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REVIEW

The Extended Land-Use Footprint of Protected Area Recreation: Assessing Off-Site Impacts and Mitigation Strategies

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ABSTRACT

Protected areas are vital for biodiversity conservation and the provision of ecosystem services, including recreation and tourism. However, while on-site ecological impacts are well-documented, the land-use footprint of protected area recreation extends well beyond protected boundaries. This paper conceptualizes the extended land-use footprint, defined as the total area of land both directly and indirectly required to sustain recreational activities linked to protected areas. It encompasses off-site impacts arising throughout the visitor journey and associated supply chains, including transportation infrastructure and energy use, accommodation and ancillary services, food production, equipment manufacturing, and waste management. Collectively, these processes contribute to land-use change, habitat fragmentation, and resource depletion at multiple spatial scales, from local to global. Methodologically, the study applies a multi-scalar analytical framework that integrates Life Cycle Assessment (LCA), Input-Output Analysis (IOA), and spatially explicit modelling to capture both proximate and distant effects. This synthesis demonstrates that existing management paradigms often neglect these externalized costs, thereby underestimating the full ecological burden of recreation. The paper advances a conceptual and methodological foundation for assessing and mitigating these off-site impacts, emphasizing the importance of data integration, standardized indicators, and cross-sectoral policy coherence.

Keywords: Protected Areas; Recreation Impacts; Land Use Change; Off-Site Impacts; Environmental Footprint; Sustainable Tourism

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1. Introduction

Protected areas represent critical components of global conservation strategies, safeguarding biodiversity, preserving ecosystems, and providing numerous benefits to human societies [1–6]. Among these benefits, nature-based recreation and tourism have become increasingly prominent, offering economic opportunities for local communities, fostering environmental awareness, and providing significant health and well-being benefits to visitors [1–3]. The popularity of protected areas as recreational destinations has grown exponentially in recent decades, driven by factors such as increased leisure time, accessibility, and a growing appreciation for nature [7,8]. This growth, while beneficial in many respects, exerts considerable pressure on the very resources protected areas are designed to conserve.

Traditionally, the focus of protected area management and research regarding recreation impacts has been primarily on direct, on-site effects [9]. These include soil compaction and erosion, vegetation damage, disturbance to wildlife, littering, and impacts on water quality within the protected area boundaries [10]. Managers have developed various strategies to mitigate these localized impacts, such as trail hardening, zoning, visitor limits, and educational signage [11,12]. However, this bounded perspective overlooks a significant portion of the environmental burden associated with protected area recreation: the "extended" or "off-site" land-use footprint (**Figure 1**).

Figure 1. Composition of extended foot-print of protected area recreation.

The concept of an extended footprint acknowledges that the resources consumed and the environmental alterations caused by recreation activities are not confined to the specific location where the activity takes place. Instead, they are distributed geographically across the entire value chain of the recreational experience [13]. This includes the land base needed for transportation infrastructure connecting visitors to the site (roads, rail lines, airports, vehicle manufacturing facilities, fuel extraction areas) [14]. It encompasses the land occupied by accommodation facilities (hotels, lodges, cabins, parking areas) located outside but often adjacent to or near the protected area boundary, as well as the land used to produce the energy, water, and handle the waste generated by these facilities [15].

Furthermore, the extended footprint encompasses the global land requirements for producing food consumed by visitors during their trips, as well as the extraction, processing, and manufacturing of recreational equipment such as tents, clothing, vehicles, and electronics [14]. It also includes the land necessary for waste treatment and disposal throughout the visitor journey, both on-site and off-site [16]. Crucially, the extended footprint is not confined to physically occupied land but extends to areas whose ecological condition or management practices are altered by recreation-driven demand. Such indirect pressures manifest through habitat fragmentation from transport infrastructure, shifts in agricultural and forestry practices to meet tourism-linked supply chains, and hydrological alterations arising from infrastructure development [17–19]. Methodologically, these relationships align with existing analytical frameworks such as Life Cycle Assessment (LCA), Input–Output Analysis (IOA), and spatially explicit land-use modelling, which together provide a means of tracing land dependencies across sectors and scales.

Ignoring this extended footprint risks presenting an incomplete and potentially misleading picture of protected area sustainability. Even when on-site ecological impacts appear well-managed, significant environmental costs may be externalized to distant regions, undermining conservation objectives or displacing ecological burdens onto other ecosystems and communities [20,21]. For instance, constructing highways or airports to enhance visitor access often causes extensive off-site habitat loss and fragmentation. Similarly, the proliferation of accommodation and commercial developments near protected boundaries can disrupt landscape connectivity and deplete local resources [22–25]. The globalized production of food, goods, and services for protected area visitors further compounds this footprint, linking local recreation activities to distant agricultural, industrial, and manufacturing landscapes. Despite the increasing attention to such off-site effects within tourism and sustainability literature, their explicit quantification and integration into protected area management remain methodologically fragmented and underdeveloped [26].

This paper therefore addresses these gaps by systematically articulating the extended land-use footprint of protected area recreation and situating it within established socio-ecological systems and resource accounting frameworks. It first delineates the conceptual dimensions and analytical boundaries of the extended footprint, followed by an examination of the diverse off-site land-use impacts that occur across the recreation value chain. It then reviews methodological approaches including LCA, IOA, and spatial data integration that can capture the cumulative and geographically diffuse nature of these impacts. Finally, it proposes mitigation strategies aimed at aligning visitor access, infrastructure development, and supply-chain governance with sustainable land-use objectives.

2. Defining the Extended Land-Use Footprint of Protected Area Recreation

The concept of a land-use footprint refers to the total area of land directly and indirectly required to sustain a given activity or population, accounting for both resource consumption and waste assimilation across spatial and temporal scales [27–29]. Initially advanced through the ecological footprint framework, which quantifies the bioproductive area needed to support human consumption [30], this notion can be extended to capture the spatial demands of recreation and tourism systems. In the context of protected areas, conventional analyses have primarily examined on-site land use such as trails, visitor centres, and campgrounds. However, this perspective overlooks the extensive off-site land requirements that underpin the visitor experience.

The extended land-use footprint concept expands this understanding by tracing the land dependencies of all activities that enable, sustain, and result from recreation within protected areas (**Figure 2**). It encompasses the land required for transportation infrastructure connecting visitors to the site such as roads, rail lines, airports, and the industrial facilities supporting vehicle manufacturing and fuel extraction [31]. It further includes the land occupied by accommodation and hospitality facilities situated outside protected area boundaries, often clustered in adjacent gateway communities, along with the land indirectly required for their energy, water, and waste services [32–34]. Similarly, the production of food consumed during trips, the extraction and processing of raw materials for recreational equipment, and the treatment or disposal of associated waste all contribute to the global spatial footprint of recreation [35,36]. Importantly, this footprint extends beyond land that is physically occupied to include land whose condition or function is altered by recreation-driven demand such as habitat fragmentation from transport corridors, changes in agricultural or forestry management to supply tourism markets, and hydrological modifications linked to infrastructure development [37].

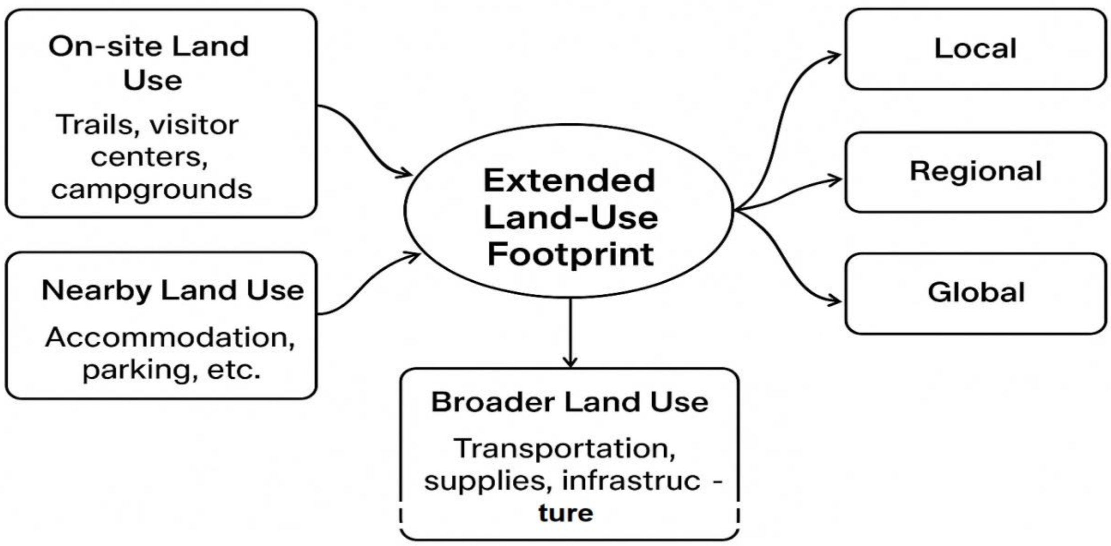

Figure 2. Schematic diagram of the extended land-use foot print of protected area recreation.

Analytically, distinguishing among spatial scales of off-site impact strengthens methodological clarity. Immediate adjacent impacts may arise from development pressures along park boundaries (e.g., resort construction), regional effects from shared infrastructure networks (e.g., energy generation, road systems), and distant or global effects transmitted through supply chains (e.g., agricultural land for food, mining sites for raw materials)[38]. This typology parallels established frameworks such as life cycle assessment (LCA) and telecoupling, which systematically trace environmental linkages between geographically separated human–environment systems. Defining the system boundaries of analysis whether to include the visitor's journey from home, the embodied impacts of vehicle manufacturing, or only the immediate tourism zone is thus a pivotal methodological step, dependent on research objectives and data availability. Ultimately, the extended land-use footprint framework highlights the embeddedness of protected area recreation within broader socio-economic and ecological systems. It challenges the traditional assumption that protected areas can be sustainably managed in isolation, emphasizing instead their dependence on— and contribution to— regional and global land-use dynamics[39]. Recognizing and quantifying these connections is essential for developing integrated management strategies that reconcile tourism benefits with long-term spatial sustainability.

3. Types of Off-Site Land-Use Impacts

The off-site land-use footprint of protected area recreation manifests through interconnected processes that extend well beyond park boundaries. These impacts are geographically dispersed, mediated through supply chains, and reinforced by infrastructure and service networks[40]. Understanding their multiple pathways spanning transportation, accommodation, food systems, and regional infrastructure is crucial for identifying leverage points for mitigation and policy intervention. Rather than discrete categories, these pathways form an integrated system of land-use pressures shaped by visitor demand, governance frameworks, and market dynamics.

3.1. Transportation

Transportation remains one of the largest and most visible contributors to recreation-related land demand. Roads, highways, railways, and airports[41] constitute linear infrastructures that fragment habitats, alter drainage systems, and facilitate further development[42]. Each additional access route often induces secondary land conversion, from rest areas and parking lots to gas stations and roadside lodging. Beyond direct land occupation, the full lifecycle of transport including vehicle manufacturing, raw material extraction, and energy production expands the footprint globally[43]. For instance, biofuel cultivation competes with cropland and natural habitats, while fossil fuel extraction degrades extensive landscapes. Emissions from transport also accelerate climate change, which indirectly reshapes land use by shifting agricultural zones or inundating coastal areas [44]. The intensity of these effects varies according to visitor origin, travel mode, and trip frequency [45]. Consequently, transportation not only connects people to protected areas but also serves as a structural driver of land transformation across regions.

3.2. Accommodation

Accommodation infrastructure ranging from hotels and lodges to rental cabins and campsites constitutes a significant land-use driver in gateway communities [3,46]. Construction activities demand land clearing and site modification, often at the expense of native vegetation and soil integrity [47,48]. The spatial scale of development is influenced by visitor volume and local planning controls, with concentrated tourism nodes frequently catalyzing urban sprawl [49]. Beyond the footprint of buildings themselves, supporting infrastructure such as roads, sewage systems, power lines, and water treatment facilities adds to cumulative land pressure [50,51]. Operational phases also carry extended footprints through energy demand, water consumption, and waste generation, all of which rely on off-site facilities and land-intensive resource production [52,53]. These dependencies demonstrate how visitor accommodation links local land-use change to distant resource frontiers, highlighting the importance of integrated spatial planning and sustainable construction standards.

3.3. Food and Supplies

Food consumption represents a less visible but extensive land-use driver in tourism systems. Agricultural production to supply visitors' dietary needs occupies substantial cropland and pasture, with environmental outcomes depending heavily on production methods [54,55]. Intensive livestock systems, for instance, contribute to deforestation and nutrient runoff, while sustainable agroecological models can mitigate these pressures. The land required for food processing, packaging, and distribution further expands the spatial reach of tourism's footprint [56]. Similarly, the production and supply of recreational goods ranging from outdoor gear to vehicles involves land for raw material extraction, factory operations, and logistics infrastructure [57]. The full lifecycle, including end-of-life waste management, demonstrates how consumption in seemingly natural settings is underpinned by industrial and agricultural land systems worldwide. Consequently, sustainable procurement and consumer awareness are essential levers for reducing this diffuse footprint.

3.4. Infrastructure Development

Protected area recreation depends on regional infrastructure extending well beyond tourism-specific facilities [58]. Energy generation for transport, accommodation, and visitor services requires land for power plants, hydropower dams, and transmission corridors [59]. Likewise, water systems demand reservoirs, pipelines, and treatment plants [50,51]. Waste management infrastructure including landfills and recycling centres further adds to the cumulative land burden [60]. These systems, though essential, are often planned independently of conservation priorities, producing spatial mismatches between energy and water provision and sensitive ecosystems. Their expansion can permanently alter terrain morphology and resource distribution, particularly where infrastructure intersects migration routes or water catchments. As visitation patterns intensify, incremental extensions of such networks can magnify ecological stress, calling for analytical mapping of infrastructural footprints and better prediction of cross-sectoral land dependencies.

3.5. Associated Services

Gateway settlements and nearby towns develop diverse services catering to visitors including restaurants, retail outlets, and equipment hire, among others [61]. While these enterprises sustain local economies, they also induce rapid landscape modification through commercial expansion, parking zones, and auxiliary infrastructure. In heavily frequented destinations, such growth transforms rural or peri-urban areas into fragmented built environments [37]. The associated loss of vegetative cover and alteration of drainage patterns reduce landscape permeability and amplify pollution loads [62,63]. Beyond direct spatial conversion, service proliferation alters settlement hierarchies, reshaping land markets and drawing labour and capital away from traditional land uses. Examining these transitions through socio-ecological frameworks reveals how visitor-oriented services indirectly restructure regional development trajectories, influencing long-term land-use intensity around protected areas.

3.6. Cumulative and Indirect Impacts

Off-site land-use effects accumulate through iterative and indirect processes that extend beyond immediate physical footprints. Tourism-induced rises in property values often encourage speculative development, converting agricultural or open land into built zones [64]. Such piecemeal transformation fragments habitats and weakens ecological connectivity vital for species dispersal [65]. Over time, dispersed infrastructure and service growth create emergent patterns of landscape homogenization that erode ecological diversity. These cumulative dynamics reflect feedback mechanisms where improved access and amenities stimulate further visitation, perpetuating a cycle of expansion. Anticipating these outcomes requires integrating spatial–temporal modelling with land-change analysis to identify threshold effects, enabling planners to intervene before ecological resilience is irreversibly compromised.

4. Methodologies for Assessing the Extended Footprint

Assessing the extended land-use footprint of protected area recreation remains challenging due to the dispersed and interconnected nature of impacts. These often span multiple sectors, countries, and temporal scales. Nevertheless, a combination of quantitative and qualitative approaches can provide a more complete picture. Each method brings distinct strengths, limitations, and data requirements, highlighting the need for methodological integration and continuous refinement. An effective assessment strategy recognises that no single approach captures the full system complexity rather, complementarity among models, spatial tools, and stakeholder insights provides the most robust foundation for decision-making.

4.1. Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) remains one of the most rigorous tools for tracing the environmental impacts of a product or service across its entire life cycle [66]. When applied to recreation, it quantifies how visitor experiences translate into cumulative land-use pressures from transportation infrastructure and accommodation construction to food and equipment supply chains [31,67]. For example, a comparative LCA of diesel and electric vehicles used in safari transport can reveal not only differences in fuel consumption but also the upstream land requirements of battery manufacturing and energy generation systems. Similarly, LCAs of eco-lodges versus conventional hotels show how energy sourcing, material choices, and waste management determine overall land-use intensity. Yet, the method's strength which is its comprehensiveness is also a limitation. Defining system boundaries remains a critical point of contention, as recreation-related activities are often intertwined with broader tourism and trade flows [68]. The lack of reliable and spatially disaggregated data further restricts the temporal sensitivity of LCAs. Future research should focus on dynamic LCA models that incorporate seasonal visitation trends and land-use changes over time, thereby allowing for longitudinal comparison. Furthermore, the development of open-access databases tailored to recreation-specific processes could enhance transparency and cross-study comparability [69]. Integrating LCA with socio-ecological indicators such as biodiversity loss, soil degradation, and restoration potential would also yield a more holistic picture of sustainability performance.

4.2. Input-Output Analysis (IOA)

Input–Output Analysis (IOA) provides a macroeconomic perspective by modelling how tourism expenditures reverberate across sectors, revealing indirect land-use demands embedded in supply chains [70]. For instance, tourist spending on food services may influence agricultural land expansion, while demand for accommodation indirectly drives urban development and construction material extraction [71]. IOA thus captures systemic linkages that single-site analyses often miss, providing critical insights into how protected area recreation shapes land-use patterns beyond park boundaries. However, traditional IOA models operate at aggregated spatial and temporal scales, making it difficult to isolate recreation-specific impacts or identify local ecological effects [72]. Recent advances in multi-regional IOA have begun to resolve this issue by tracing cross-border resource flows and identifying the geographic origin of land-based inputs. Hybrid IOA-LCA models integrate the structural comprehensiveness of IOA with the environmental specificity of LCA, offering a more nuanced understanding of land-use dynamics [73]. For example, hybrid applications can quantify the land embedded in imported tourism goods while simultaneously mapping domestic land conversion. The analytical strength of IOA lies not only in quantifying total impacts but also in revealing structural dependencies that perpetuate unsustainable land use, highlighting potential leverage points for policy interventions such as green procurement or eco-labelling.

4.3. Spatially Explicit Modeling and Geographic Information Systems (GIS)

Spatially explicit modelling and GIS techniques enable the visualization and analysis of how tourism-related pressures manifest across landscapes [74,75]. These tools integrate diverse datasets such as land cover maps, road networks, visitor flows, and development pressures to identify spatial patterns and hotspots of land-use change [76]. For example, remote sensing data have been used to map the proliferation of tourism infrastructure around the Galápagos Islands and monitor vegetation loss along high-altitude trails in the Himalayas. Such spatial analyses illustrate how accessibility and visitation intensity correlate with environmental transformation, providing crucial evidence for zoning, buffer design, and infrastructure planning. Beyond mapping static impacts, GIS enables temporal monitoring of landscape change through time-series satellite imagery [74–77]. Coupling these data with agent-based models or regression frameworks allows analysts to simulate how future visitor growth might influence land conversion. Nevertheless, the quality and availability of fine-scale spatial data remain major obstacles. Integrating open-source geospatial platforms with participatory mapping initiatives can help fill these gaps, while machine learning and cloud-based image processing now offer cost-effective means for continuous monitoring. The analytical challenge is to link spatial patterns with underlying socio-economic processes; thus, combining GIS with IOA or qualitative insights can reveal not only where land-use changes occur, but also why and under whose influence [78].

4.4. Ecological Footprint Accounting

Ecological Footprint Accounting translates complex patterns of consumption into bioproductive land equivalents, making it a communicative and policy-friendly indicator of sustainability [79,80]. In protected area recreation, it quantifies the land required to sustain visitor consumption, including food, energy, and materials [81]. This method is particularly effective for comparing different sites or tourism models, for example, contrasting the per-visitor footprint of high-end wildlife lodges with that of community-based ecotourism enterprises. These comparisons can inform targeted interventions and behavioural campaigns. However, the method's simplicity can mask underlying heterogeneity. Aggregating diverse land types into a single footprint value often conceals spatial and ecological variation. Integrating ecological footprint models with spatially explicit datasets or LCA outputs enhances interpretive depth, enabling identification of which ecosystems bear the highest pressure [82]. Furthermore, most footprint studies remain static snapshots; temporal extensions could capture whether improvements in efficiency such as renewable energy adoption or waste reduction translate into absolute decreases in total land demand over time. This longitudinal perspective is essential to avoid the rebound effect, where efficiency gains prompt higher overall consumption. Developing adaptive footprint indicators that reflect regenerative land use or restoration potential could further align this approach with the principles of ecological integrity.

4.5. Qualitative and Mixed Methods

Quantitative approaches, while powerful, cannot capture the social complexity, governance dynamics, and behavioural drivers underlying tourism's extended footprint. Qualitative and mixed methods provide essential interpretive depth by exploring how actors perceive, negotiate, and respond to off-site land-use pressures [83]. Surveys can elucidate travel behaviour, consumption patterns, and awareness of environmental consequences [84], while interviews with residents and policymakers reveal conflicting land-use priorities and governance trade-offs [3,85]. Participatory observation and stakeholder workshops facilitate shared understanding and joint problem-solving, ensuring that analyses reflect local realities rather than external assumptions [4–6]. A key analytical advantage of qualitative integration lies in its capacity to contextualize quantitative indicators, for instance, explaining why certain communities tolerate tourism-induced land-use change while others resist it. These insights are indispensable for designing equitable interventions. Nonetheless, methodological challenges persist. Data sources are fragmented and inconsistent across regions, spanning national tourism statistics, satellite imagery, trade data, and facility-level operational reports [86–88]. Bridging these sources requires harmonized frameworks capable of managing scale mismatches and uncertainty. Developing open-data protocols, standardised reporting formats, and longitudinal social–ecological observatories could substantially enhance comparability and robustness. Moreover, future assessments must evolve from measuring land area alone to evaluating land quality, ecological function, and socio-economic resilience [89–92]. Only through such integrative, iterative approaches can researchers fully capture the complexity of protected area recreation's extended land-use footprint and devise pathways for its sustainable transformation.

5. Mitigation Strategies for Off-Site Impacts

Mitigating the extended land-use footprint of protected area recreation requires a systemic and adaptive approach that acknowledges the interdependence between tourism, infrastructure, and local economies. Effective strategies must therefore extend beyond the boundaries of protected sites to encompass the wider landscapes and supply chains that sustain recreation. This calls for a shift from reactive management toward anticipatory planning integrating evidence, stakeholder perspectives, and flexible policy mechanisms. Embedding sustainability criteria in routine decision-making and recognising trade-offs between ecological integrity and local well-being remain central to achieving durable outcomes.

5.1. Addressing Transportation Impacts

Transportation is both an enabler of access and a principal source of externalised land-use pressures. Promoting public transit, electric mobility, and shared-ride networks offers a direct means of lowering the land and energy intensity of visitor movement [93,94]. Practical examples such as low-emission shuttle systems in U.S. national parks and electric ferry services in Northern Europe demonstrate that accessible, well-integrated networks can reduce private vehicle reliance without limiting visitation. Encouraging rail-linked destinations and synchronising transport schedules with park entry systems can further consolidate efficiency gains [95,96]. Spatially concentrating access along existing corridors also mitigates habitat fragmentation [97]. Beyond infrastructure, behavioural interventions such as dynamic pricing, reservation-based parking, or carbon-inclusive ticketing can gently shift travel preferences, while digital mobility platforms allow real-time traffic management and enhance the visitor experience [98,99]. Together, these tools illustrate how technological design and behavioural economics can reinforce conservation goals.

5.2. Promoting Sustainable Accommodation

Accommodation facilities, though peripheral to protected areas, frequently determine the scale of associated land-use demand. Green building practices, low-impact site design, and renewable energy integration substantially reduce their environmental burden [31,100–102]. Strengthening local supply chains for food and construction materials not only lowers transport emissions but also circulates value within regional economies [103]. Collaboration between hospitality operators and local authorities on waste management further limits downstream impacts [104]. Certification and ecolabel programmes remain useful signals to consumers [105,106]; yet, when oversight is weak or costs are prohibitive, they risk entrenching inequality or symbolic compliance. Developing transparent, performance-based auditing systems and offering targeted financial incentives to smaller enterprises can enhance fairness and effectiveness. Digital energy tracking and circular resource systems now enable accommodation networks to demonstrate verifiable progress, transforming sustainability from a marketing claim into measurable performance.

5.3. Influencing Visitor Behavior and Consumption

Visitor choices are critical levers for reducing dispersed impacts, yet behavioural change depends on more than environmental awareness. Social norms, convenience, and perceived authenticity often shape decisions more strongly than formal education [107]. Encouraging visitors to choose durable equipment, sustainably sourced food, and low-impact activities can gradually shift demand patterns [108,109]. Supporting locally owned businesses embeds environmental ethics within community well-being [110]. Insights from behavioural science such as social comparison, framing, and feedback suggest that subtle interventions at decision points, including booking platforms or itinerary planners, can normalise sustainable behaviour. Participatory experiences like citizen science projects or restoration volunteering also create emotional investment, which reinforces pro-environmental identity beyond the visit itself.

5.4. Integrated Planning and Policy

Integrated spatial planning remains the linchpin for addressing the external land footprint of recreation. Aligning tourism development with land-use and transport policy ensures that growth supports, rather than undermines, ecological connectivity [111,112]. Effective examples, ranging from coordinated zoning in alpine regions to transboundary habitat corridors in East Africa demonstrate that multi-level cooperation can balance conservation and access [113]. Fiscal measures such as tax incentives or carbon pricing schemes can embed environmental accountability in business decisions [114–116]. However, aligning the diverse interests of agencies, investors, and communities requires governance structures that reward collaboration rather than competition. Shared data systems, cross-sector planning forums, and joint monitoring mechanisms can bridge institutional divides. Embedding environmental metrics in regional development frameworks ensures that sustainability becomes an integral not peripheral criterion in decision-making.

5.5. Collaboration and Partnerships

Collaboration forms the social infrastructure of effective mitigation. Partnerships between protected-area managers, tourism enterprises, communities, and NGOs can leverage complementary expertise and resources [117–119]. Examples include destination stewardship councils and landscape-scale conservation alliances that jointly plan visitor infrastructure and monitor ecosystem health [120–122]. Community participation anchors these initiatives in local legitimacy and equity [123]. From an analytical standpoint, collaboration functions as both a coordination mechanism and a learning system. Institutionalising it through formal agreements, transparent reporting, and shared benefits enhances resilience, while ongoing dialogue ensures that priorities remain adaptive to environmental and economic change.

5.6. Market-Based Approaches and Voluntary Initiatives

Market-oriented mechanisms such as certification, ecolabels, and voluntary agreements provide flexible pathways to incentivise sustainability [124,125]. They help signal environmental responsibility to consumers and encourage innovation among operators, while localised value chains reduce dependence on resource-intensive imports [120,126]. Nonetheless, such instruments are vulnerable to inequities and symbolic participation: small operators may face financial barriers, and weak verification can enable "greenwashing." Integrating independent auditing, transparent performance disclosure, and consumer feedback loops is critical to maintain trust. Recent advances in blockchain-based traceability systems offer potential for real-time verification of sustainable sourcing, though their success depends on institutional capacity and inter-stakeholder trust [127]. In practice, voluntary mechanisms should complement not replace regulatory frameworks, ensuring that market signals reinforce, rather than substitute, long-term governance commitments [118,121,128,129].

6. Challenges and Future Directions

Despite growing recognition of the extended land-use footprint of protected area recreation, its assessment and mitigation remain constrained by methodological, institutional, and behavioural challenges. Standardisation and data availability continue to hinder robust evaluation of ecotourism impacts [130]. The fluid nature of global trade, persistent data gaps, and inconsistent corporate reporting complicate efforts to measure land footprints across complex supply chains for food, equipment, and visitor services [131]. Attribution remains problematic [132]; isolating recreation-driven land-use changes from broader economic development or demographic pressures requires sophisticated modelling and long-term spatial datasets [133]. For example, estimating the land footprint of a visitor's meal depends on agricultural practices, transport modes, and waste management systems, all of which are rarely tracked comprehensively [134,135].

Governance fragmentation further constrains integrated management [136–138]. The disjointed authority over transport, land-use, agriculture, and conservation sectors prevents coherent policy responses. Successful initiatives such as cross-jurisdictional land stewardship in the European Green Belt and collaborative tourism zoning in Costa Rica illustrate the potential of multi-level governance when supported by shared data infrastructures and participatory planning. However, these remain exceptions rather than norms. Emerging digital tools, including blockchain-based governance and Internet of Things (IoT) monitoring platforms, have shown promise in improving traceability and coordination across jurisdictions.

Balancing environmental integrity with socioeconomic objectives requires policy tools that internalize external costs while safeguarding community benefits [139,140]. Mechanisms such as eco-certification, payment for ecosystem services, and community benefit-sharing schemes can align incentives but demand transparent governance and accountability. Recent applications of Geographic Information Systems (GIS) for mapping visitor flows and spatial pressures offer practical models for balancing conservation and local development priorities. Future research should refine integrated assessment frameworks combining LCA, IOA, and spatial analytics [141–143], while leveraging digital innovations—including AI-assisted decision systems and blockchain for sustainable supply-chain traceability—to enhance data quality, behavioural insights, and policy responsiveness [144].

Crucially, addressing behavioural and institutional inertia will determine success. Effective mitigation depends on shifting consumer norms, strengthening cross-sectoral collaboration, and embedding sustainability into tourism business models [145,146]. AI-driven visitor management systems and digital nudging tools, for instance, can influence low-impact travel behaviour and optimize capacity limits within protected areas [147–149]. Advancing these goals requires an adaptive, transdisciplinary approach that bridges science, governance, and practice.

7. Conclusions

Sustainable recreation in protected areas cannot be understood or managed in isolation from its wider land-use context. This review highlights that off-site impacts arising from transport, accommodation, food systems, and material consumption often exceed on-site pressures, revealing a systemic gap in current conservation and tourism strategies. Focusing narrowly on within-boundary impacts risks displacing rather than reducing environmental costs. Methodologically, quantifying this extended footprint remains constrained by fragmented data, unclear attribution, and scale mismatches. While Life Cycle Assessment (LCA), Input–Output Analysis (IOA), and spatial modelling each contribute valuable insights, they often oversimplify behavioural, temporal, and contextual variability. A more robust approach requires methodological integration combining quantitative footprinting with qualitative and participatory inquiry to expose the socio-economic drivers and feedbacks that conventional models overlook. Practically, translating this understanding into management action demands governance innovation. Policy instruments must extend beyond park boundaries to influence mobility systems, supply chains, and consumption patterns. Also, coordinated strategies such as carbon pricing on visitor transport, circular resource use in tourism infrastructure, and cross-jurisdictional land-use planning can more effectively internalize externalities. Therefore, future research should prioritise dynamic, spatially explicit models that link visitor behaviour with real-time environmental data, enabling adaptive management across scales. Without confronting these off-site dependencies, efforts to make protected area recreation "sustainable" risk reinforcing the very ecological degradation they aim to prevent. A critical, system-wide perspective is therefore essential to reconcile recreation growth with genuine conservation outcomes.

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