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Designing a Sustainable Forest Information System: A GIS-AHP Model for Policy-Constrained Decision Support and Information Management

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Abstract

In recent years, the occurrence of forest fires has increased across many regions of the world, creating significant risks for biodiversity and intensifying global concern regarding the conservation and sustainable utilisation of forest resources. In response to these challenges, this study develops a forest resource sustainability assessment system that operates within a geographic information system framework. The system is constructed, implemented and subsequently evaluated to determine its effectiveness. Building on this foundation, the study examines the degree of policy convergence associated with sustainable forest information systems and puts forward recommendations for improving budget performance management. The principal findings are summarised as follows. (1) The relative weights assigned to schemes C1, C2, C3 and C4 are 0.205, 0.267, 0.309 and 0.220, respectively. Among these, Scheme C exhibits the highest relative weight, indicating that it represents the most suitable alternative. (2) The Forestry Bureau's management planning process is highly intricate because it incorporates ecological, economic and social dimensions of forest benefits. Each plan reflects a different prioritisation of these three categories of benefits. (3) All four evaluated schemes satisfy the requirements of the consistency test. The optimal scheme is characterised by its emphasis on economic benefits, supported by ecological and social considerations. (4) The division of policy convergence into two causal forms, namely obedience and acceptance, offers a direct explanation for convergence patterns within forestry-related budget performance management. The underlying factors contributing to such convergence are examined through established analytical approaches and game theory.

Keywords: Forestry Information System, Forest Information System, Policy Convergence, Budget Performance Management.

Introduction

In recent years, the frequency of forest fires has risen across the globe, posing severe risks to biodiversity and intensifying international concern regarding both the conservation and the utilisation of forest resources. As early as 2014, the United Nations Open Working Group on Sustainable Development Goals (OWG) incorporated the objective of promoting sustainably managed forests to support efforts to combat desertification. Forest ecosystems represent some of the largest terrestrial carbon reservoirs, and their capacity to absorb carbon emissions enables them to make a substantial contribution to climate regulation and the attainment of carbon neutrality. More than 50 countries have already reached their peak $CO2$ emission targets (Lü and Hu, 2021; Zou, 2013). China is among these nations and has entered a new phase of development. However, the progressive articulation of national goals relating to carbon peaking and neutrality has introduced new pressures for the development and use of its forest resources. Since China holds extensive forest reserves, its approach to safeguarding and utilising these resources holds significant implications not only for national development but also for forest resource management at the global level. Consequently, it is essential for the Chinese forestry sector to develop a more suitable mechanism for allocating funds directed at forest resource protection (Myers, 2006, 2012).

To contribute to more effective and sustainable forest resource management, this study introduces a forest resource sustainability assessment system designed within a geographic information system environment. The system is developed, implemented and evaluated to determine its practical utility. Based on these results, the study further investigates the policy convergence associated with sustainable forest information systems and proposes a budget performance management strategy intended to support future research and practical applications.

Sustainable Forest Information Systems

Forest Geographic Information System (GIS)

GIS (Geographic Information System), referred to in Mei and Liu (2012), has undergone more than four decades of development, during which it has gradually matured into a stable and widely adopted technology. It is now applied extensively in fields such as environmental monitoring, resource assessment, transportation and navigation, and military operations. During the first decade of the twenty-first century, the role of GIS expanded considerably, largely because of its strong capabilities in spatial analysis, especially when integrated with GPS technologies and route optimisation procedures (Mason, 2013). GIS operates on geospatial databases and relies on computer hardware and software, drawing upon concepts from systems engineering and information science. Through this framework, GIS supports the effective management and detailed analysis of spatially related geographic data and offers a technical foundation for managerial tasks and policy decision-making (Heichel et al., 2005; Holzinger et al., 2008).

The core functions of GIS include data acquisition, data editing, storage and management, spatial querying, analytical processing and the visual presentation and dissemination of outputs. To ensure high-quality outcomes, the GIS database must maintain integrity and logical coherence across both temporal and spatial dimensions. GIS is inherently interdisciplinary. Geography provides the conceptual framework and analytical approaches for spatial investigation (Drezner, 2001); surveying and mapping supply the positional datasets and associated algorithms necessary for processing and transforming spatial information; and computer science contributes a variety of supporting technologies, including remote sensing, digital processing, data storage and visualisation tools. The principal characteristics of GIS can be summarised as follows.

1. It is founded on shared geographic location information.
2. It enables the unified storage and management of extensive spatial and attribute data while supporting systematic and scientifically grounded planning and design processes.
3. Its spatial analysis models facilitate effective simulation, informed selection of evaluation schemes and optimisation of alternatives according to practical requirements. This ensures the reliability of analyses involving spatial and attribute datasets and allows the generation of more advanced geographic information through dynamic prediction features.
4. It is designed primarily to support geographic analysis and decision-making, providing a platform for interactive spatial decision support.

A GIS-Based Forest Resource Sustainability Evaluation System

Principle of the System Design

During the whole design process of the regional forest resource sustainability evaluation system, the following principles should be followed:

Practical

The primary function of the system is to support decision-making in forest resource management and to enable computer-based evaluation of regional forest resource sustainability. For this reason, the design must be grounded in real needs and oriented towards addressing practical management challenges.

Easy to Operate

Since the system will be used by individuals at various levels, it must present an interface that is accessible, straightforward and simple to learn. The ease of operation often determines whether a software tool is widely accepted, making this principle essential.

Scalability

To accommodate future development, the system is constructed using a modular design. Each module operates with a high degree of independence, which means that adjustments, additions or removals of modules exert minimal influence on the system as a whole. This structure makes it easier to update, refine and extend the system as improvements become necessary.

Generality

To ensure that the system can be applied beyond a single region and serve a wide range of contexts, some functional components must be designed to be configurable. This allows the system to respond effectively to differing conditions and to the requirements of varied user groups.

Functional Structure Design of the System

The system realises the following categories of functions through a window-based interface combined with drop-down menu options. The map control function is responsible for importing geospatial information into the system, managing and displaying spatial graphics and supplying geographic data required for interpreting subsequent evaluation outcomes. The map control component incorporates several sub-functions, including selecting and displaying map files, zooming and panning across map views and identifying specific graphical elements within the map.

The database control function focuses on integrating the various datasets required for regional forest resource sustainability assessment into a unified database, which facilitates the extraction of indicator data during the evaluation process (Meyer et al., 2021). This component includes sub-functions such as opening and viewing the selected database, establishing links between spatial and attribute information and enabling the association between the indicator system and the calculation procedures that use attribute data. The indicator system and evaluation computation function support the creation of the regional forest resource evaluation indicator framework, the retrieval of indicator values from the database and the calculation of the necessary metrics (Dupuy, 2014; Popp, 2021). Sub-functions include the configuration and revision of the indicator system, extracting and computing relevant indicator data from the forest resource evaluation database and generating evaluation outputs.

The evaluation results analysis function is designed to facilitate comparative study of sustainability assessment outcomes and to support the creation of graphical outputs. Its sub-functions include generating comparison maps of evaluation results for multiple regions using geographic information and producing comparison maps that display indicator values across regions based on spatial data. The data preservation and recovery function enables the system to store the indicator system, database and final evaluation outputs used in the regional forest resource sustainability assessment. It also allows previously saved information to be reloaded into the evaluation environment, supporting discontinuous operation and enabling future access to historical datasets (Bennett, 1991).

Design of the Index System and the Evaluation and Calculation Function Module

The index system mainly realises the presentation of the indicator framework and allows users to modify its components. These adjustments may involve adding new indicators, removing existing ones or altering the assigned weights within the system. Once the user selects the evaluation area, the indicator structure is displayed in a tree format. When an indicator node is chosen, the interface automatically presents the information associated with that node in the text box positioned below the tree. Right-clicking on the tree activates a menu that permits additions or deletions of indicators, depending on the type of node selected. The tree contains three categories of nodes: root nodes, branch nodes and leaf nodes (Li and C., 2010; Xia and Wang, 2006).

The evaluation calculation function is designed to obtain the actual indicator values and perform sustainability calculations for regional forest resources. Although many indicator values can be retrieved directly from the evaluation database, some values do not exist in a ready-made form and must be derived from related data stored within the system (Chang, 2004). For example, an indicator such as per capita forest area may not be explicitly recorded in the database. However, demographic information for the relevant county and forest area survey data for all sub-compartments can be found, enabling the required indicator value to be calculated. Accessing such information can be achieved through embedded SQL language, which extends standard SQL for use directly within applications. For instance, the sum of forest areas across all sub-compartments of a county can be obtained using a statement such as:

SELECT SUM ("Area") FROM evaluation database WHERE "County Name" =.

Since users may not be familiar with SQL, the system must include an interface that assists in generating SQL statements. Through this function, users can obtain the required data automatically by relying on the system to construct the appropriate SQL queries.

System Application of Forest Sustainable Evaluation System Based on GIS

Essential Information

The Baihe Forestry Bureau covered a total area of 190,470 km^2 in the year 2000, comprising ten forest districts and 13,750 sub-compartments. Forestry land occupied 182,445.8 hm^2, representing 95.79 percent of the entire area, while non-forestry land accounted for 8,024.2 km^2, or 4.21 percent. Woodland formed 171,354 km^2 of the total, which corresponds to 89.96 percent of the bureau's area. Tree species within the Baihe Forestry Bureau originate from two main sources, namely plantations and natural forests. Natural forests are further divided into two types: mature natural growth and naturally regenerated stands. Their respective distributions within the Baihe Forestry Bureau, based on area, are presented in Table 1.

Table 1: Statistics of Origin Distribution of Tree Species.

Origin of Tree Species	Plantation	Natural Forests		Else; Other; Other One
		Real Life	Produce; Conceive	
Acreage	13454.4	160308.8		16706.8
		159169.8	1139	
Percentage of the Total Area	7.10%	84.16%		8.77%
		83.56%	0.6%	

Alternative Scheme

In making decisions related to sustainable forest management, the management plan serves as the fundamental reference, and the selection of the most appropriate plan is essential for ensuring that ecological, economic and social benefits develop in a balanced and mutually reinforcing manner. Forest management plans typically encompass a wide range of complex elements, and the three major benefit dimensions of forest resources play central roles. However, the relative priority assigned to ecological, economic and social benefits varies depending on specific management goals. On the basis of these differing emphases, this study proposes four hypothetical management schemes, which are presented in Table 2.

Table 2: The 4 Programmes for Sustainable Forest Management.

Plan	The Consideration of the Three Major Benefits in the Operation
Scheme C1	At the same time, ecological, economic and social benefits are considered
Scheme C2	Focus on considering the ecological benefits, supplemented by considering the economic benefits and social benefits
Scheme C3	Focus on considering economic benefits, supplemented by considering ecological benefits and social benefits
Scheme C4	Focus on considering the ecological benefits and economic benefits, supplemented by considering the social benefits

Scheme Selection

Following the construction approach used for the earlier judgment matrix, pairwise comparisons are carried out. In accordance with Saaty's 1 to 9 scaling method, a judgment matrix is developed for the three primary benefit categories in sustainable forest management, namely ecological, economic and social benefits. The resulting matrix is presented in Figure 1.

After normalisation, the weights assigned to ecological, economic and social benefits within the framework of sustainable forest management are 0.297, 0.539 and 0.164. The contribution of each forest type varies when these three categories of benefits are considered. For instance, timber forests are generally more effective in supporting economic outcomes than shelterbelt forests or special-use forests. Consequently, the four forest categories carry different weights in terms of their ability to contribute to ecological, economic and social functions. Figure 2 presents the judgment matrix, the calculated weights and the corresponding test coefficients for the four forest types in relation to the three benefit dimensions.

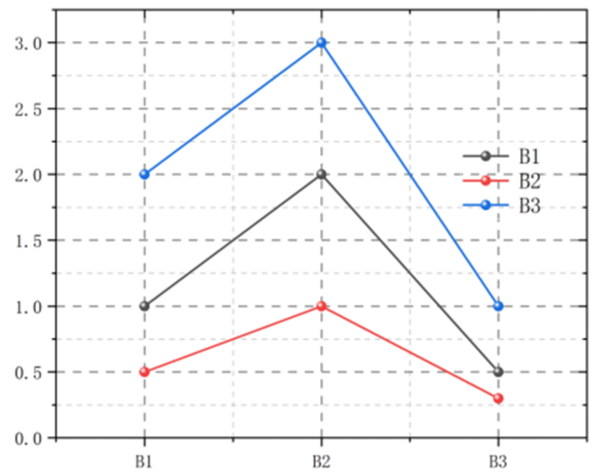

Figure 1: Judgment Matrix of the Three Major Benefits.

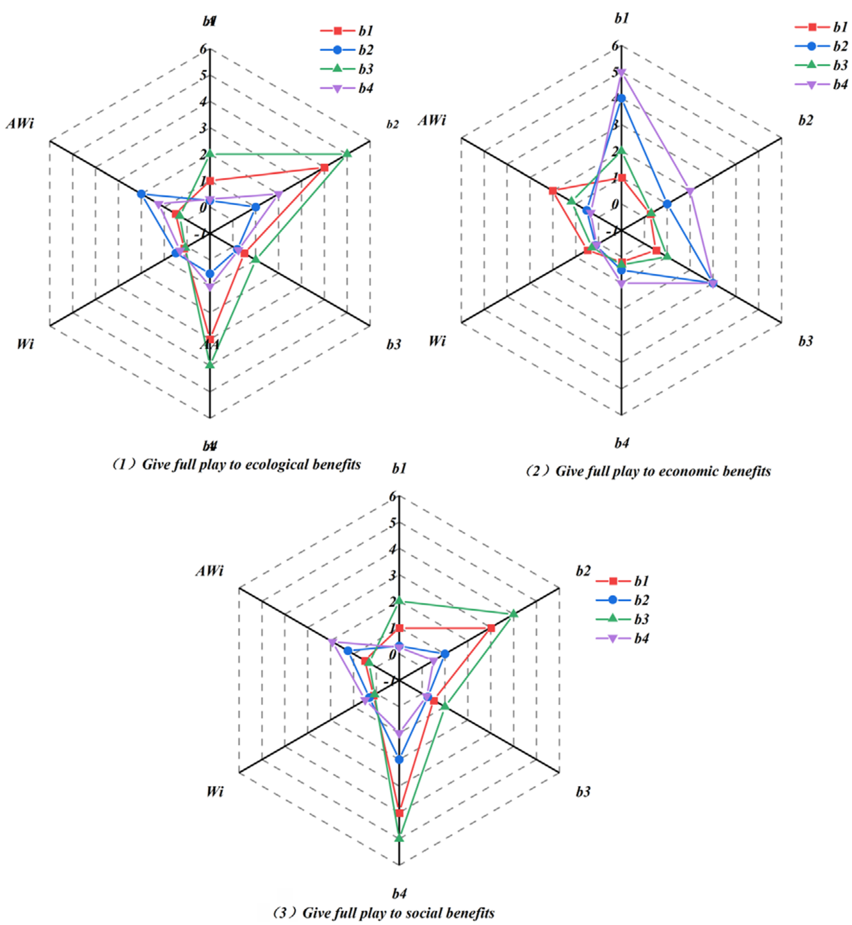

Figure 2: Judgment Matrix of the Four Forest Species.

The consistency of the judgment matrix for the four forest types in relation to the three primary benefits is deemed acceptable. Although the four forest types contribute similarly across ecological, economic and social dimensions, the four proposed management plans assign different weights to timber, shelterbelt, economic and special-use forests. Figures 3 and 4 present the judgment matrices for each forest type corresponding to the four management schemes.

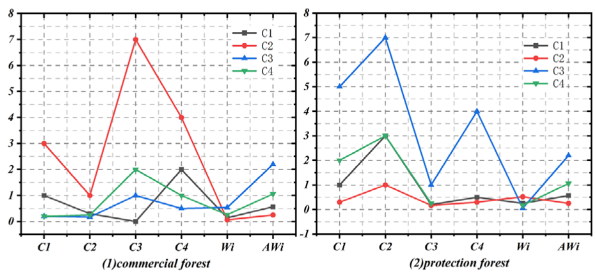

Figure 3: Judgment Matrix of the Four Business Schemes for All Kinds of Woods.

It can be observed that the consistency of these judgment matrices is also within acceptable limits. Sustainable forest management in the Baihe Forestry Bureau encompasses three primary benefit categories, each of which is realised through a combination of four forest types. By applying the weights assigned to the three benefits, the corresponding relative weights of the four forest types in the overall forest sustainability management can be determined as follows.

The weight of the three primary benefits in sustainable forest management:

$$\Omega = \begin{pmatrix} 0.297 \\ 0.539 \\ 0.164 \end{pmatrix}$$

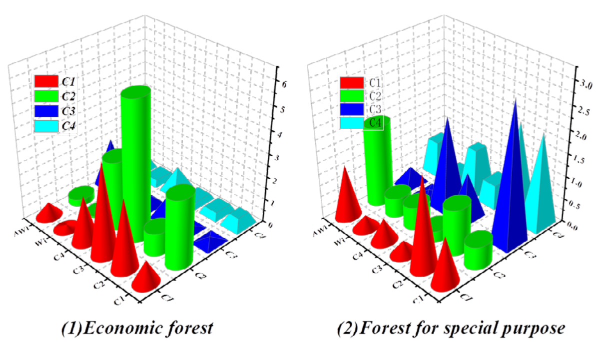

Figure 4: Judgment Matrix of the Four Business Schemes for All Kinds of Woods.

Figure 5 presents the relative weights of the four forest types in relation to ecological, economic and social benefits. Using the same methodology described previously, the weights and consistency tests for the sub-decision layer, specifically for the four forest types in sustainable forest management, can also be obtained.

Calculation of the combination weights:

$$\omega = (0.297 \quad 0.539 \quad 0.164) \begin{pmatrix} 0.126 & 0.490 & 0.079 & 0.305 \\ 0.496 & 0.130 & 0.289 & 0.086 \\ 0.126 & 0.305 & 0.079 & 0.490 \end{pmatrix}$$

$$= (0.297 \times 0.126 + 0.539 \times 0.496 + 0.164 \times 0.164 \times 0.126, 0.297 \times 0.490 + 0.539 \times 0.130 + 0.164 \times 0.305, 0.297 \times 0.097 + 0.539 \times 0.289 + 0.164 \times 0.079, 297 \times 0.305 + 0.539 \times 0.086 + 0.164 \times 0.490)$$

$$(0.325, 0.266, 0.192, 0.217)$$

Therefore, the weights assigned to timber, shelterbelt, economic and special-use forests in sustainable forest management are 0.325, 0.266, 0.192 and 0.217, respectively. Using the same procedure as described above, the relative weights of scenarios C1, C2, C3 and C4 under the overall objective of sustainable forest management are calculated as 0.205, 0.267, 0.309 and 0.220, respectively. The combination consistency index for these calculations is 0.017, which falls within acceptable limits. Accordingly, Scheme C3, having the highest relative weight, is identified as the optimal management scheme.

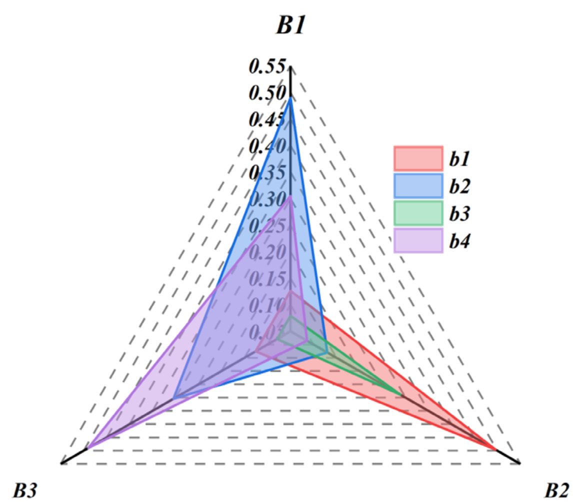

Figure 5: The Relative Weight of the Four Forest Species in the Three Major Benefits.

Research on Policy Convergence and Surplus Performance Management

This study examines and demonstrates the convergence of budget performance management (PM) policies within provincial forestry departments. Building on prior research, the analysis focuses on the alignment of policy objectives, content, instruments and implementation style (Ma, 2009), providing a foundation for evaluating budget policy convergence in Chinese forestry authorities. The 20th National Congress of the Communist Party of China, a pivotal event in the country's development trajectory, took place in the same year. This research collates policy documents relevant to current budget PM issued by national and provincial forestry authorities since the 19th National Congress in 2017. Documents were provided by Chinese officials and 17 provincial governments and are accessible via PKULAW.com and the official websites of the respective finance departments.

All documents considered in this study were active at the time of submission and cover 17 provincial regions across northeast, northern, northwest, southwest, southern, eastern and central China, thereby reflecting diverse forest conditions across different geographical settings. These regions represent approximately half of China's provinces, autonomous regions and municipalities. The remaining regions can be categorised into two groups. Some follow centrally issued policies, analogous to the alignment of federal and state tax policies in the United States (Mayo, 1975; Ren and Chen, 2017). In other regions, however, forestry is not the principal natural resource, with local priorities oriented toward agriculture, animal husbandry, fisheries or mineral extraction. Consequently, these areas are less representative for analyses of forestry budget PM content.

To provide an intuitive explanation of policy convergence, this study adopts Myers' classification of two forms of consistency—obedience and acceptance—and investigates the underlying causes (Mikesell, 2020). The reasons for observed convergence are analysed through established game-theoretic approaches and are interpreted within the framework of public sector institutional relationships and integrative psychology (Zhu et al., 2015). By applying this research framework, the study explores the factors driving policy convergence in the budget project management of China's provincial forestry departments.

Obey to the Policy Convergence Caused by Conformity

Within China's current institutional framework, the central government enforces policy implementation through mandatory measures (Xie and Xiao, 2019). Local forestry departments bear full responsibility for the budget items under their jurisdiction, while national forestry authorities oversee and supervise the execution of these budgets. For clarity, this study categorises institutions into national and provincial forestry departments. The provincial forestry department is designated as a "same-level" department, the national forestry department as a "superior department," and the county forestry department as a "lower-level" department. Departments at the same level face two options when implementing policies issued by superior authorities: full compliance or appropriate adjustment. Local departments generally opt for full compliance, which limits the development of forestry-specific budget PM practices and contributes to policy convergence. Several factors underpin this tendency.

In interactions between superior and subordinate departments, the superior possesses two main instruments: rewards and punishments. Departments are therefore more likely to fully comply rather than risk penalties by making adjustments to the superior's budget PM policies. Since higher authorities are responsible for national-level macro policies and societal stability, it is considered reasonable for them to penalise certain departments for inappropriate adjustments. Even when a department chooses full compliance, it may still face inverse incentives, indicating that paternalistic leadership exerts dual influences. First, it reinforces complete obedience among peer departments at the same level, discouraging independent adjustments. Second, this authority extends downward, encouraging subordinate departments to also adhere strictly to superior directives. As a result, same-level departments are less inclined to make modifications to policies issued by higher authorities. In cases where adjustments are necessary to implement budget project management procedures, departments risk punitive action from the superior department.

This analysis suggests that provincial forestry departments fully observe the budget PM policies formulated by superior authorities to ensure compliance and avoid sanctions. This behaviour aligns with the findings of Obedience Experiment 2, demonstrating that individuals tend to follow authority. As regional and provincial forestry departments recognise that their decisions may be rewarded or punished by superior bodies, their actions converge to maintain consistency and minimise risk. This approach reduces the likelihood of incurring excessive tangible or intangible costs. At the same time, higher authorities may implement punitive measures applicable across peer departments; however, if multiple departments are penalised, the sense of urgency diminishes, and the ideal state of "peer department" differentiation becomes difficult to achieve.

Acceptance of Policy Convergence Due to Consistency

Under China's current institutional framework, provincial forestry departments face two simultaneously opposing forces. First, as subordinate units, their primary response is influenced by an obedience mentality, as discussed previously. Second, they are affected by the actions of peer forestry departments at the same hierarchical level. When lower-level departments accept the practices of their peers, it facilitates broader and more effective implementation of budget project management, largely as a mechanism to align with peer behaviour and protect the interests of the group. From this perspective, the acceptance-based consistency of provincial forestry departments contributes significantly to policy convergence in budget management.

The first scenario, in which lower-level departments accept directives from superior authorities, mirrors the obedience dynamic described earlier. However, the locus of influence shifts within the organisational hierarchy. When a superior department communicates budget management requirements to a subordinate unit, the latter has two options: full compliance or appropriate modification of the superior's policies. Once a choice is made, the subordinate unit's response may take the form of acceptance or rejection. Macro-level factors, including the vertical organisational structure of the public sector and bureaucratic management practices, create inherent risks for subordinate units that attempt to reject superior directives. Consequently, peer departments at the same level frequently opt for complete compliance with superior decisions, which accelerates policy implementation, enhances performance, and reduces the costs and risks associated with policy adjustments. This alignment simplifies the acceptance process for lower departments, promoting smoother execution of specific policies. Nonetheless, the hierarchical rollout of budget PM policies complicates the integration of local conditions, making tailored adjustments challenging and reinforcing policy convergence. Thus, provincial forestry departments occupy a critical intermediate role within the institutional hierarchy.

Second, consistency in acceptance can also emerge among departments at the same level, though the underlying dynamics differ from those described previously. Peer-level departments that fully comply with superior policies reduce disputes arising from unhealthy competition and efforts to secure additional development resources. This mutual acceptance fosters a herd-like behaviour, whereby departments hesitate to diverge from the majority, analogous to a reluctance to be "the first to take risks." Such collective conformity reinforces policy convergence during the implementation and promotion of budget project management rules.

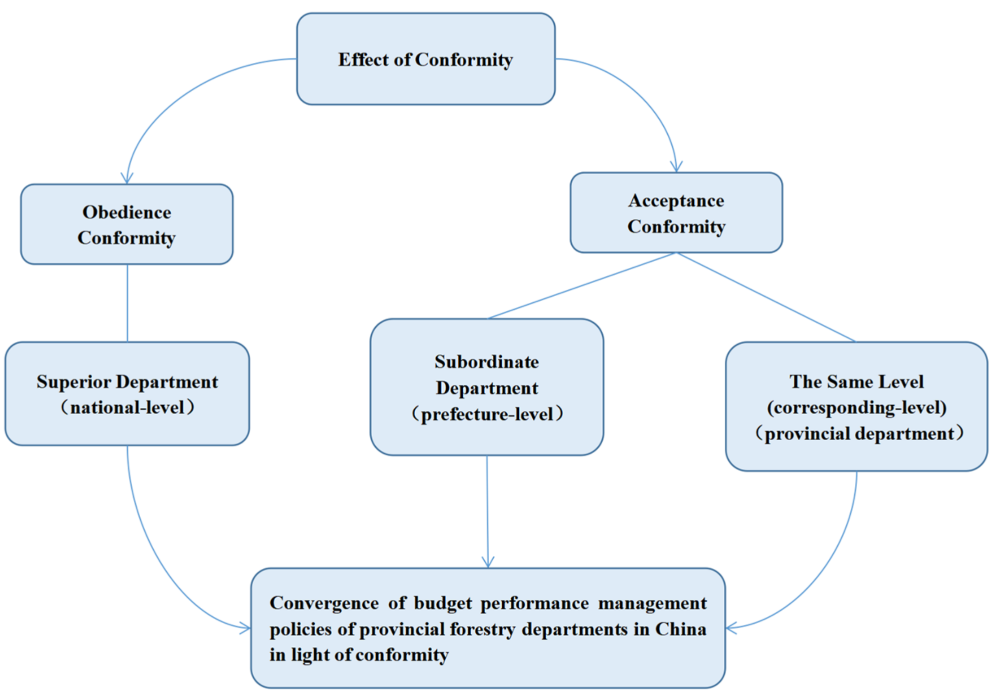

Figure 6: Convergence of PM Policy of Provincial Forest Department Budget Caused by Consistency.

Policy convergence is further reinforced when some provincial departments comply fully with superior directives while others make minor adjustments according to local conditions. Departments that follow superior instructions closely often implement policies more effectively, creating an implicit incentive for others to align their practices. Departments that modify policies slightly may experience comparatively lower efficiency, encouraging consistent adherence to standard procedures. While it is theoretically possible for most provincial departments to adapt policies to local circumstances, in practice this occurs infrequently, and widespread conformity continues to dominate, sustaining the convergence of budget PM practices.

From the analysis above, it is evident that, regardless of the options available to implementing departments, forestry departments at a given level tend to fully comply with and adopt policies issued by higher authorities. This approach represents a practical and rational implementation strategy at the provincial level. The choice is primarily shaped by the reward and punishment mechanisms imposed by superior departments, as well as by the acceptance behaviours of subordinate and peer departments. To ensure psychological security, provincial forestry departments typically make cautious decisions that align with the practices of the majority of provinces. This tendency results in policy convergence, a phenomenon clearly reflected in China's forestry budget performance management policies.

The Influence of the Internal and External Environment

Existing research on policy convergence identifies four main types: σ convergence, which arises from a reduction in policy diversity; β convergence, driven by developing countries attempting to catch up with developed nations; γ convergence, which occurs when relative rankings change as countries compare policy outcomes across different periods; and δ convergence, resulting from coordinated efforts by countries or organisations to follow a common benchmark. Among these, σ convergence primarily reflects the lack of diversity in national policy formulation, whereas β-, γ- and δ-type convergences are influenced predominantly by external actors. Consequently, the causes of policy convergence can be classified as either internal or external. Building on this framework, the present study further examines the factors driving policy convergence in China's forestry budget PM.

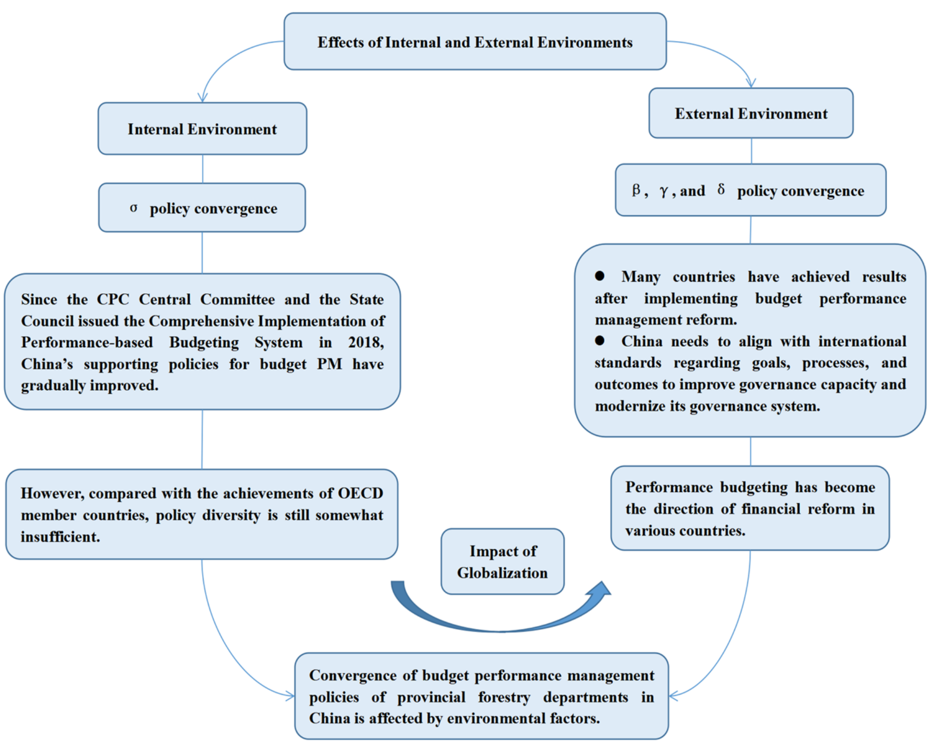

Figure 7: Policy Convergence of Provincial Forestry Departments Caused by Environmental Factors.

Regarding σ convergence, domestic factors are particularly significant. Since the Communist Party of China (CPC) Central Committee and the State Council issued the Comprehensive Implementation of the Performance-based Budgeting System in 2018, policies supporting budget PM have gradually improved. Nevertheless, in comparison with the achievements of OECD member states, the range of policy diversity in China remains limited. Given the country's extensive forest resources and the heterogeneous distribution of these resources, the insufficient diversity in budget PM policies easily facilitates convergence in forest budget performance management.

Second, external influences account for the subtle differences underlying β, γ and δ types of policy convergence. Generally, δ convergence emphasises alignment of development goals, β convergence focuses on the convergence of development processes, and γ convergence relates to the harmonisation of outcomes over time. Budget PM has its origins in Western countries. In response to economic crises during the 20th century, these countries initiated the New Public Management movement, which prioritised maximising government performance. Simultaneously, public expectations demanded greater accountability to taxpayers and improvements in the efficiency of government expenditure. Within this context, governments increasingly emphasised performance management. By the end of 2018, most of the 36 OECD member states had implemented performance-based budgeting frameworks, and several non-OECD countries had also adopted similar approaches. Financial reforms in various countries have centred on performance-oriented budgeting, making the subsequent policy convergence in China's forestry sector unsurprising following the introduction of budget PM. As China continues to align its goals, processes and outcomes with international standards to strengthen governance and modernise its institutional framework, budget PM emerges as a critical component of institutional modernisation in the forestry sector. This process is inherently shaped by international practices, which naturally drives policy convergence.

Conclusion

To facilitate more rational and sustainable management of forest resources, this study proposes a GIS-based forest resource sustainability evaluation system and tests its functionality. On this basis, the convergence of policies within sustainable forest information systems is examined, and corresponding budget performance management strategies are developed. The principal conclusions are as follows:

1. Under the overarching goal of sustainable forest management, the relative weights of scenarios C1, C2, C3 and C4 are 0.205, 0.267, 0.309 and 0.220, respectively. The combination consistency index is 0.017, which satisfies the acceptable threshold. Among the scenarios, Scheme C3 has the highest relative weight and is therefore identified as the optimal scheme.
2. The management plan of the Forestry Bureau is highly complex, encompassing ecological, economic and social benefits. Variations in management objectives result in differing emphasis on these three benefit dimensions. To address this, the study establishes four hypothetical management plans and evaluates them to select the most suitable option.
3. Comparison of the four schemes indicates that all meet the consistency criteria. One particular scheme prioritises economic benefits while also incorporating ecological and social considerations, rendering it the optimal choice.
4. The classification of consistency into two forms, obedience and acceptance, provides a direct explanation for the observed policy convergence in forestry budget management.

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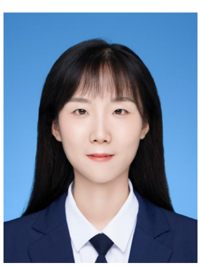

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