students [73]. SDSS contribute to this strategy by analyzing student flows,

mapping existing target markets, and selecting geographically advantageous locations for the establishment of new university units or foreign-language study programs. Factors such as proximity to international airports, city connectivity, and cultural/economic ties with countries of origin can be incorporated into spatial interaction models within an SDSS, enhancing strategic decision-making. This is typically operationalized through spatial interaction (gravity-type) models that estimate and compare expected international student flows under alternative hub locations and program offerings, supporting evidence-based selection of strategic sites.

4. Limitations and Challenges for SDSS

The integration of SDSS into education policy is not just a matter of technological sophistication. It is a complex process where documentation meets the reality of institutions, people, and decisions. Despite the clear advantages of SDSS in transparency, analysis, and goal setting, their implementation often stumbles upon obstacles that go beyond technology: from organizational inertia and a low data culture to institutional gaps and policy inconsistency. As summarized in **Figure 2**,

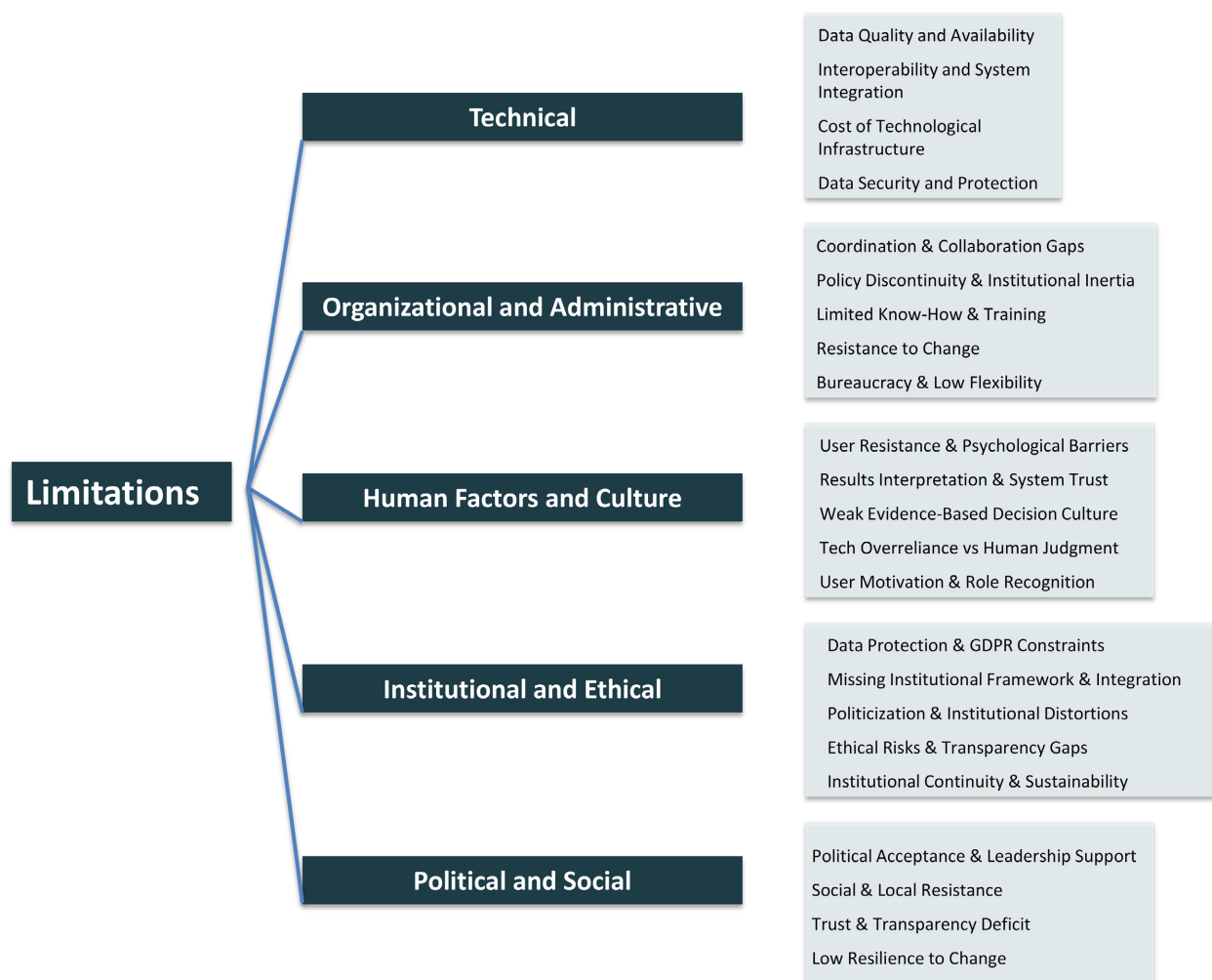


Figure 2. Basic categories of constraints for the implementation of Spatial Decision Support Systems in higher education.

these constraints are organized into five interrelated categories, each highlighting a different challenge (technical, administrative, institutional, or social) and setting the stage for strategies to overcome them based on international experience and theoretical evidence.

4.1. Technical Limitations

The development of SDSS in higher education faces significant technical barriers that affect their functionality and acceptance. Two key challenges stand out: limited access to reliable, up-to-date data and the difficulty of interoperability between heterogeneous systems. Ensuring high-quality data remains a critical challenge, while requirements for complex architectures often undermine usability.

Data quality and availability: The effectiveness of an SDSS depends directly on the quality, completeness, and timeliness of the data that feed it. However, access to reliable data is a major obstacle. Available data is often incomplete, outdated, or insufficiently analyzed, as is the case with the absence of accurate geospatial coordinates for some institutions or the lack of recent demographic indicators. Furthermore, data such as student home addresses are subject to personal data protection restrictions, limiting their integration. The SDSS may rely on indirect estimates or secondary sources, which affects the accuracy of the results [74]. Addressing these challenges requires upgrading existing systems, integrating geospatial information, and establishing synergies with entities such as statistical services and educational registries.

Interoperability and system integration: The development of an SDSS requires the integration of different digital infrastructures, such as databases, GIS, algorithmic models, and web applications. However, incompatibilities arise in terms of file formats, coordinates, or software requirements. For example, administrative data in Excel must be combined with shapefiles from geographic organizations, which requires technical expertise. At the same time, the integration of computational models and their parameterization often exceeds the capabilities of staff. Specialized software or tailor-made applications are required, increasing costs and limiting wider use. Furthermore, integration into existing workflows (such as student records) increases technical requirements. As noted, “the complexity of SDSS can be a barrier to their adoption” [26].

Technological infrastructure costs: Although open GIS tools have reduced initial costs, the full operation of an SDSS requires investment in equipment, software licenses, application development, and technical support. In many cases, institutional resources are limited, especially when there is no provision for system maintenance and updating after the completion of funded projects. Technology evolves, security needs increase, and data requires constant updating.

Data security and protection: The use of sensitive information (such as student geolocation or socioeconomic data) creates increased requirements for security and compliance with the legal framework on personal data. Technical measures such as encryption, strong access controls, network security, and logging are re-

quired. These increase complexity and require specialized staff. Lack of trust in systems may deter educational institutions from participating due to fears of data leakage or misuse.

GeoAI and predictive analytics as an emerging direction: Beyond current technical constraints, a growing direction for SDSS in higher education planning is the integration of predictive analytics (including Machine Learning) to support proactive decision-making under uncertainty. Predictive models can enrich scenario design by forecasting enrollment demand and testing the robustness of planning options (e.g., alternative service locations or capacity configurations) before implementation, complementing established SDSS practices in spatial optimization and decision evaluation [40]. Such integration also aligns with the broader SDSS paradigm of combining spatial decision models (e.g., multi-criteria evaluation and optimization) with evidence-based planning, while extending these models toward forward-looking predictions rather than purely descriptive assessments [41]. However, predictive components introduce additional requirements for data quality, transparency/interpretability, and bias monitoring, which are particularly critical in education policy contexts where equity is a core objective [39].

4.2. Organizational and Administrative Issues

The integration of a Spatial Decision Support System (SDSS) into higher education is not only a technical challenge, but also a profound organizational and administrative one. It requires strong political and administrative commitment, cross-sectoral cooperation, and the development of new roles, such as that of the geospatial data analyst. At the same time, it is essential to cultivate a culture of evidence-based decision-making and to transition from traditional models of administration to more flexible and transparent forms of governance.

Lack of institutionalized collaboration and coordination: Developing an SDSS requires collaboration between ministries, universities, research institutions, and other organizations. However, the absence of a stable coordination mechanism often leads to fragmented actions. The lack of a common data-sharing infrastructure or institutional link between the actors involved undermines the synergy and functionality of the system.

Policy discontinuity and institutional inertia: The implementation and maintenance of an SDSS is affected by institutional discontinuity. Changes in political or administrative leadership can lead to the abandonment of initiatives, even if they are successful. At the same time, slow and rigid public sector procedures hamper the flexibility needed to adapt SDSSs to constantly changing conditions.

Lack of know-how and training: Limited familiarity of staff with GIS tools and spatial analysis techniques is a major obstacle. Reliance on external partners, without investment in building internal expertise, is not sustainable. At the same time, the lack of training for end users leads to the underutilization of the SDSS's decision-making capabilities.

Resistance to change and organizational mindsets: The introduction of an SDSS

brings about changes in an organization's operations and hierarchies, often causing internal resistance. Increased transparency and the highlighting of potential problems can be perceived as a threat. A lack of understanding of the advantages of GIS technology reinforces reluctance to implement it.

Bureaucracy and lack of flexibility: SDSS require continuous data updates and the ability to make dynamic interventions. However, the bureaucratic nature of public organizations, with static planning cycles and time-consuming procedures, does not favor the effective use of such tools. Delays in decision-making can render the interventions proposed by the system obsolete and ineffective.

4.3. Human Factors and Culture

The successful adoption of a Spatial Decision Support System (SDSS) does not depend solely on technical or institutional components, but also on a range of human and cultural parameters that are often less visible but decisive. The attitudes, perceptions, fears, and motivations of end users largely determine the acceptance or rejection of the system in practice.

User resistance and psychological barriers: Even when users have been trained in the use of an SDSS, deeper psychological barriers may persist that limit the use of the tool. Technophobia, especially among older people or those with limited experience in using digital technologies, is a common phenomenon. The use of a GIS in a public decision-making environment may cause embarrassment or fear of failure. For example, studies on educational technology report phrases such as "fear of using GIS software" [75] and "lack of comfort with technology" [76]. These attitudes are closely related to a lack of practical experience, uncertainty about one's abilities, and doubts about the usefulness of the system, especially when it is in an experimental stage.

Interpretation of results and trust in the system: Interpreting the results produced by an SDSS is a critical challenge. Users are required to read thematic maps, statistical charts, and complex indicators. When adequate explanation is lacking, the indications may cause mistrust. For example, reporting "80% suitability" for an area may be considered arbitrary without clear documentation. A typical example is the difficulty in accepting suggestions from the system when they contradict users' empirical knowledge, as in the reaction: "Why is this area classified as problematic when registrations were successful?". Trust in the system requires understanding of the methodology, involvement of end users in the design, and full transparency in the mechanisms for producing predictions [77].

Absence of a culture of evidence-based decision-making: In many cases, decision-making in education policy is based more on political expediency, historical precedents, or institutional habits than on thorough data analysis. Even when data are available, they may be ignored or undermined when political considerations or electoral costs dictate a different course. An SDSS cannot function as an automatic mechanism for change. Instead, it needs to be gradually integrated into the decision-making cycle as a tool that enhances human judgment rather than re-

placing it.

Balance between technological trust and human judgment: Overreliance on technology can lead to wrong decisions. Accepting the results of an SDSS as infallible, simply because “the system says so,” overlooks methodological assumptions, errors in input data, and model limitations. An SDSS should function as a tool to enhance, not replace, human thinking. Conscious use, with evaluation and judgment, is a prerequisite for its safe exploitation.

Motivation and recognition of users’ role: Active participation of users in an SDSS is enhanced when their contribution is recognized and rewarded. When using the system is seen as “extra work” with no payoff, it’s often neglected. Conversely, when linked to quality indicators, evaluation, or professional development, it acts as a motivator. This recognition is critical not only for daily use but also for establishing the importance of SDSS as a strategic management tool.

4.4. Institutional, Legal and Ethical Issues

The implementation of an SDSS in higher education is not merely a technological challenge, but requires a coherent institutional, legal, and ethical framework to guide and legitimize its use. The absence of such a framework or the existence of distortions may lead to implementation failure, even when the system is technically adequate.

Legislation and data protection: A key obstacle is the strict legal framework for the protection of personal data, such as the GDPR in the European Union. Student data, particularly when it contains geographical or identifiable information, is considered highly sensitive. Restrictions on sharing or the need for anonymization often limit the spatial accuracy and analytical power of an SDSS. The operational use of such data requires clear regulations and coordination at the institutional level.

Institutional framework and strategic integration: In many countries, including Greece, there is no explicit institutional provision for the role and mandatory use of SDSS in educational administration. These are often fragmented initiatives without continuity or institutional support. The absence of regulatory provisions incorporating the use of SDSS in planning and evaluation processes makes their implementation uncertain and dependent on individual agencies or individuals.

Policy interventions and institutional distortions: The effectiveness of an SDSS is undermined when its results are ignored for reasons of political expediency. The conflict between rational planning and political interests can turn SDSS into a tool for ratifying decisions that have already been made. The lack of political commitment to use the system’s findings limits its strategic value.

Ethical issues and transparency: The selection and weighting of indicators, the analysis criteria, and the algorithmic assumptions carry value judgments. Prioritizing efficiency over equity, for example, is an ethical choice. A lack of transparency in the design or participation of stakeholders can lead to the rejection of the results. The legitimacy of an SDSS requires open documentation, institutionalized

participation, and clear limits on use.

Institutional continuity and sustainability: The sustainability of an SDSS depends on its support over time. In environments with administrative instability, information systems are often abandoned after changes in political leadership. If the SDSS is not institutionally embedded, it is vulnerable to disruption, with serious consequences for transparent and informed decision-making. For this reason, its institutional integration is a necessary prerequisite for its long-term performance.

4.5. Political and Social Constraints

The technical soundness of an SDSS is not sufficient for its effective integration into decision-making processes. Its success depends on political, institutional, and social factors that influence its use and acceptance. Despite its benefits in terms of transparency, accountability, and rationality, its implementation often encounters political obstacles, administrative inertia, and social resistance.

Political acceptance and support: Active support from political leaders is crucial for the adoption and use of an SDSS. Without political will, such tools remain inactive or are implemented in a fragmented manner. Leaders must not only recognize their usefulness, but also commit to using their findings, even when they highlight complex or unpopular issues. Similarly, their implementation in polarized environments or those with low institutional trust may provoke suspicion, with data being perceived as biased or manipulated. Pilot implementation, accompanied by evaluation, can strengthen their legitimacy.

Social and local reactions: The introduction of SDSS in education policy may provoke resistance, particularly when it documents the need for interventions that affect existing structures. Local communities and trade unions may see the results as a threat to the presence of university units in their area. The involvement of stakeholders in the design and implementation of SDSS is essential to ensure that it is perceived as a tool for documentation rather than enforcement.

Trust and transparency: Social acceptance depends to a large extent on the degree of transparency in the use and communication of findings. When decisions are presented in a documented manner, with understandable graphs and spatial representations, understanding and trust are enhanced. Conversely, the use of technology to validate existing policies without dialogue increases mistrust and resistance.

Resilience to change: An SDSS can highlight the need for extensive reforms, such as mergers or departmental relocations. In institutionally rigid or conservative environments, such changes are often rejected regardless of their validity. Political leaders must weigh both the validity of proposals and their potential for social acceptance and implementation so that they do not remain unutilized due to resistance.

5. Conclusions

This paper has demonstrated that Spatial Decision Support Systems (SDSS) are

powerful tools for strategic thinking and informed decision-making in higher education. Through a systematic literature review, we showed how SDSS, by combining geospatial analysis, multiple data sources, and dynamic decision support functions, enable complex educational problems to be approached in a holistic, transparent, and scalable manner. However, their use in educational policy, particularly in higher education, remains limited and uneven, despite their well-documented contribution in other sectors such as urban and environmental planning.

Higher education is an institutionally complex and politically sensitive sector where the need for evidence-based, geographically tailored interventions is more pressing than ever. Despite advances in analytical technologies and the wealth of available data, there is a significant lag in the integration of SDSS into policy design and evaluation processes. There is a lack of institutional framework, insufficient interoperability between information systems (e.g., EMIS, GIS, statistical platforms), and a lack of mechanisms for evaluating the effectiveness of such interventions.

This article makes a double contribution: on the one hand, it accurately records existing SDSS applications in higher education, methodically highlighting their uses and dynamics; on the other hand, it proposes a unified analytical framework for assessing the feasibility and limitations of SDSS, contributing to the development of a common research and implementation discourse. A comparative review of international experience has shown that in countries with limited resources, SDSS are mainly used to combat geographical inequalities and enhance access, while in developed environments they focus on sustainability, energy efficiency, and the design of “smart” campuses. However, fragmentation of approaches, underrepresentation of rural and remote areas, and persistent inability to use quality and up-to-date data for long-term planning remain evident.

The application of SDSS to educational governance offers tangible opportunities: identifying areas with low educational coverage, documenting policies for merging or establishing new departments, forecasting future needs, and supporting a geographically equitable and socially sensitive policy. Examples studied in this paper demonstrate their potential value even in low-resource environments. The integration of social, economic, and geospatial data, combined with visualization in interactive tools, makes policies more transparent, participatory, and resilient over time.

Despite the theoretical maturity and recognized potential of SDSS, their adoption in higher education faces a complex and multi-layered set of barriers. The analysis highlighted critical technical challenges, such as insufficient access to quality and up-to-date data, difficulty of interoperability between heterogeneous information infrastructures, increased computing resource and security requirements, and development and maintenance costs. However, beyond technical issues, there are significant organizational and administrative barriers: the lack of institutionalized coordination, limited expertise, the absence of a culture of evidence-based decision-making, and administrative rigidity seriously limit the potential for inte-

grating SDSS into educational planning processes. In addition, human and cultural factors, including technophobia, distrust of technology, lack of motivation, and excessive dependence on the system's results, largely determine its ultimate acceptance or rejection. Institutional, legal, and ethical challenges, including data protection, lack of a legal framework for use, political interference, and lack of institutional continuity, complete the landscape of barriers. Finally, the implementation of an SDSS cannot be isolated from its socio-political environment: without political will, social trust, transparency, and adaptability to emerging changes, even the most well- and technically sound system risks remaining inactive or being misinterpreted. The findings indicate that the successful integration of an SDSS into educational policy requires a holistic approach that combines technical competence, institutional support, and active user participation in an environment of trust and continuous reflection.

Building on the findings of this review, future work should be framed as a research and implementation roadmap for SDSS in higher education governance. Priorities include: 1) designing and validating an SDSS reference architecture tailored to tertiary education, 2) integrating decision models beyond visualization (e.g., multi-criteria evaluation, scenario simulation, and location-allocation optimization), 3) ensuring interoperability with educational and statistical information systems under robust data governance, and 4) evaluating usability and institutional adoption through real decision contexts. This roadmap positions SDSS as actionable infrastructures that can strengthen transparent, spatially equitable, and evidence-based policy formulation in higher education.

The path to a digitally enhanced education policy does not simply involve the integration of SDSS. It involves redesigning the very logic of decision-making. SDSS are no longer static information tools but evolving computational ecosystems capable of interacting with artificial intelligence, real-time data, decentralized information networks, and adaptation algorithms. Internally, they incorporate predictive analytics, spatial dynamics models, and self-learning mechanisms, transforming educational design into a continuous, intelligent, and localized system for supporting strategic thinking. The challenge is no longer technical, and it is strategic and institutional: how do we create conditions for systems that predict, transform, and learn simultaneously with the society they serve?

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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