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ORIGINAL ARTICLE

An Exploratory Study for Modeling an Environmental Footprint Assessment

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Abstract

Excessive human activity driven by the pursuit of growth has pushed the Earth's environment beyond its capacity, leading to complex and unpredictable environmental crises. Accordingly, research on integrated approaches that align with the concepts of sustainability and environmental mainstreaming is ongoing. In this context, South Korea is currently implementing institutional changes and conducting continuous research to integrate land use and environmental planning. However, South Korea still faces various challenges in this integrated operation, and research on assessment tools that can reconcile the conflicting interests between land use and environmental conservation remains insufficient. Therefore, this study aimed to establish a conceptual framework for an environmental footprint assessment model as a foundational tool for achieving a balance between land use and environmental conservation in South Korea. This exploratory research was conducted through a literature review on sustainability and an analysis of case studies on sustainability assessment tools. Consequently, the study derived implications for effective and efficient environmental footprint assessment models that ensure sustainability in South Korea and proposed recommendations based on the country's institutional framework.

Key words : Sustainability, Sustainability assessment, Environmental mainstreaming, Environmental footprint assessment

1. Introduction

Unpredictable environmental crises caused by human activities that impact Earth's climate and ecosystems have long threatened the stability of the planet. In 1968, the ecologist Garret Hardin published "The Tragedy of the Commons," highlighting that activities aimed at human growth would deplete the environment and diminish its regenerative capacity. Additionally, the World Wildlife Fund (WWF) releases the 'Living Planet Report' every six months, presenting ecological footprint data for over 150 countries. According to these data, since the late 1980s, humanity has been consuming more resources annually than Earth can regenerate within the same year, exceeding the planet's sustainable capacity. Furthermore, according to 'The Global Risks Report 2024' published by the World Economic Forum, the current climate change-related risks for the next decade include extreme weather events,

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significant changes in the Earth's system, biodiversity loss, ecosystem destruction, and natural resource shortages.

In response to today's complex and interconnected global issues, numerous international cooperative frameworks have emerged to address environmental crises, beginning with the 1972 United Nations Conference on the Human Environment (UNCHE), followed by the 1987 Montreal Protocol and the 1992 UN Framework Convention on Climate Change (UNFCCC) at the Rio Conference. Simultaneously, to resolve conflicts arising from the exploitation of natural resources, the concepts of sustainability or sustainable development emerged in the 1970s, leading to continuous research. Sustainability and sustainable development are often interpreted as having nearly the same meaning. The concept and direction were outlined in the Brundtland Report published by the World Commission on Environment and Development (WCED) in 1987. This report indicates that sustainability is concerned with exploring the interrelationships among the causes of environmental degradation, social equality, and economic growth, with the goal of establishing policy solutions to address these issues (Jarvie, 2016).

In this context, various policies and development activities aimed at contributing to global sustainability are being studied, and quantitative assessment tools are being developed to evaluate the trade-offs in environmental values. Moreover, there is growing recognition that a single field's theories or problem awareness alone is insufficient to achieve a wise balance between human activities and the environment, emphasizing the need for an integrated approach. However, studies (Lafferty and Hoveden, 2003; Ahn et al., 2016; Nilsson and Persson, 2017) have pointed out that the integrated approach is still limited by its tendency to merely compile existing policies, lack inter-departmental connectivity, or suffers from insufficient policy applicability.

This study aims to establish the implications and a framework for a conceptual model of environmental footprint assessment as an effective integration tool, focusing on South Korea, which is currently attempting to manage national land and environmental planning in a unified manner. In March 2018, South Korea institutionalized the "Joint Directive for Integrated Management of National Land Planning and Environmental Conservation Planning," and has been collaboratively attempting to bring about policy and planning changes. Accordingly, through a literature review of sustainability and environmental mainstreaming and by examining assessment case tools being researched and implemented both domestically and internationally, this exploratory study seeks to propose directions for constructing an environmental footprint assessment model.

2. Methods and Materials

The methodology of this study involves a literature review on sustainability and environmental mainstreaming as well as an examination of case studies of assessment tools based on sustainability. The concept of sustainability was reviewed by examining its basic definitions and underlying principles. This study explores the role of sustainability assessment, criteria for establishment, and approaches to implementation. The case study analysis of the assessment tools focused on examples related to economic growth, the environmental impacts of human activities, and the classification of ecological values, both domestically and internationally. Particularly,

the analysis of assessment tools in South Korea considers those with a legal basis and established guidelines. Furthermore, these case studies were subjected to a detailed analysis by applying sustainability assessment evaluation criteria based on a literature review. Through this process, an exploratory study was conducted to establish the implications and framework for a conceptual model of environmental footprint assessment aimed at the integrated management of national land and environmental planning that can be practically applied in South Korea.

3. Results

3.1. Exploring sustainability concept and environmental mainstreaming

3.1.1. Sustainability and sustainability assessment

Sustainability has been extensively researched to resolve conflicts arising from the excessive exploitation of natural resources owing to the accelerated pace of development. It has become a central agenda in various fields such as urban development, the green economy, and the circular economy. The concept of sustainability, articulated in 1987 by the World Commission on Environment and Development (WCED), was developed to explore the causes of environmental degradation, examine the interrelationship between social equity and economic growth, and formulate policy solutions for sustainable development. In 1994, John Elkington popularized the term 'triple bottom line,' which integrates the three dimensions of sustainability: social, environmental, and economic.

When viewed independently of each of these three dimensions, sustainability can be considered as follows: environmental sustainability focuses on various types of pollution and impacts that affect the environment, with an emphasis on biodiversity; social sustainability emphasizes the bio-psychosocial environment and connections among people in relation to health, equity, and cultural heritage; and economic sustainability concentrates on wealth, employment, and the flow of money through long-term resource management (Vallance et al., 2011; Ajmal et al., 2018; Clune and Zehnder, 2018; Abbasi et al., 2023; Banco Santander, 2024). Sustainability encompasses the social, political, institutional, economic, and ecological aspects. However, when measuring sustainability, the relationships among these dimensions are often weighted differently depending on the specific sub-goals, leading to varying interpretations.

Based on the concept of sustainability, continuous research has been conducted to develop evaluation tools that can be practically applied to our lives and cultures. Sustainability assessment is a tool that helps decision-makers and policymakers ensure the ultimate contribution of sustainability, evaluate sustainability performance, and build a society that guarantees sustainability through proactive consideration and strategic planning (Berke and Manta, 1999; Devuyst, 2001; Verheem, 2002; Ludin, 2003; Spohn, 2004). To achieve this, a decision-making system that incorporates top-down approaches using indicators and bottom-up approaches requires the systematic participation of various stakeholders (Holmberg and Karlsson, 1992; Wu and Wu, 2012).

Building a sustainability assessment requires data that provide information on the phenomenon, indicators that are collections of such data, and indices that are quantitative aggregates of indicators. Guidelines for the criteria that can be used to evaluate the suitability of a sustainability assessment have been proposed, including 'The Bellagio

Principles,' introduced at the 1996 Bellagio Conference in Italy (Hardi and Zdan, 1997). The Bellagio Principles are composed of a clear vision and goals (Principle 1), key elements of sustainability assessment (Principles 2–5), issues related to the assessment process (Principles 6–8), and the continuing capacity for assessment (Principles 9 and 10). These principles served as reference points for measuring sustainability.

Specifically, the ten principles of the Bellagio Principles are defined as follows: First, guiding vision and goals refer to whether clear visions and goals for sustainability are specified; Second, holistic perspective pertains to whether main systems and sub-systems are adequately considered from a macro perspective, including social, ecological, and economic aspects; Third, essential elements involve aspects of equity concerning past, present, and future situations in activities aimed at achieving human/social well-being; Fourth, adequate scope considers long-term timeframes and local spaces as well as a comprehensive range; Fifth, practical focus involves considering an appropriate framework of indicators and evaluation criteria according to goals; Sixth, openness refers to the transparency of uncertainties, assumptions, and public accessibility; Seventh, effective communication involves consideration for decision-makers who aim for efficiency and simplicity; Eighth, broad participation guarantees the participation of representative stakeholders and decision-makers; Ninth, ongoing assessment considers a framework of cyclical feedback structures; And tenth, institutional capacity addresses the responsibility in the decision-making process, continuous resource provision, and database construction.

Structural approaches to sustainability assessment can be understood in various ways, including cause-effect chain structures, theme structures, capital-based structures, and integrated accounting structures. Among these, the European Union(2014) suggested cause-effect chain structures, which focus on the factors influencing the phenomena to be assessed, and theme structures, which categorize phenomena by field and subdivide them into sub-fields according to policy goals to derive indicators.

The cause-effect structure builds a model by focusing on the causal relationships between phenomena that influence each other, with specific model examples being the Pressure-State-Response (PSR) model and the Driving force-Pressure-State-Impact-Response (DPSIR) model. The PSR model was developed by the OECD in 1993 and adopted as a basic methodology for developing environmental indicators. It was later adapted by the European Environment Agency in 1999 as an effective model for analyzing causal relationships in complex systems (Zare et al., 2019; Cao and Bian, 2021). The theme structure includes various analysis models, such as strengths, weaknesses, opportunities, and threats (SWOT) analysis, political, economic, social, technological, legal, and environmental (PESTLE) analysis, and the Design Science Research (DSR) model. In particular, the PESTLE analysis is considered highly useful for evaluating phenomena at various scales, as it clearly distinguishes between policy, economic, social, technological, legal, and environmental categories from a holistic perspective.

3.1.2. Environmental mainstreaming

Scott et al.(2022) described mainstreaming as an activity that creates a long-term and effective system within a policy domain through a multidisciplinary approach. It has been interpreted as a holistic approach for addressing socioeconomic issues caused by climate change, biodiversity loss, and other environmental

Table 1. Precedent research of environmental mainstreaming (Reorganized by the author based on: Scott et al., 2022)

Authors	Contents
Lafferty and Hovden (2003)	• Environmental Policy Integration: the origins of the concept and conceptural clarification regarding its definition and context. • An analytical framework for Environmental Policy Integration, incorporating both vertical and horizontal dimensions.
Cowling et al.(2008)	• Develop a practical operational model to effectively ensure the protection of ecosystem services.
Benson et al.(2014)	• Analyze the integration of environmental and climate considerations into development policy, planning, and budgeting. • Explain the importance of integrating environment and climate, highlighting the associated challenges and successes.
Karlsson-Vinkhuyzen et al.(2017)	• Facilitate the identification of innovative opportunities for mainstreaming that realistically and optimally leverage the broader governance context. • Introduces a framework with institutional, motivational, and means dimensions to identify key barriers and drivers for integrating biodiversity into economic sectors.
Russel et al.(2018)	• This paper employs a micro, meso, and macro-level institutional behavior framework, grounded in new institutionalism perspectives, to identify and explain the factors that enable or hinder policy integration. • It focuses on policy integration within the coastal and marine sectors, which are particularly vulnerable to climate change impacts, and is based on data gathered from document reviews and interviews with key informants.
Runhaar et al.(2018)	• This paper reviews peer-reviewed empirical studies on climate adaptation mainstreaming to evaluate current progress and identify key factors that contribute to its effectiveness.
Scott et al.(2018)	• Mainstreaming Ecosystem Science in spatial planning practice explores a hybrid opportunity space and develops a typology for evaluating mainstreaming efforts using the diffusion of innovation model.
Runhaar et al.(2020)	• Conducts a meta-analysis of scientific and empirical research on Environmental Policy Integration (EPI) to address this question.
Candel(2021)	• Proposes a heuristic for assessing policy integration opportunities, focusing on two key factors: integrative capacity and leadership.

challenges. Tlaiye and Awe(2010) and Forbes et al.(2015) defined mainstreaming within the economic sector as integrating decision-making processes and directly collaborating with financial planning departments. In recent years, as environmental issues arising from climate change have become more prominent, the OECD(2019) has defined mainstreaming as the active integration of environmental and climate issues into development policies, plans, budgets, and actions. In other words, mainstreaming can be understood as both a process and outcome of an approach (Scott et al., 2018). Karlsson-Vinkhuyzen et al.(2017) and Persson and Runhaar(2018) discuss the need for an integrated approach that sets specific goals for major issues in one domain and links them to other domains. This concept has been widely explored in Environmental Policy Integration (EPI) literature.

According to previous studies on the integration of various policies aimed at realizing environmental mainstreaming (Table 1), Lafferty and Hovden(2003) provided a framework for vertical and horizontal policy integration within environmental policy, emphasizing the principle's priority over other objectives and addressing policy integration at various scales. Cowling et al.(2008) proposed an operational model for ecosystem services from a socio-ecological system perspective, emphasizing the need for interdisciplinary research to effectively manage stakeholder

engagement and evaluate the overall system state within the policy cycle. Benson et al. (2014) investigated the mainstreaming of environmental and climate change into development policies and budget allocations, expanding the focus to the economic domain and proposing strategies for achieving development goals based on the UN Environment Programme (UNEP) environmental planning and poverty alleviation initiatives. Karlsson-Vinkhuyzen et al.(2017) reviewed biodiversity mainstreaming within the economic sector through expert consultations, while Russel et al.(2018) analyzed policy integration within the EU at the micro, meso, and macro levels. Runhaar et al.(2018) developed a typology for evaluating mainstreaming activities using spatial planning, and Scott et al.(2018) assessed the effectiveness of empirical studies on mainstreaming through a literature review of climate adaptation. Runhaar et al.(2020) conducted a detailed analysis of scientific and empirical research on policy integration and Candel(2021) developed a framework to understand the validity and convenience of policy integration processes.

The international community defines environmental mainstreaming as the integration of considerations for issues arising within the environmental domain into decision-making systems. According to Lee(2020), mainstream environmental approaches in the international community can be broadly classified into passive and active approaches. The passive approach aims to proactively consider environmental impacts, whereas the active approach goes beyond preventive measures and focuses on spreading the effects of environmental improvement by considering the policy's effectiveness from a macro perspective. Environmental mainstreaming, which takes a holistic approach, can realize mutual benefits, reduce policy redundancy, and promote long-term resilience (Adger et al., 2005; Runhaar et al., 2014; Scott et al., 2021). However, challenges, such as timing mismatches with other sectors, difficulties in achieving collaborative governance concerns over long-term timeframes, and the complexity of guidelines that are difficult to apply, have been identified as limitations to environmental mainstreaming.

3.2. Overview of sustainability assessment cases

In this study, to facilitate an integrated approach, we reviewed assessment tool cases classified by scale into the national level, metropolitan level, regional/local level, and others. The assessment tools selected for this review were those currently developed and implemented both domestically and internationally, with a focus on tools related to economic growth, environmental impacts, and studies on human life and the environment. To understand the overall framework of these assessment tools by scale, we examined their objectives, indicators, and weighting methods, and whether they were implemented domestically or abroad (Table 2). Although weighting methods may vary depending on policy objectives or specific situations, the commonly used approaches have been summarized.

At the national level, these tools focus on assessing the environmental severity or potential issues affecting the nation, the environmental impacts of human activities and development plans, and ecological values. In the social sector, tools evaluate factors related to achieving a healthy and high quality of life for humans, whereas in the economic sector, tools that replace GDP evaluations with assessments that extend to environmental factors have been identified. Additionally, in the policy sector,

Table 2. Overview of sustainability assessment cases based on levels (Reorganized by the author based on: Singh et al., 2012)

Level	Name	Purpose	Indicators and elements	Weighting	Internal / External
National	Human development index	Valuate the quality of human life, such as human standard of living and healthy living	• Life expectancy at birth • Expected years of schooling • Mean years of schooling • GNI per capita	equal	External
	Index of sustainable and economic welfare	Economic indicators to replace GDP, a macroeconomic indicator of the system of national accounts (SNA)	• Personal consumption • Public non-defensive expenditures • Private defensive expenditures • Capital formation • Services from domestic labour • Costs of environmental degradation • Depreciation of natural capital	equal	External
	Ecological footprint	A tool that measures the extent to which human activities affect the natural environment and measures the amount of nature needed to support human life and the economy	• Carbon footprint • Cropland • Grazing land • Forest • Fishing Ground • Built-up land	equal	External
	Environmental quality index	Evaluate the relationship between the environment and human health	• Air • Water • Land • Built • Sociodemographic environment	AHP	External
	Environmental performance index	Evaluate the achievement of national environmental policy objectives and present directions for national guidelines	• Climate change • Environmental health • Ecosystem vitality	PCA/ experts	External
	Environmental vulnerability index	Evaluate the severity of the environment as well as the potential for potential damage	• Climate change • Biodiversity • Water • Agriculture and fisheries • Human health aspects • Desertification • Exposure to natural disaster	equal	External
	Strategic environmental assessment	Environmentally impactful plans are applicable to the environmental conservation planning department and environmental aspects	• Policy making • Development master plan	equal	Internal
	Protected area	A system that is legally protected or managed to protect cultural resources related to biodiversity and the natural environment	• Naturalness • Biodiversity • Ecosystem • Academic value	AHP/ experts	Internal
	Ecological and natural map	Database map for utilizing the natural environment in land-use or development planning according to its ecological value, naturality, landscape value, etc	• Natural ground green area • Artificial area by type • Weight • Total target area	AHP/ experts	Internal
	National environmental assessment map	A map that evaluates the environmental value of the national land and evaluates it by grade	• Legal evaluation items • Environmental and ecological evaluation items	AHP/ equal	Internal

Level	Name	Purpose	Indicators and elements	Weighting	Internal / External
Metropolitan	Restricted development	A system to preserve the natural environment by preventing reckless development and to systematically restrict development for a healthy living environment in the city	• Natural environmental elements • Living environmental elements	AHP/ experts	Internal
Regional/ Local	Urban sustainability index	A tool for assessing sustainability in the physical, social, economic and emotional aspects of cities	• Environment • Social • Economy • Governance	AHP	External
	City development index	An index that measures the social life of the city in the social, economic, and cultural areas of the city	• Social • Economic • Education & Culture	PCA/ experts	External
	Land suitability assessment	A system for comprehensively evaluating the spatial characteristics of land for the establishment of a national land management system for pre-planning and post-development	• Development suitability • Conservation suitability	AHP/ experts	Internal
	Urban ecological status map	A database of evaluation values by evaluating the ecological characteristics of biotopes for local governments	• Land-use status map • Land cover status map • Topographic thematic map	AHP/ experts	Internal
	Ecological area ratio	A system for evaluating to prevent reckless artificial packaging and secure urban green areas	• Natural ground green area • Artificial area by type • Weight • Total target area	apply weight set by area type	Internal
Other	Environmental impact assessment	Evaluation system to avoid, eliminate, or reduce the environmental impact of projects in advance	• Natural ecological environment sector • Atmospheric environment sector • Water environment sector • Living environment sector • Social and economic environmental status	equal	Internal
	Small-scale environmental impact assessment	A system to evaluate the feasibility of the location and its impact on the environment in advance when implementing projects in areas requiring environmental preservation or development areas concerned about reckless development	• Project overview and regional environmental status • Prediction assessment and conservation measures for environmental impact	equal	Internal

these tools are used to evaluate overarching plans, provide an overall direction, and typically apply methods such as equal-weight analysis or ranking national territories based on grades.

At the metropolitan level, restricted development is governed by metropolitan urban plans that define the allowable amount of development to be lifted. It was confirmed that the lifting of development restrictions is pursued only when there is a public demand for development, with public development being the principle. Furthermore, the lifting of development restrictions is determined based on expert opinions and environmental assessment

grades, where only areas rated between grades 3 and 5 can be lifted and those rated 1 or 2 are generally prohibited from being lifted.

At the regional/local level, the focus is on cities, or, in South Korea's case, on systems related to urban and county master plans. Generally, tools at this level measure various factors, such as the social, economic, cultural, and emotional aspects of a city, or assess the spatial characteristics and ecological values to build databases. Weighting at this level typically involves hierarchical grading using the Analytic Hierarchy Process (AHP), expert opinions, or weight settings specified in guidelines or is applied through the identification of representative variables to account for the characteristics of the region or accumulate spatial data.

Other cases that do not fall under the national, metropolitan, or regional/local levels involve assessment tools based on area or type of business plan. Generally, these tools operate with a focus on spatial validity and preventive measures during project implementation, with flexible weight settings depending on the project's purpose and specific situation.

4. Discussion

4.1. Implications for modeling environmental footprint assessment

Through a literature review on sustainability, sustainability assessment, and environmental mainstreaming, several implications can be drawn for the development of a framework for an environmental footprint assessment model that ensures sustainability.

First, to establish an effective environmental footprint assessment, it is necessary to consider the connection between assessment tools and policy decision-making systems. There should be a cyclical system that evaluates the degree of environmental degradation and its impacts caused by development activities or land use, and incorporates the results of these evaluations into policy analysis and implementation.

Second, to contribute to sustainability across the environmental, social, and economic dimensions, it is essential to understand the impacts of development activities from a holistic perspective. This perspective should encompass not only the environment, society, and economy, but also the policies, institutions, and technologies that are necessary to balance development and conservation. Within this scope, it is crucial to efficiently establish indices, indicators, and data to assess and systematically build relationships between these factors.

Third, to establish an integrated environmental footprint assessment, it is necessary to overcome the limitations of current integrated approaches by integrating scale units and expanding the interaction and participation opportunities among various stakeholders. The main challenges to an integrated approach include duplication with other ministries, difficulties linking different sectors, and the burden of addressing long-term issues. To address these issues, there is a need to unify the scales for integrated planning and systematically address long-term challenges by facilitating coordination among different ministries or between higher and lower levels of government, thereby expanding the space and opportunities for stakeholder participation.

In addition to these implications, an analysis was conducted using the Bellagio Principles based on the sustainability assessment cases reviewed earlier (Table 3). The results indicate that sustainability-based assessment systems generally have clearly defined visions and goals, which are often supported by legal frameworks. A holistic perspective was evaluated to determine whether appropriate indicator systems were established from a macro perspective. Most

Table 3. Analyzing of sustainability assessment cases applying the Bellagio Principles

Level	Name	Guiding vision and goals	Holistic perspective	Essential elements	Adequate scope	Practical focus	Openness	Effective communi-cation	Broad participa-tion	Ongoing assessment	Institutional capacity
National	Human development index	●	▲	X	▲	●	●	X	▲	▲	●
	Index of sustainable and economic welfare	●	▲	X	▲	●	▲	X	X	X	X
	Ecological footprint	●	▲	X	▲	●	●	X	▲	▲	●
	Environmental quality index	●	▲	▲	X	●	●	X	▲	▲	●
	Environmental performance index	●	▲	X	▲	●	●	X	▲	▲	●
	Environmental vulnerability index	●	▲	X	X	●	▲	X	X	X	X
	Strategic environmental assessment	●	▲	X	●	●	●	●	●	▲	●
	Protected area	●	▲	X	●	●	●	▲	●	▲	●
	Ecological and natural map	●	▲	X	●	●	●	▲	●	▲	●
	National environmental assessment map	●	▲	X	▲	●	●	▲	▲	▲	●
Metropolitan	Restricted development	●	▲	X	●	●	●	●	●	▲	●
Regional/ Local	Urban sustainability index	●	●	X	●	●	▲	X	▲	▲	X
	City development index	●	▲	X	▲	●	●	X	▲	▲	●
	Land sustainability assessment	●	▲	X	●	●	●	●	▲	▲	●
	Urban ecological status map	●	▲	X	▲	●	●	▲	▲	▲	●
	Ecological area ratio	●	▲	X	▲	●	▲	▲	▲	▲	X
Other	Environmental impact assessment	●	▲	X	●	●	●	●	●	▲	●
	Small-scale environmental impact assessment	●	▲	X	●	●	●	●	●	▲	●

● : strong, ▲ : middle, X : weak

assessment tools were found to have indicators suitably aligned with their objectives. However, when reviewing the sustainability concept based on environmental, social, and economic dimensions, it was found that some assessment tools only partially consider certain dimensions or place greater emphasis on one dimension, depending on their objectives.

Regarding essential elements, the assessment tools examined the equality of people's quality of life across the present, past, and future but lacked long-term evaluations. This may be due to the difficulty in accumulating or utilizing long-term data or the complexity of conducting such evaluations. Adequate scope was assessed to determine whether the assessments were comprehensive and connected to policy. Most assessment tools considered linkages to policy applications, whereas those that did not were typical cases where the assessment tool had been developed but not continuously updated.

The analysis of the practical focus showed

that the assessment frameworks were generally appropriate, as the tools were designed with indicators suited to their objectives. Openness was examined in terms of public access, with most assessment tools sharing data and methodologies with the public. Effective communication was analyzed in terms of decision-making systems. While international assessment tools typically covered broad areas without specific mention of decision-making systems, South Korean examples were often linked to national land-use planning or established legal foundations.

South Korean assessment tools typically have legal provisions that ensure stakeholder involvement, whereas international tools focus more on expert participation and policy recommendations. Finally, an ongoing assessment was conducted to determine whether the tools allowed cyclical feedback. Generally, feedback is more qualitative, taking the form of reports on assessment results rather than on the system itself. The institutional capacity was assessed in terms of continuous data provision and development. Most assessment tools provide data from the past to present or have established spatial information systems, except for tools that were developed for specific research purposes or where the focus was on formalized tools.

4.2. Conceptual framework of environmental footprint assessment model

Based on the previously derived implications, we sought to develop a conceptual framework for an environmental footprint assessment model applicable to South Korea that aims to integrate national land-use planning and environmental planning (Fig. 1). Environmental footprint assessment, as a tool that ensures sustainability, seeks to achieve a balance between land use and environmental conservation. The framework was derived by considering Bellagio's Principles.

Above all, to proceed efficiently with the environmental footprint assessment, it is important to distinguish between sustainability assessment and decision-making systems. To apply sustainability assessments in South Korea, it is necessary to establish uniform criteria that can simultaneously evaluate both national land use planning and environmental planning. These criteria correspond to South Korea's hierarchical structure, which is typically categorized as national, metropolitan, regional/ local, and other levels. After establishing these criteria, it is crucial to conduct a thorough analysis of the assessment targets and group the diverse types of targets into representative categories for evaluation. Following the analysis of assessment targets, it is necessary to construct indicators from a holistic perspective. A representative example is the use of the PESTLE structure, which is a framework for sustainability assessment, to set relevant indicators and weights for the targets under evaluation. Accordingly, models such as the DPSIR model, which considers the causes, pressures, and responses related to degradation, should be employed to evaluate the causal relationships and further refine the assessment.

The decision-making system should focus on accumulating spatial data and accounting for uncertainties while building an efficient and straightforward system by minimizing redundant steps. The system should address the complexities of overlapping jurisdictions and policies arising from various ministries by enhancing connectivity with other departments and expanding opportunities for stakeholders involved in the upper and lower planning processes. This will help establish a more integrated approach within the decision-making system, thereby resolving issues such as lack of continuous feedback and policy duplication. Moreover,

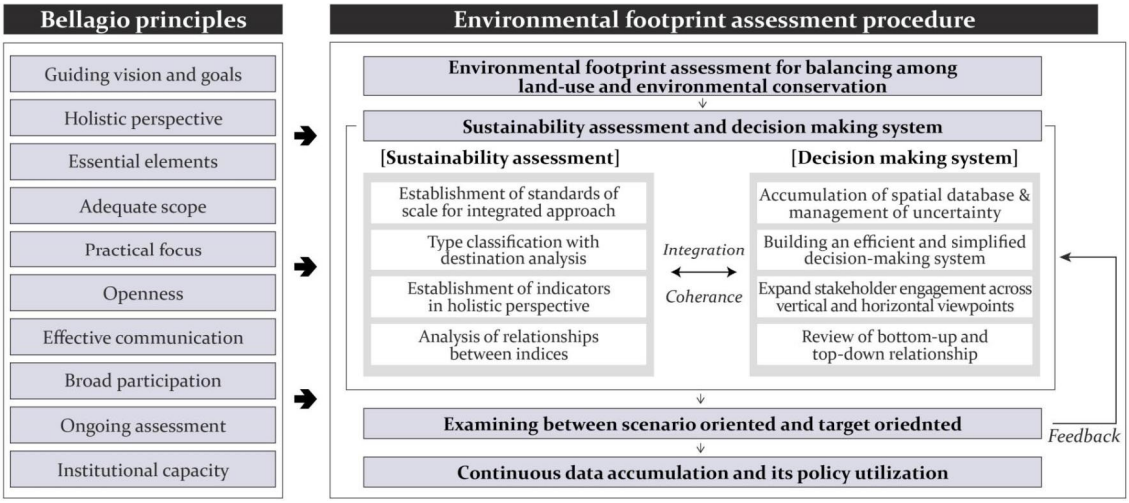

Fig. 1. Conceptual framework of environmental footprint assessment model.

while South Korea's current system is primarily top-down owing to its decentralized governance structure, achieving a more effective and long-term assessment tool requires consideration of a bottom-up approach to complement the top-down system, thus fostering a reciprocal framework.

Through the integration and coherence of the sustainability assessment and decision-making system, the assessment results should be reviewed in line with existing objectives, enabling a feedback process that facilitates a cyclical system. Additionally, environmental footprint assessments should be used to accumulate spatial data, which can then be expanded for application in relevant policy decisions.

5. Conclusion

Due to the excessive use of resources today, the Earth has surpassed its carrying capacity, leading to complex and nonlinear environmental crises. In response, various international cooperative frameworks have emerged to address these issues. Additionally, since the 1970s, the concept of sustainability has been introduced and extensive international research has been conducted on sustainability, along with the development of assessment tools that can quantitatively measure it. Furthermore, as the need for a transdisciplinary approach beyond the narrow scope of environmental issues has been recognized, research on integrated approaches within the framework of environmental mainstreaming has begun to emerge. In this context, South Korea has also attempted to integrate national land use planning and environmental planning, but there are still significant challenges in effectively implementing these efforts.

This study proposes a direction and framework for developing an environmental footprint assessment model that ensures sustainability and balances land use with environmental conservation, specifically tailored for applications in South Korea. The exploratory research conducted in this study led to several key findings on how to apply an environmental footprint assessment in South Korea.

First, to establish an assessment tool that ensures sustainability, it is necessary to clearly define goals and the relationships among appropriate dimensions, weights, indices, indicators, and data corresponding to these goals. The analysis of the case studies revealed that the relationships and weights between dimensions varied according to goals, indicating that the selection of assessment indicators and the relationships among these indicators must be appropriately structured to achieve the desired outcomes.

Second, a thorough understanding and analysis of assessment targets is required. It is essential to analyze the land use, zoning, relevant stakeholders, attractiveness of development, and environmental value of the targets to efficiently evaluate them by clustering them into representative categories. This finding suggests the need for a systematic approach to effectively assess these targets.

Third, it is necessary to recognize the institutional framework of South Korea's decentralized governance system and develop strategies to strengthen the interrelationships among various ministries. To achieve a balance between land use and environmental conservation through an integrated approach and ensure the effective policy application of the assessment tools, it is important to consider the complementary relationships between different ministries and between higher- and lower-level plans.

Fourth, when developing an assessment model that ensures sustainability, it is crucial to establish a cyclical system. To effectively respond to dynamic changes in policy trends and land use, a cyclical system that allows for flexible assessments through feedback within the existing framework is necessary.

Based on these findings, this study proposes a conceptual framework as a foundational role for the application of environmental footprint assessment in South Korea. However, the analysis based on the established criteria should be further validated by involving a larger pool of experts to ensure objectivity. Additionally, there is a need to further refine the environmental footprint assessment model based on a conceptual framework. Future research should include empirical analyses that apply the developed environmental footprint assessment model to actual sites to advance subsequent studies.

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