



# **Living Edges: Reclaiming Dynamic Interfaces Against Urban Sprawl, a Data-Informed Conceptual Framework for Adaptive Greenbelt Governance**

**Margherita Meta<sup>1</sup>**

<sup>1</sup>*Research Fellow, Department of Planning, Design and Architecture Technology, Sapienza University of Rome*

---

## **Abstract**

Urban sprawl continues to intensify ecological fragmentation, carbon emissions, infrastructure inefficiencies, and socio-spatial inequalities across metropolitan regions. Greenbelts have historically functioned as regulatory containment tools designed to limit outward expansion and preserve open land; however, their later institutionalized, boundary-based regulatory logic increasingly appears misaligned with contemporary urban resilience, climate adaptation, and social inclusion challenges. While extensive literature examines urban sprawl metrics, housing impacts of containment policies, and green infrastructure planning, limited research integrates greenbelt regulation within adaptive ecological infrastructure and urban metabolism frameworks: in particular, the potential transformation of greenbelts from static zoning devices into multifunctional and performance-based spatial systems remains under-theorized and insufficiently structured from a methodological perspective. This paper introduces the concept of Greenbelt 2.0 as a data-informed conceptual framework for reframing greenbelts as adaptive ecological and social infrastructures: rather than presenting original GIS modelling or a fully implemented quantitative assessment, the study combines qualitative policy analysis of the London Green Belt with a structured indicator framework derived from secondary literature, publicly available datasets, and comparative planning references. The methodological approach integrates policy review, functional decomposition across ecological, productive, social, and governance dimensions, and conceptual performance-gap analysis. The analysis suggests that while the traditional greenbelt model remains effective in limiting direct land encroachment and preventing settlement coalescence, it appears less developed in relation to ecological connectivity management, public accessibility, governance adaptability, and metabolic integration. The proposed Greenbelt 2.0 framework identifies adaptive zoning, multifunctional landscape management, performance monitoring, and participatory governance as potential mechanisms for resilience-oriented transformation, and these elements are presented as a basis for future empirical testing rather than as completed measured outcomes. The study advances greenbelt theory beyond preservationist containment by positioning greenbelts as dynamic metropolitan interfaces that can integrate ecological resilience, productive landscapes, and spatial justice: by bridging containment planning with resilience theory, green infrastructure, and metabolic urbanism, the paper provides a structured and transferable framework for reconfiguring greenbelt governance in the context of climate-responsive and inclusive urban development.

© 2026 The Authors. Published by IEREK Press. This is an open-access article under the CC BY license (<https://creativecommons.org/licenses/by/4.0/>). Peer-review under the responsibility of ESSD's International Scientific Committee of Reviewers.

## **Keywords**

*Greenbelt 2.0; Green infrastructure; Adaptive governance; Indicator-based assessment; Urban containment*

---

## 1. Introduction

### 1.1. Background: urban sprawl and the crisis of the later institutionalized model of greenbelt containment

Beginning with the period marked by rapid industrialization and large-scale urbanization, metropolitan regions have undergone profound spatial restructuring. Throughout the twentieth and early twenty-first centuries, urban growth has increasingly manifested in dispersed, low-density, and automobile-dependent forms commonly defined as urban sprawl; this development pattern is associated with land consumption beyond demographic growth rates, spatial fragmentation, and the functional separation of residential, commercial, and productive areas (Organisation for Economic Co-operation and Development [OECD], 2018; Ewing & Hamidi, 2015). Empirical research has demonstrated that sprawled urban forms generate significant environmental externalities, including habitat fragmentation, biodiversity loss, and increased greenhouse gas emissions due to transport-related energy consumption (Seto et al., 2012). At the metropolitan scale, low-density expansion also reduces ecological resilience by interrupting green corridors, increasing impervious surfaces, and intensifying pressure on peri-urban agricultural systems. Beyond environmental impacts, sprawl produces structural socio-economic effects: higher infrastructure costs per capita, fiscal stress on municipalities, and reinforced socio-spatial polarization, as access to housing, employment, and services becomes unevenly distributed (OECD, 2018).

In response to uncontrolled outward expansion, several countries adopted containment strategies during the mid-twentieth century; among these, greenbelts emerged as one of the most emblematic spatial planning tools. Conceived as protected rings of open land surrounding urban cores, greenbelts were designed to prevent coalescence between settlements, safeguard agricultural landscapes, and preserve access to open space (Amati, 2008). The London Green Belt, formalized within post-war British planning policy, became a globally influential reference model, shaping containment strategies in Europe, North America, and parts of Asia (Hall, 2002).

Historically, the London Green Belt should be understood within the broader planning vision articulated by Patrick Abercrombie in the County of London Plan and the Greater London Plan (Forshaw & Abercrombie, 1943; Abercrombie, 1944); in this context, the Green Belt was not conceived merely as a negative or conservative prohibition against urban development. Rather, it formed part of a wider metropolitan strategy aimed at limiting uncontrolled expansion, preventing the coalescence of settlements, preserving open land, and supporting a more ordered regional structure. Abercrombie's vision linked containment with decentralization, regional balance, and access to open space. Therefore, the critique developed in this paper does not suggest that the original Green Belt idea was exclusively static or preservationist. Instead, it argues that the subsequent institutionalization of greenbelt policy increasingly emphasized permanence, boundary protection, and land-use restriction, while giving comparatively less attention to adaptive ecological management, social accessibility, and performance-based governance.

Recent sprawl measurement research increasingly operationalizes dispersion and land take through multi-dimensional indices and global remote-sensing products (e.g., refined compactness/sprawl indices and settlement-layer analytics), enabling cross-metropolitan comparability and SDG-aligned monitoring (Ewing & Hamidi, 2015; Schiavina et al., 2019; Zhao et al., 2022). While greenbelts have proven effective in limiting continuous outward expansion, scholarly debate increasingly highlights the limitations of relatively rigid containment frameworks as they have become institutionalized in post-war planning systems, as research indicates that strict development constraints within protected boundaries may displace growth pressures toward more distant locations, producing leapfrog development patterns and longer commuting distances (OECD, 2018); furthermore, land supply restrictions have been linked to significant upward pressure on housing prices in constrained markets such as England, contributing to affordability crises and widening socio-spatial disparities (Hilber & Vermeulen, 2016). Critical perspectives argue that the institutionalized implementation of greenbelt policy often lacks adaptive mechanisms capable of responding to demographic change, housing demand, and evolving environmental priorities; in some cases, limited public accessibility and uneven ecological quality within protected areas further challenge the assumption that permanence alone guarantees sustainability outcomes (Amati, 2008). As a result, the contemporary planning debate increasingly calls for more flexible, performance-based, and regionally integrated approaches that reconcile environmental protection with housing provision and metropolitan resilience. More recently, the greenbelt debate has expanded from a binary "protect vs. release" framing toward questions of multifunctionality, access, and governance capacity: whether greenbelts can be actively managed as socio-ecological infrastructures rather than passive constraints (Kirby & Scott, 2023; Koster, 2024).

### 1.2. Research Gap

Although extensive scholarship has examined the environmental, economic, and spatial impacts of urban sprawl, as well as the regulatory function of greenbelt policies, a significant gap persists in the critical assessment of static

containment models within contemporary metropolitan dynamics. Much of the existing literature either evaluates greenbelts in terms of their effectiveness in limiting land consumption or focuses on their unintended effects on housing markets. However, fewer studies adopt an integrated perspective that simultaneously considers ecological performance, socio-spatial equity, housing accessibility, and adaptive governance capacity: in particular, the London Green Belt has been widely discussed as a paradigmatic containment model, yet limited research systematically interrogates its long-term resilience under current pressures, including demographic growth, housing shortages, climate adaptation imperatives, and shifting planning paradigms. This fragmentation of perspectives highlights the need for a more holistic analytical framework capable of reassessing the role of static greenbelts in twenty-first-century metropolitan regions.

A further methodological gap concerns the translation of greenbelt reform debates into transparent and reproducible indicator structures. While recent literature increasingly discusses multifunctionality, ecosystem services, accessibility, and adaptive governance, these dimensions are often treated separately and are rarely organized into a unified assessment framework. As a result, it remains unclear how greenbelts can be evaluated not only as regulatory boundaries, but also as socio-ecological infrastructures with measurable performance domains; this paper addresses this gap by proposing an indicator-based framework that is explicitly conceptual, data-informed, and designed for future GIS-based implementation.

### **1.3. Research Questions**

Considering these issues, the paper is guided by the following research questions:

1. How has the London Green Belt evolved from Abercrombie's metropolitan planning vision into a relatively static regulatory containment instrument?
2. What are the main ecological, social, spatial, and governance limitations of the traditional greenbelt model when assessed through a multifunctional resilience perspective?
3. How can a data-informed indicator framework support the conceptual transformation of greenbelts into adaptive socio-ecological infrastructures?
4. What datasets, variables, and methodological steps would be required to operationalize Greenbelt 2.0 through future GIS-based assessment?

These questions aim to bridge environmental, economic, and spatial planning perspectives in order to reassess the sustainability of traditional greenbelt strategies.

### **1.4. Objectives**

The primary objective of this research is to develop a data-informed conceptual framework for reassessing the role of greenbelts within contemporary metropolitan systems; rather than producing a full empirical evaluation, the study aims to clarify how greenbelt performance can be interpreted, structured, and prepared for future spatial operationalization.

Specifically, the study aims to:

- Critically reinterpret the London Green Belt in relation to its historical planning origins and subsequent institutionalization;
- Identify the main limitations of static containment when considered through resilience, green infrastructure, and social accessibility perspectives;
- Define a set of ecological, productive, social, and governance indicators for the Greenbelt 2.0 framework;
- Distinguish between directly documented indicators, proxy-based indicators, proposed targets, and future GIS-operational indicators;
- Outline a reproducible methodological pathway for future empirical testing

Through this approach, the research seeks to contribute to the ongoing debate on sustainable urban containment strategies and to inform future policy reforms in rapidly evolving metropolitan contexts.

## 2. Methodology

### 2.1. Research Design

This study adopts a conceptual–analytical research design supported by qualitative policy analysis and structured indicator development, and does not conduct original GIS modelling, statistical testing, or field-based ecological measurement. Instead, it constructs a data-informed framework that identifies how the performance of greenbelts could be assessed across ecological, productive, social, and governance dimensions. The methodology is therefore positioned between policy analysis and operational framework design: it uses the London Green Belt as a reference case to identify structural limitations of the traditional containment model and to define a replicable pathway for future empirical testing. The research integrates three methodological components:

- A literature-based review of greenbelt policy, urban containment, resilience planning, green infrastructure, and urban metabolism;
- A qualitative policy analysis of the London Green Belt as a historically significant containment model;
- The construction of a performance-oriented indicator framework, referred to as Greenbelt 2.0, is intended for subsequent GIS-based operationalization.

The design follows an interpretative policy analysis approach (Rydin, 2013), combined with spatial performance evaluation principles commonly used in land-use and resilience studies (Ahern, 2011; Alberti, 2016). The intent is not to test a statistical hypothesis but to construct and operationalize a transferable analytical model grounded in documented empirical evidence.

### 2.2. Case study selection criteria

The London Green Belt was selected based on four criteria:

- Historical relevance: It represents one of the earliest and most influential containment policies globally
- Spatial scale: its territorial extension exceeds three times the built-up area of Greater London, making it a structurally significant planning instrument.
- Institutional consolidation: it is embedded in national planning legislation (Town and Country Planning Act, National Planning Policy Framework).
- Contemporary policy debate: it is central to discussions on housing affordability and urban sprawl (Cheshire, 2009).

The case, therefore, provides both historical depth and current policy relevance, making it suitable for testing the *Greenbelt 2.0* framework; the London Green Belt is therefore not used as a statistically representative case, but as a historically paradigmatic and theoretically revealing case. Its significance lies in the fact that it connects Abercrombie’s metropolitan planning vision with the later institutionalization of greenbelt policy as a durable regulatory boundary: this makes it particularly suitable for examining the tension between greenbelt origins as part of a broader regional planning project and their contemporary operation as relatively static containment instruments.

### 2.3. Data sources

The analysis draws on multiple data categories to ensure triangulation:

Policy Documents

- UK National Planning Policy Framework (NPPF)
- Local development plans

- Reports from the London Green Belt Council

#### Land-Use and Spatial Data

- UK land use statistics (Office for National Statistics)
- Agricultural land classification data
- Environmental and biodiversity reports

#### Secondary Academic Sources

- Studies on urban sprawl metrics (Ewing, 1997; Seto et al., 2012)
- Ecological resilience frameworks (Ahern, 2011; Alberti, 2016)
- Green infrastructure planning literature (Kirby & Scott, 2023).

All data sources are publicly available, ensuring methodological transparency and partial replicability, and are used differently according to the scope of the paper. Policy documents are used for qualitative coding of institutional objectives, boundary stability, and governance adaptability. Land-use and spatial datasets are not processed through original GIS modelling in this study, but are identified as required inputs for future operationalization. Secondary academic sources are used both to interpret the London Green Belt debate and to justify the selection of performance indicators. The distinction between sources used for conceptual interpretation and datasets required for future spatial calculation is essential to the methodological positioning of this paper.

## 2.4. Analytical framework

The analytical framework is structured around four functional domains derived from literature synthesis:

1. Ecological performance (connectivity, carbon, biodiversity)
2. Productive capacity (peri-urban agriculture, biomass potential)
3. Social accessibility (public access, recreational integration)
4. Governance adaptability (regulatory flexibility, performance review mechanisms)

This functional decomposition builds on green infrastructure (Hansen & Pauleit, 2014) theory and resilience planning principles (Ahern, 2011). Each domain is operationalized through measurable indicators to reduce normative interpretation. The framework enables comparison between the traditional containment model (Green Belt 1.0) and the proposed adaptive model (Green Belt 2.0). These four domains are not treated as completed empirical measurements in the present study; rather, they function as analytical categories that organize the transition from a containment-based interpretation of greenbelts toward a multifunctional performance-based framework. Each domain is associated with indicators that can be classified as directly documented, proxy-based, normative, or requiring future GIS implementation.

## 2.5. Indicator-based assessment: bibliographic rationale and evidence levels

To strengthen methodological transparency, the study develops an indicator-based framework rather than a complete quantitative evaluation. The indicators are selected through literature synthesis and organized according to four dimensions: land consumption and spatial structure, ecological performance, social accessibility, and governance adaptability; their function is to define what should be measured in a future empirical application of Greenbelt 2.0, while allowing the present paper to compare the traditional Green Belt model and the proposed adaptive framework at a conceptual and policy-analytical level.

The first group of indicators concerns land consumption and spatial structure. These indicators include urban expansion rate, density gradient discontinuity, and the leapfrog development proxy. Their selection is grounded in the literature on urban sprawl measurement and land-use efficiency, which emphasizes the relationship between urban expansion, settlement density, spatial fragmentation, and the mismatch between land consumption and population

growth (Ewing & Hamidi, 2015; OECD, 2018; Schiavina et al., 2019; Zhao et al., 2022). These indicators are included because greenbelt policies cannot be evaluated only by measuring land protected inside the boundary; they must also be assessed in relation to displacement effects, peripheral growth, and spatial discontinuities beyond the protected area.

The second group concerns ecological performance. These indicators include land-cover composition, estimated carbon sequestration potential, and habitat connectivity proxy. Their selection is informed by green infrastructure, ecosystem services, landscape ecology, and nature-based solutions literature, which stresses that protected land contributes to resilience only when it supports ecological connectivity, biodiversity conservation, carbon regulation, and hydrological functions (Ahern, 2011; Hansen & Pauleit, 2014; Seto et al., 2012; International Union for Conservation of Nature [IUCN], 2020; Kabisch et al., 2022). Within the Greenbelt 2.0 framework, ecological performance is therefore not treated as a passive consequence of land preservation, but as a measurable function requiring active spatial management and monitoring.

The third group concerns social accessibility. These indicators include the share of publicly accessible land and proximity to recreational green space, and their selection is based on environmental justice, public health, and urban green space accessibility literature, which shows that the presence of green land does not automatically produce social benefits if access is restricted, unevenly distributed, or disconnected from everyday mobility networks (Cole et al., 2017). For this reason, the framework distinguishes between the spatial extent of greenbelt land and its actual usability as social infrastructure.

The fourth group concerns governance adaptability. These indicators include boundary revision frequency and the presence of performance-based review mechanisms. Their selection is grounded in resilience planning and adaptive governance literature, which emphasizes feedback cycles, institutional learning, monitoring systems, and the capacity to recalibrate planning instruments in response to changing environmental and social conditions (Ahern, 2011; Sharifi, 2020; Kirby & Scott, 2023). These indicators are included because the transition from Green Belt 1.0 to Green Belt 2.0 depends not only on spatial design but also on the governance capacity to monitor, revise, and adapt policy over time.

To avoid conflating conceptual design with empirical measurement, each indicator used in the Greenbelt 2.0 framework is classified according to its evidentiary status: this distinction is necessary because the present study does not implement original GIS modelling but instead proposes an operational structure that can be empirically tested in future research. Four evidence levels are used.

Level 1 indicators are directly documented through policy documents, statutory planning frameworks, or publicly available land-use data. These include, for example, boundary revision frequency and the presence or absence of formal performance review mechanisms.

Level 2 indicators are proxy-based indicators derived from secondary literature or available spatial categories; examples include ecological connectivity potential, land-cover-based carbon function, and accessibility estimates.

Level 3 indicators are normative or proposed performance targets associated with the Greenbelt 2.0 model, such as expanded public accessibility or periodic indicator-based review.

Level 4 indicators are future GIS-operational indicators that are not calculated in this paper but are defined in terms of required datasets, processing steps, and expected outputs.

This classification clarifies that the values presented in the comparative framework should not all be interpreted as directly measured empirical results: some values summarize evidence from secondary sources, some represent qualitative policy interpretations, and others define proposed targets for a more adaptive greenbelt model. The purpose of the indicator framework is therefore to establish a transparent basis for future replication rather than to claim a complete quantitative evaluation of the London Green Belt.

The indicators are grouped as follows:

Land consumption and spatial structure

- Urban expansion rate

- Density gradient discontinuity
- Leapfrog development proxy

#### Ecological performance

- Land-cover composition
- Estimated carbon sequestration potential
- Habitat connectivity proxy

#### Social accessibility

- Share of publicly accessible land
- Proximity to recreational green space

#### Governance adaptability

- Boundary revision frequency
- Presence of performance-based review mechanisms

Indicator selection is literature-informed and based on publicly available statistics, policy documents, and secondary academic sources; although the framework is not derived from primary GIS modelling, it establishes a transparent basis for future quantitative testing and cross-case comparison.

## 2.6. GIS – oriented operationalization pathway

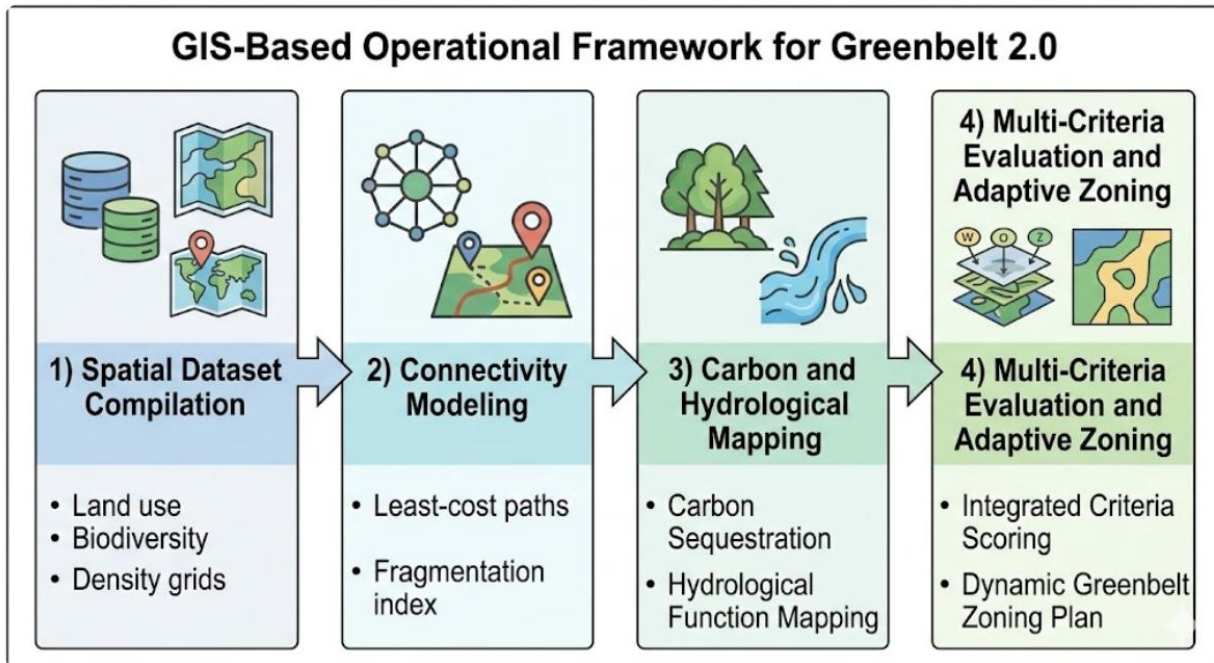
Although the present study does not conduct original GIS modelling, it defines a reproducible operationalization pathway for future spatial implementation of the Greenbelt 2.0 framework. This pathway specifies the sequence of datasets, spatial operations, and analytical outputs required to transform the proposed indicators into measurable variables; the workflow is intended to ensure that the conceptual framework can be tested, revised, and transferred to other metropolitan greenbelt contexts.

A future GIS-based implementation would include:

1. Compilation of land-use classification layers and settlement density grids;
2. Ecological corridor modelling through least-cost path analysis;
3. Carbon storage and flood mitigation mapping;
4. Multi-criteria spatial evaluation integrating ecological, social, and productive variables.

Each step corresponds to a specific analytical function. Land-use classification and settlement density grids would allow the calculation of land consumption, internal encroachment, and density discontinuity indicators. Ecological corridor modelling through least-cost path analysis would operationalize habitat connectivity and fragmentation. Carbon storage and hydrological mapping would translate land-cover categories into ecosystem service indicators. Finally, multi-criteria evaluation would combine ecological, social, productive, and governance variables into a spatial decision-support layer for adaptive zoning.

This approach aligns with contemporary green infrastructure planning methodologies and resilience-based spatial modelling frameworks (Ahern, 2011): by outlining the workflow, the study enhances reproducibility and positions Greenbelt 2.0 as a spatial decision-support framework rather than a purely theoretical construct. **Figure 1** illustrates the future spatial workflow required to operationalize the framework. It does not represent GIS modelling conducted in the present study. Instead, it identifies the sequence of analytical steps — spatial dataset compilation, connectivity modelling, carbon and hydrological mapping, and multi-criteria evaluation — through which the proposed indicators could be transformed into measurable spatial outputs.



**Figure 1.** Proposed GIS-based operational framework for Greenbelt 2.0.  
 Source. The figure was generated with Google Gemini AI based on author-written prompts and reviewed by the author.

## 2.7. Dataset structure and variable definition

The analytical framework developed in this study is operationalized through a structured set of spatial and governance variables designed for reproducible application. Each indicator corresponds to a measurable dataset category that can be retrieved from publicly accessible repositories.

Spatial variables include:

1. Land-use classification (polygon shapefiles, 1:10,000–1:25,000 scale)
2. Settlement density grids (100 m–1 km resolution raster datasets)
3. Vegetation cover layers (remote sensing-derived land-cover datasets)
4. Accessibility networks (vector road and pathway datasets)

Ecological indicators are derived from land-cover categories and may be operationalized using carbon sequestration coefficients documented in peer-reviewed literature (Seto et al., 2012; Hansen & Pauleit, 2014). Governance variables are constructed through structured policy coding, enabling qualitative-to-quantitative transformation. All variables are designed to be compatible with standard GIS software environments (QGIS, ArcGIS) and allow recalculation across different metropolitan contexts.

The variables listed above should be understood as a metadata structure for future operationalization; in the present paper, they are not processed as a complete spatial dataset. Their purpose is to define the minimum data requirements for replicating the Greenbelt 2.0 framework in a GIS environment: future applications should specify dataset provider, spatial resolution, temporal coverage, coordinate system, preprocessing steps, and calculation rules for each variable.

## 3. Results

### 3.1. Structural Limits of the London Green Belt

The qualitative policy analysis of the London Green Belt suggests a structural asymmetry between containment effectiveness and adaptive capacity: historically, the Green Belt has contributed to preventing the coalescence of settlements and preserving extensive peri-urban open land. However, when interpreted through the Greenbelt 2.0

framework, its performance appears less developed in relation to ecological connectivity, public accessibility, and adaptive governance.

Yet, empirical and policy literature identifies several structural constraints: first of all, the displacement of development beyond protected areas has contributed to leapfrog urbanization patterns, extending commuting distances and reinforcing car dependency (Cheshire, 2009; Seto et al., 2012); this effect does not invalidate containment but indicates spatial redistribution rather than suppression of growth.

Second, regulatory rigidity limits adaptive recalibration: as the London Green Belt operates under long-term boundary stability with limited performance-based review mechanisms, it nurtures a condition described as “regulatory inertia” (Amati, 2007; Kirby & Scott, 2023), that in “resilience terms” corresponds to a fail-safe logic rather than a safe-to-fail adaptive model (Ahern, 2011).

Finally, land accessibility remains structurally uneven because a significant share of Green Belt territory consists of privately owned agricultural land with limited public access, and therefore its contribution to social infrastructure, health benefits, and daily recreational use is inhibited, despite extensive spatial coverage (Cole et al., 2017). These structural characteristics suggest that while containment remains effective in preventing direct land encroachment, the Green Belt underperforms as an integrated ecological and socio-spatial system.

### **3.2. Indicator-informed Performance Interpretation**

The following assessment should be understood as an indicator-informed interpretation rather than as a completed quantitative measurement exercise: since this paper does not conduct original GIS modelling, the performance categories discussed below are derived from qualitative policy analysis, secondary literature, and the proxy logic defined in the methodology. The aim is not to provide a definitive numerical measurement of the London Green Belt, but to identify the types of performance gaps that a future empirical application of the Greenbelt 2.0 framework should test more systematically.

#### **Land Consumption and Spatial Structure**

Urban expansion within Green Belt boundaries remains marginal, confirming containment performance. However, consistent with global urban expansion projections (Chen et al., 2020), peripheral development beyond the protected perimeter exhibits measurable growth rates. Density gradients display abrupt discontinuities between inner metropolitan zones and outer commuter settlements, indicating spatial fragmentation rather than a graduated transition.

#### **Ecological Performance**

Land cover composition suggests moderate ecological capacity. Agricultural land and woodland areas provide potential carbon sequestration and hydrological regulation. Yet ecological connectivity is not systematically managed as a coordinated green infrastructure network. Contemporary planning literature emphasizes that multifunctional ecosystem performance requires active connectivity design rather than static protection (Hansen and Pauleit, 2014).

#### **Social Accessibility**

Accessibility metrics indicate uneven public access. Proximity to green space does not automatically translate into usable public infrastructure, particularly where ownership patterns restrict entry. This gap undermines the integration of environmental justice principles within containment policy (Cole et al., 2017).

#### **Governance Adaptability**

Institutional evaluation shows limited integration of performance indicators into boundary revision processes. In contrast, resilience governance frameworks advocate adaptive review cycles and measurable performance benchmarks (Sharifi, 2020).

Overall, the proxy-based synthesis suggests that the London Green Belt performs strongly as a containment instrument, while its multifunctional ecological, social, and governance performance requires more systematic

empirical testing. This interpretation supports the need for a future GIS-based and policy-coded assessment rather than replacing such an assessment.

### 3.3. Functional Reframing: The Greenbelt 2.0 Model

Greenbelt 2.0 is proposed as a conceptual and methodological framework rather than as an empirically validated model. Its purpose is to reorganize the greenbelt debate around measurable performance domains and to identify how traditional containment could be recalibrated through adaptive ecological, social, productive, and governance functions. The findings suggest that the primary limitation of the traditional model lies not in spatial restriction but in functional underutilization. Greenbelt 2.0 reframes the belt as an adaptive, multifunctional infrastructure structured across four integrated domains:

1. Ecological Connectivity: corridor planning, habitat restoration, and nature-based solutions. To strengthen conceptual alignment with the NbS literature, Greenbelt 2.0 can be positioned against established quality and governance standards—particularly the IUCN Global Standard for Nature-based Solutions and recent principles for urban NbS design and governance (IUCN, 2020; Kabisch et al., 2022).
2. Productive Metabolism: peri-urban agroecological systems integrated into urban resource cycles (Kennedy et al., 2007).
3. Social Infrastructure: expanded accessibility, recreational networks, and participatory stewardship.
4. Adaptive Governance: periodic boundary review based on spatial performance indicators and open-data monitoring.

This reframing aligns containment policy with contemporary resilience planning and ecosystem service integration: these domains are intended to guide future empirical operationalization. Their value lies in defining what should be measured and governed, rather than in claiming that these functions are already fully implemented within the London Green Belt.

### 3.4. Conceptual Performance Gap Analysis

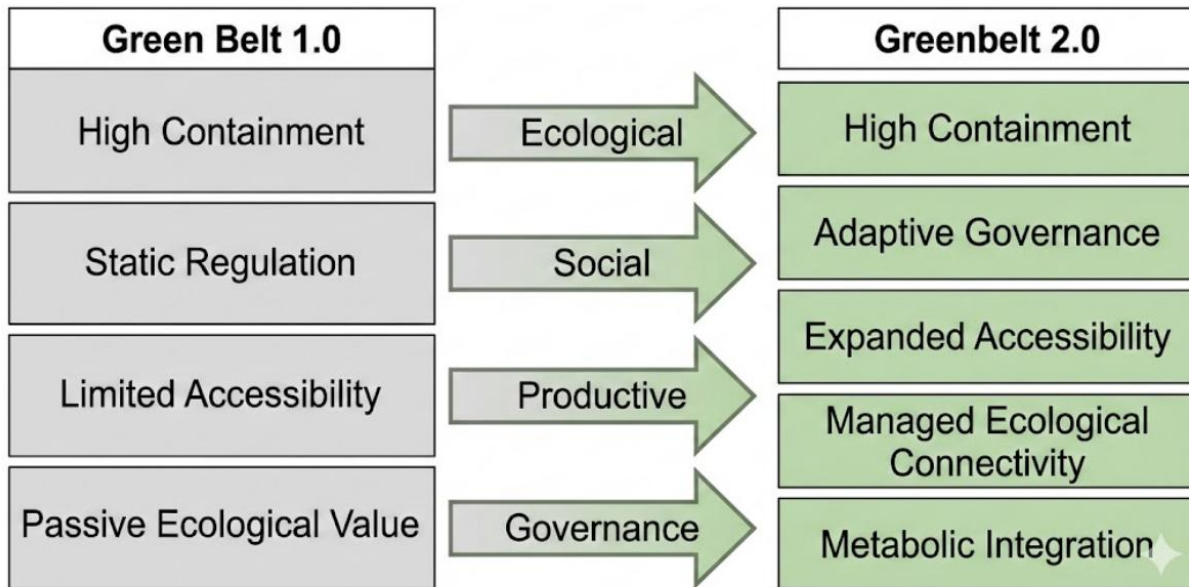
The comparative evaluation presented here should be understood as a conceptual performance gap analysis, which does not assign final empirical scores to the London Green Belt but identifies the main dimensions along which the traditional containment model appears underdeveloped when assessed through the Greenbelt 2.0 framework. The categories of high, moderate, limited, and low performance are therefore interpretative classifications based on literature synthesis and policy analysis, not the result of a completed quantitative scoring procedure; on this basis, the traditional Green Belt model can be interpreted as follows:

- Containment effectiveness: high
- Ecological network integration: moderate
- Social accessibility: limited
- Governance adaptability: low

The gap is therefore not spatial in extent, but systemic in integration; addressing this gap requires performance-based recalibration rather than deregulatory expansion.

**Figure 2** illustrates the proposed transition from a static containment-oriented model to an adaptive socio-ecological framework. It should be read as a conceptual synthesis of the paper's analytical argument, not as an empirically scored performance model. The figure identifies the domains in which future empirical testing should be conducted: ecological connectivity, social accessibility, productive integration, and adaptive governance.

## Structural Performance Gap between Green Belt 1.0 and Greenbelt 2.0



**Figure 2.** Conceptual performance gap between Green Belt 1.0 and Green Belt 2.0.

Source. The figure was generated with Google Gemini AI based on author-written prompts and reviewed by the author.

### 3.5. Dataset harmonization and transferability

To ensure cross-regional applicability, the indicator structure is aligned with internationally recognized land-use efficiency metrics, including SDG 11.3.1 (Schiavina et al., 2019). Harmonization is achieved through:

- Standardized land-cover reclassification
- Comparable density thresholds
- Replicable connectivity modelling procedures

The modular design of the dataset allows adaptation to alternative greenbelt or peri-urban systems without altering the core variable structure. The values and categories reported in **Table 1** are classified according to the evidence levels defined in the methodology; they should not be read as uniformly measured empirical results. Some entries summarize documented policy conditions, others represent proxy-based interpretations from secondary sources, and others define proposed Greenbelt 2.0 targets. This distinction is particularly important for accessibility, ecological connectivity, and governance indicators, where future GIS modelling and systematic policy coding would be required for full empirical validation. The table compares the traditional containment model with the proposed adaptive framework across selected performance dimensions. Values and categories should be interpreted according to their evidence status: some are derived from policy analysis or secondary sources, some are proxy-based qualitative assessments, and others represent proposed Greenbelt 2.0 targets rather than measured outcomes. The table is therefore intended as a conceptual and methodological framework for future empirical testing, not as a completed quantitative assessment.

**Table 1.** Indicator-based comparison between Green Belt 1.0 and Green Belt 2.0.

Dimension	Indicator	Green Belt 1.0	Greenbelt 2.0 proposed framework	Data source/method	Evidence status
Land containment	Internal urban encroachment rate	Very low	Maintained low	ONS land-use data; Green Belt boundary overlay	Documented policy evidence / future GIS indicator
Spatial structure	Density gradient discontinuity	High	Moderated through buffer zoning	Density grid analysis; urban morphology assessment	Future GIS indicator
Spatial structure	Leapfrog development proxy	Present beyond the protected boundary	Reduced through coordinated regional planning	Urban expansion datasets; commuting and peripheral growth analysis	Proxy-based interpretation / future GIS indicator
Ecological connectivity	Corridor continuity index	Moderate	High traffic planned ecological corridors	GIS least-cost modelling; habitat connectivity analysis	Future GIS indicator
Carbon function	CO <sub>2</sub> sequestration management	Passive	Managed carbon accounting	Land-cover datasets; carbon coefficients from literature	Proxy-based interpretation / future GIS indicator
Social accessibility	Share of publicly accessible land	25–35%	≥60% target	Accessibility mapping; public rights-of-way and open-access land datasets	Proxy-based interpretation / proposed target
Governance adaptability	Boundary review frequency	Rare	Periodic and indicator-based	Policy audit of planning documents and boundary review mechanisms	Qualitative policy coding
Monitoring capacity	Performance dashboard	Absent	Open-data monitoring system	Spatial database; public monitoring platform	Proposed target

## 4. Discussion

### 4.1. Theoretical advancement

Greenbelt 2.0 advances three theoretical domains simultaneously.

First, it bridges containment planning and resilience theory by embedding adaptive review mechanisms within spatial restriction frameworks (Sharifi, 2020). Traditional containment models emphasize permanence; resilience planning emphasizes flexibility and monitored adaptation (Ahern, 2011).

Second, it extends green infrastructure theory by incorporating formal regulatory instruments into ecosystem service planning. While green infrastructure literature focuses on multifunctionality (Hansen & Pauleit, 2014), it rarely addresses statutory zoning mechanisms as active components of ecological networks.

Third, it integrates urban metabolism concepts into peri-urban governance. By positioning the greenbelt as a metabolic interface, the framework links land-use planning with resource cycles, carbon regulation, and food systems (Kennedy et al., 2007; Alberti, 2016). This integrative positioning contributes to international debates on land-use efficiency, particularly within SDG monitoring frameworks (Schiavina et al., 2019). Within spatial planning scholarship, resilience thinking has increasingly been discussed as a governance and design challenge, requiring multi-level coordination, learning cycles, and anticipatory adaptation embedded in statutory planning instruments (Uhlhorn et al., 2025).

The theoretical contribution of Greenbelt 2.0 should be interpreted in relation to the methodological scope of the paper: the framework does not claim to provide a definitive empirical measurement of the London Green Belt's ecological, social, or governance performance; rather, it identifies the conceptual and operational categories through which such performance could be measured. Its value lies in integrating previously separated debates — containment planning, green infrastructure, urban metabolism, accessibility, and adaptive governance — into a single assessment architecture. Future research is required to test this architecture through GIS modelling, longitudinal datasets, and comparative multi-case analysis.

## 4.2. Applicability and emerging operational practices

Although Greenbelt 2.0 remains a conceptual framework, emerging initiatives demonstrate partial alignment with its defining features. Experimental participatory mapping practices, cross-border ecological networks, and integrated peri-urban management programs indicate a gradual shift toward multifunctional and data-informed governance. European cooperative programs focused on peri-urban ecological connectivity illustrate how spatial planning can transition from static designation to monitored ecological infrastructure: these initiatives demonstrate that adaptive evolution can occur incrementally within existing statutory frameworks (Albert et al., 2021). These examples should be interpreted as partial operational analogues rather than direct applications of Greenbelt 2.0. They demonstrate that several components of the framework, such as ecological connectivity planning, participatory mapping, and integrated peri-urban governance, are already present in contemporary planning practice. However, the full Greenbelt 2.0 model would require their systematic integration into a single performance-based governance structure.

## 4.3. Scalability and implementation challenges

Scalability depends on three enabling conditions:

1. Data Integration Capacity: Availability of spatial datasets and monitoring tools.
2. Institutional Coordination: Multi-level governance alignment across municipalities and regional authorities.
3. Incentive Structures: Stewardship mechanisms for private landholders.

Without measurable performance indicators, adaptive recalibration risks remaining rhetorical. The transition, therefore, requires systematic data integration and transparent monitoring infrastructures. These conditions also define the boundary between conceptual transferability and empirical replicability: Greenbelt 2.0 can be transferred conceptually to other metropolitan regions because its four domains are generalizable; empirical replication requires locally available spatial datasets, harmonized land-use classifications, explicit calculation rules, and institutional access to planning documents. Without these elements, the framework risks remaining a normative planning vision rather than an operational decision-support tool. **Table 2** identifies the main data categories required for implementing the Greenbelt 2.0 framework. It distinguishes between the sources used in the present conceptual assessment and the datasets required for future GIS-based replication; the framework does not claim that all indicators have been fully calculated in this paper; rather, it defines the data infrastructure, accessibility conditions, and processing logic needed to make the framework empirically reproducible. Detailed indicator metadata and calculation requirements are provided in **Appendix A**.

**Table 2.** Data Availability and Reproducibility Framework.

<b>Component</b>	<b>Description</b>	<b>Data Source / Accessibility</b>	<b>Replicability Notes</b>
<b>Land-Use Data</b>	National land-use classification and agricultural land distribution	UK Office for National Statistics (public access)	Downloadable datasets; compatible with GIS software
<b>Planning Policy Documents</b>	Green Belt regulatory framework (NPPF, local plans)	UK Government planning portal	Public documents; qualitative policy coding replicable
<b>Urban Expansion Metrics</b>	Urban growth trends and density gradients	Published datasets (Chen et al., 2020; Seto et al., 2012)	Indicator recalculation possible using density grids
<b>Ecological Indicators</b>	Carbon sequestration ranges; land cover composition	Peer-reviewed literature; environmental agency reports	Requires land-cover reclassification in GIS
<b>Accessibility Indicators</b>	Public access estimates; green space proximity	Public land registry data; local authority datasets	Reproducible via network analysis tools
<b>Governance Assessment</b>	Boundary revision frequency; policy adaptability	Official planning documentation	Replicable through institutional audit
<b>Analytical Workflow</b>	Four-step GIS-oriented operational pathway	Described in Sect. 2.6	Replicable in QGIS/ArcGIS using standard spatial tools
<b>Indicator Framework</b>	Ecological, social, productive, and governance domains	Defined in Sect. 2.5	Transferable to other metropolitan regions
<b>Code Availability</b>	No proprietary code used	Not applicable	Standard GIS functions required
<b>Data Restrictions</b>	No restricted or confidential datasets used	Fully public sources	No ethical restrictions

## 5. Limitations

This study has four main limitations:

- It does not conduct original GIS modelling, statistical testing, or field-based ecological measurement. The spatial indicators proposed in the framework are therefore not presented as fully calculated empirical results, but as operational categories for future implementation.
- The analysis focuses on the London Green Belt as a single reference case. While this case is historically and institutionally significant, it does not allow statistical generalization across all greenbelt systems.
- Several performance dimensions rely on proxy indicators or qualitative policy interpretation, particularly ecological connectivity, public accessibility, and governance adaptability. These indicators require further validation through spatial modelling, accessibility analysis, and systematic policy coding.
- Some Greenbelt 2.0 values represent normative targets rather than observed conditions. They should therefore be interpreted as proposed performance objectives, not as measured outcomes.

These limitations do not invalidate the framework, but they define its proper scope: the paper should be understood as a conceptual and methodological contribution that prepares the ground for future empirical testing. A full validation of Greenbelt 2.0 would require harmonized spatial datasets, reproducible GIS workflows, longitudinal monitoring, and comparative application across multiple metropolitan regions.

### 5.1. Reproducibility and technical implementation notes

The proposed *Greenbelt 2.0* dataset structure can be reproduced using the following workflow:

- Download publicly available land-use and density datasets.
- Reclassify land-cover categories into ecological performance groups.
- Compute density gradient and discontinuity ratios.
- Perform least-cost connectivity modelling for corridor assessment.
- Generate performance dashboard outputs.

No proprietary software, closed data sources, or confidential datasets are required: all computational steps can be replicated using open-source GIS platforms. To strengthen reproducibility, **Appendix A** provides an indicator metadata protocol specifying dataset requirements, units of analysis, processing logic, expected outputs, and evidence status. This appendix is intended to make explicit which components of the framework are directly documentable, which require proxy assumptions, and which remain dependent on future GIS-based implementation.

## 6. Future research directions

Future research should prioritize five directions:

- The Greenbelt 2.0 indicators should be tested through original GIS-based modelling, including density-gradient analysis, land-cover reclassification, accessibility mapping, and least-cost connectivity modelling.
- The framework should be aligned more explicitly with SDG 11.3.1 and other land-use efficiency metrics to improve international comparability.
- Future studies should construct comparative multi-case datasets across European metropolitan regions in order to evaluate whether the Greenbelt 2.0 framework is transferable beyond London.
- Governance indicators should be validated through systematic policy coding of boundary review mechanisms, performance monitoring systems, and participatory planning instruments.
- Pilot applications should test whether indicator-based monitoring can support adaptive zoning, public accessibility improvements, and ecological corridor planning in real planning processes.

Such developments would transform *Greenbelt 2.0* into a spatial decision-support system grounded in reproducible datasets.

## 7. Data availability

No new dataset is generated in this conceptual and methodological study. The analysis relies on publicly available policy documents, land-use and spatial data sources, and secondary literature identified in the sections. 2.3, 2.7, 5.1, and Appendix A. Future empirical implementation of the Greenbelt 2.0 framework should report dataset-specific DOIs, review links, or access links at the time of application.

## 8. Code availability

No new code was developed or executed for the present study. The proposed workflow can be implemented using standard GIS functions in open-source or commercial GIS software, as described in the sections. 2.6 and 5.1.

## 9. Conclusion

The London Green Belt confirms that spatial containment remains a structurally effective instrument in limiting continuous urban encroachment and preserving peri-urban open land. Its long-term capacity to prevent settlement coalescence demonstrates the enduring relevance of growth boundaries within metropolitan governance. Nonetheless, the analysis also reveals that containment alone is insufficient to address the complexity of contemporary urban challenges, as climate adaptation, biodiversity restoration, carbon regulation, housing accessibility, and socio-spatial equity require governance mechanisms that extend beyond static restriction and binary land-use designation. The analysis suggests a structural asymmetry in the traditional greenbelt model: while the London Green Belt remains highly significant as a regulatory barrier against continuous urban expansion, its role as an integrated socio-ecological infrastructure appears less developed when assessed through the proposed Greenbelt 2.0 framework. This conclusion should be interpreted as a conceptual and policy-based finding rather than as the result of a completed quantitative performance assessment. Ecological connectivity is not systematically managed, public accessibility remains irregular, and governance mechanisms lack adaptive, performance-based recalibration: the limitation of the conventional model lies not in the principle of containment itself, but in its functional underutilization and institutional rigidity.

The proposed *Greenbelt 2.0* framework reconceptualizes the greenbelt as adaptive ecological and social infrastructure, while remaining explicitly positioned as a conceptual and methodological model requiring future empirical validation. By structuring greenbelt governance across four measurable domains, ecological connectivity, productive metabolism, social accessibility, and adaptive governance, the investigation translates containment policy into a performance-based spatial system. This reframing integrates resilience planning, green infrastructure theory, and urban metabolism principles into a coherent operational architecture. Importantly, the contribution does not advocate dismantling containment policy; instead, it demonstrates how performance-based recalibration, indicator monitoring, and spatial data integration can enhance the strategic relevance of greenbelts within climate-responsive and equity-oriented metropolitan planning. By embedding measurable review mechanisms and multifunctional design principles, containment can evolve from a static boundary into a dynamic interface between urban development and ecological systems.

More broadly, the study advances greenbelt theory by shifting the debate from preservation versus development toward systemic integration, adaptive governance, and measurable multifunctionality: its main contribution is not to provide a definitive empirical evaluation of the London Green Belt, but to define a transparent framework through which such evaluation can be conducted in future research. By clarifying indicator categories, evidence levels, and reproducibility requirements, the paper offers a transferable basis for evidence-based recalibration of containment policies in diverse metropolitan contexts.

### Acknowledgments

The abstract of this paper was presented at the Green Urbanism (GU) – 9th edition Conference, which was held on the 25<sup>th</sup>-27<sup>th</sup> of November 2025.

### Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sector/ individuals

### Ethics Approval

Not applicable.

### Conflict of Interest

The author(s) declare(s) that there is no competing interest.

### References

- Abercrombie, P. (1944). *Greater London Plan 1944*. His Majesty's Stationery Office.
- Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning*, 100(4), 341–343. <https://doi.org/10.1016/j.landurbplan.2011.02.021>
- Albert, C., Schröter, B., Hauck, J., Brillinger, M., Henze, J., Herrmann, S., & Fürst, C. (2021). Planning and governing nature-based solutions in river landscapes: Concepts, cases, and insights. *Ambio*, 50, 1445–1459. <https://doi.org/10.1007/s13280-021-01569-z>
- Alberti, M. (2016). *Cities that think like planets: Complexity, resilience, and innovation in hybrid ecosystems*. University of Washington Press.

- Amati, M. (2007). From a blanket to a patchwork: The practicalities of reforming the London green belt. *Journal of Environmental Planning and Management*, 50(5), 579–594. <https://doi.org/10.1080/09640560701475121>
- Amati, M. (Ed.). (2008). *Urban green belts in the twenty-first century*. Routledge.
- Chen, G., Li, X., Liu, X., Chen, Y., Liang, X., Leng, J., & Huang, K. (2020). Global projections of future urban land expansion under shared socioeconomic pathways. *Nature Communications*, 11, 537. <https://doi.org/10.1038/s41467-020-14386-x>
- Cheshire, P. (2009). *Urban containment, housing affordability and price stability: Irreconcilable goals* (SERC Policy Paper No. 004). London School of Economics.
- Cole, H. V. S., Garcia-Lamarca, M., Connolly, J. J. T., & Anguelovski, I. (2017). Are green cities healthy and equitable? Unpacking the relationship between health, green space, and gentrification. *Journal of Epidemiology & Community Health*, 71(11), 1118–1121. <https://doi.org/10.1136/jech-2017-209201>
- Ewing, R. (1997). Is Los Angeles-style sprawl desirable? *Journal of the American Planning Association*, 63(1), 107–126.
- Ewing, R., & Hamidi, S. (2015). Measuring sprawl and its impacts: An update. *Urban Studies*, 52(7), 1217–1235.
- Forshaw, J. H., & Abercrombie, P. (1943). *County of London Plan*. Macmillan.
- Hall, P. (2002). *Urban and regional planning* (4th ed.). Routledge.
- Hansen, R., & Pauleit, S. (2014). From multifunctionality to multiple ecosystem services? A conceptual framework for multifunctionality in green infrastructure planning for urban areas. *Ambio*, 43, 516–529. <https://doi.org/10.1007/s13280-014-0510-2>
- Hilber, C. A. L., & Vermeulen, W. (2016). The impact of supply constraints on house prices in England. *The Economic Journal*, 126(591), 358–405. <https://doi.org/10.1111/eoj.12213>
- International Union for Conservation of Nature (IUCN). (2020). *IUCN global standard for nature-based solutions: A user-friendly framework for the verification, design, and scaling up of NbS* (1st ed.). <https://doi.org/10.2305/IUCN.CH.2020.08.en>
- Kabisch, N., Frantzeskaki, N., & Hansen, R. (2022). Principles for urban nature-based solutions. *Ambio*, 51, 1388–1401. <https://doi.org/10.1007/s13280-021-01685-w>
- Kennedy, C., Cuddihy, J., & Engel-Yan, J. (2007). The changing metabolism of cities. *Journal of Industrial Ecology*, 11(2), 43–59. <https://doi.org/10.1162/jie.2007.1107>
- Kirby, M. G., & Scott, A. J. (2023). Multifunctional green belts: A planning policy assessment of green belts' wider functions in England. *Land Use Policy*, 132, 106799. <https://doi.org/10.1016/j.landusepol.2023.106799>
- Koster, H. R. A. (2024). The welfare effects of greenbelt policy: Evidence from England. *The Economic Journal*, 134(657), 363–401. <https://doi.org/10.1093/ej/uead077>
- Organisation for Economic Co-operation and Development (OECD). (2018). *Rethinking urban sprawl: Moving towards sustainable cities*. OECD Publishing.
- Rydin, Y. (2013). *The future of planning: Beyond growth dependence*. Policy Press.
- Schiavina, M., Melchiorri, M., Corbane, C., Florezyk, A. J., Freire, S., Pesaresi, M., & Kemper, T. (2019). Multi-scale estimation of land use efficiency (SDG 11.3.1) across 25 years using global open and free data. *Sustainability*, 11(20), 5674. <https://doi.org/10.3390/su11205674>
- Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences*, 109(40), 16083–16088. <https://doi.org/10.1073/pnas.1211658109>
- Sharifi, A. (2020). Urban resilience assessment: Mapping knowledge structure and trends. *Sustainability*, 12(15), 5918. <https://doi.org/10.3390/su12155918>
- Uhlhorn, B., Pflitsch, G., & Radinger-Peer, V. (2025). Resilience thinking in spatial planning: Challenges and opportunities for climate change adaptation. *European Journal of Spatial Development*, 22(2), 136–147. <https://doi.org/10.5281/zenodo.17424953>
- Zhao, M., Cheng, C., Zhou, Y., Li, X., Shen, S., & Song, C. (2022). A global dataset of annual urban extents (1992–2020). *Earth System Science Data*, 14(9), 4421–4438. <https://doi.org/10.5194/essd-14-4421-2022>

## Appendices

### Appendix A. Indicator metadata and reproducibility protocol

Indicator	Dataset required	Unit	Processing logic	Output	Evidence status
Internal urban encroachment rate	Green Belt boundary; built-up land-use polygons	% or ha	Overlay built-up areas with the Green Belt boundary	Share of built-up land inside the Green Belt	Future GIS/direct
Density gradient discontinuity	Settlement density grids; administrative boundaries	density ratio	Calculate the density change across the inner and outer buffer zones	Discontinuity index	Future GIS
Leapfrog development proxy	Urban expansion layers; transport network	distance/growth pattern	Identify new urban growth beyond the protected boundary	Leapfrog tendency	Proxy/future GIS
Corridor continuity index	Land-cover data; habitat patches	index score	Least-cost path or fragmentation analysis	Connectivity score	Future GIS
Carbon sequestration potential	Land-cover categories; carbon coefficients	tCO <sub>2</sub> /ha/year	Assign carbon coefficients to land-cover classes	Estimated sequestration potential	Proxy/future GIS
Public accessibility share	Public rights of way; open access land; cadastral data	%	Overlay accessible land with the Green Belt area	Accessible land share	Proxy/future GIS
Boundary review frequency	Planning documents; policy archives	years/count	Code frequency of formal boundary review	Governance adaptability score	Direct policy audit
Performance monitoring system	Planning documents; open-data portals	present/absent	Identify the existence of a monitoring dashboard or indicators	Monitoring capacity	Direct policy audit

This appendix provides the metadata structure required to operationalize the Greenbelt 2.0 framework in future empirical research: it specifies the dataset requirements, units of analysis, processing logic, expected outputs, and evidence status for each indicator. The purpose is to clarify which indicators can be directly documented, which require proxy assumptions, which represent proposed targets, and which depend on future GIS-based implementation. This protocol allows future studies to distinguish between indicators that can be directly calculated, indicators requiring proxy assumptions, and indicators representing normative targets, and also makes clear that the present paper provides the framework and operational logic, while full empirical validation would require spatial modelling, dataset harmonization, and longitudinal monitoring.