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REVIEW

Innovative Strategies for Sustainable Resource Management: Balancing Ecosystem Integrity and Human Development

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ABSTRACT

With the increased pressure on natural resources in the world, sustainable management of resources that resonates with both the integrity of ecosystem maintenance with the development of humankind has been a burning issue of concern. This review discusses new approaches, including the ecological protection in the framework of the developmental aims, when systemic approaches are used, instead of an individual intervention. The paper discusses some of the major directions towards sustainability, such as technological solutions (e.g., precision agriculture, digital monitoring), nature-based solutions (e.g., restoration, agroecology), circular economy, financial mechanisms (e.g., payments to ecosystem services, green bonds), and governance innovations (e.g., adaptive management, polycentric governance). It highlights the importance of multi-sectoral approaches that realize both ecological and social aspects of sustainability, and specifically equity and inclusiveness. The review also gives much attention to the role of measurements and monitoring, which is very critical and identifies the necessity to monitor not only the results of ecological integrity but also the results of human development. It also talks about the issue of balancing trade-offs between trade and conservation and provides advice on the reduction of risks of the leakage effect, rebound effects, and unfair allocation of benefits. Finally, the article also introduces the need to replace the concept of balancing with the co-optimizing of human development and ecosystem health, and its future agenda of research, policies, and practices will be to construct a resilient, just, and sustainable future of both people and nature.

Keywords: Sustainable Resource Management; Ecosystem Integrity; Innovation Pathways; Equity; Governance

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1. Introduction

The global world is encountering a dilemma of a scale never witnessed before: the immediate desire to develop ourselves, with the necessity to preserve the health of our nature. The amount has never been greater as populations are increasing, economies are expanding, and patterns of consumption are changing [1]. In this regard, the attainment of sustainable resource management (SRM) has emerged to be a primary objective in the world. However, the connection between environmental sustainability the well-being, and the diversity of natural systems, the existence of human civilization can seem to go directly against each other. This obstacle is magnified by the problems of managing resources that cut across numerous fields, including water, food, energy, and materials that are becoming more interdependent. Even the same human activities that are aimed at satisfying our growing needs threaten the very systems on which we rely to survive, i.e., our ecosystems [2,3].

It is necessary to comprehend and overcome this difficulty by new innovative approaches that should, at the same time, assist in sustaining the health of the ecosystem and support human health. With the increasing realization of the effects of environmental degradation, there has been an increased consciousness that we need to devise methods by which we cannot only alleviate the effects of pollution but also try to rebuild and rejuvenate the ecosystem. This is especially essential since ecosystems have been known to be very important in offering crucial services like clean water, air, soil fertility, food, as well as carrying out carbon sequestration, which are fundamental to the survival and success of humanity. Meanwhile, the economic growth, societal equity, and health of the population are at the center stage of developmental plans in the world. These pressures frequently put us in a dilemma, whereby the desire to improve the welfare of humankind may destroy those same ecologies that comfort us [4–6].

This review aims to focus on new approaches to sustainable management of resources that can meet each of these two imperatives to ensure the sustainability of the ecosystem and human development. It will seek to provide real answers to important questions concerning the possibility of synergies, trade-offs, as well as the combination of ecological and human development goals. This is not only an academic issue but a practical issue that has very far-reaching consequences for policies, governments, and the realization of sustainable development goals (SDGs) across the world. Discussing the innovative strategies, frameworks, and policies that are being proposed and experimented with, this article manages to give us an idea of how we can attain sustainable resource management in the 21st century [5,7,8].

In order to know the challenges and opportunities better, it is crucial to define the key terms first. Sustainable management of resources can be said to be the practice of using resources in a manner that they can satisfy the needs of the present generation without necessarily reducing the future generations in order to satisfy their needs. This includes the reconciliation of the ecological health with human development objectives, including the reduction of poverty, infrastructural development, and food security. Ecosystem integrity, on the other hand, is the capability of an ecosystem to preserve its structure, functions, and processes over time despite some external influences. This is the concept that is directly connected to the notion of resilience, which denotes the ability of an ecosystem to recuperate following the disruptions and proceed to provide the necessary services [9].

Researchers and practitioners have, in recent decades, found several avenues towards getting sustainable resource management improvements through technological inventions that enhance efficiency and reduce waste, and nature-based solutions (NbS) that exploit the capabilities of nature to solve human problems [10]. A novel form of governance, e.g., adaptive co-management and polycentric forms of governance, has also proven to be an effective tool to govern complex social-ecological systems, particularly where the failed top-down approach of management has been applied. Ecosystem services (PES) and green bond financial innovations are financial approaches that have put market-based strategies to encourage preservation and restoration work [11,12].

However, even in the light of such innovations, the way to making successful implementation still has plenty of pitfalls. The trade-offs between environmental protection and human development can be observed in most areas. Here, taking an illustration, increasing agricultural output to nourish an increase in population is a common occurrence that results in alterations of land-use that undermine ecosystems and reduce biodiversity. Otherwise, the shift to renewable energy may pose a threat to the ecosystem because of land-use change, resource exploitation, and disturbance of habitats. It is important to learn how to deal with these trade-offs and to identify ways that would maximize human development and ecosystem integrity.

The meshing of interrelated industries, including water, energy, food, and materials, is one of the main issues in fulfilling this balance. These industries are interconnected and should be treated as a unit without engaging in undesired adverse impacts. As an example, the agricultural irrigation of water can impact water availability to generate energy, and deforestation can influence the water cycle and food security. In this complex system, the actions in one sphere can cause influence in many other spheres, and it makes the work of finding sustainable solutions even difficult. Thus, there is a need to implement coordinated solutions that consider these interdependencies and not consider individual solutions, which are implemented in exclusive settings of a particular sector[13,14].

Besides these technical difficulties and sectoral issues, the management of the resource is another vital issue in determining whether the strategies are effective and fair. Management styles that do not consider the local situation, participation by stakeholders, and power dynamics are usually unpopular and have lower chances of success. Creative governance systems, such as the decentralization of decision-making, the involvement of multi-stakeholders, and the integration of Indigenous knowledge, have been promising in developing more inclusive and adaptable systems[7]. Nevertheless, the same general issue of equity, i.e., handling the unbalanced effects of environmental violations and resource deficit on minority groups, is at the core. The latter implies that sustainable resource management strategies should be built to protect ecosystems as well as to guarantee that the value of resource management is distributed equally, especially in areas whose levels of poverty and inequality remain elevated[15].

This review examines these problems via synthesizing the multiplicity of innovative approaches to sustainable resource management, and in particular, the areas in which and how the innovative approaches produce co-benefits (i.e., increasing ecosystem health and human well-being) as well as where trade-offs occur. It will look at the interaction between emerging technologies, NbS, financial mechanisms, and more adaptive, resilient, and sustainable systems. This analysis will enable the paper to outline critical lessons learnt and also provide recommendations on how to go about a future where the quality of the ecosystem and the development of the human being will not be viewed as competing elements but more as complementary focuses[16–18].

Finally, the purpose of this review is to provide a holistic framework in terms of designing and implementing innovative strategies that would allow societies to survive within the ecological boundaries of our planet. We think that by making people know more about the interaction between ecosystems and development, we can make our contribution to the current work to create a more sustainable, just, and resilient world that would benefit future generations.

2. Conceptual Foundations: From Trade-Offs to Social–Ecological Synergies

2.1. Sustainable Resource Management as a Social–Ecological Systems Problem

Sustainable resource management is also interpreted as a social-ecological systems issue, not necessarily a technical or sectoral issue[19]. Ecological space contains resources like fresh water, fertile soils, forests, fisheries, and mineral deposits that are embedded in ecological processes and regulated by social institutions, social markets, and cultural customs. Human activities in the form of irrigation systems, land conversion systems, conservation systems, and supply chain specifications change the structure and functionality of the ecosystem, and the ecological modification is backed into social consequences in the form of yield generation, health, incomes, and risk exposure. It is this feedback-custodial structure that creates some interventions that seem effective in the short run but undermine resilience in the long run, such as degrading groundwater, habitat fragmentation, simplifying the landscape, or limiting adaptive possibilities in communities[20–22]. According to **Figure 1**, a social-ecological systems (SES) framework connects both ecosystem integrity and human development to emphasize the feedback between drivers, pressures, states, impacts, and responses.

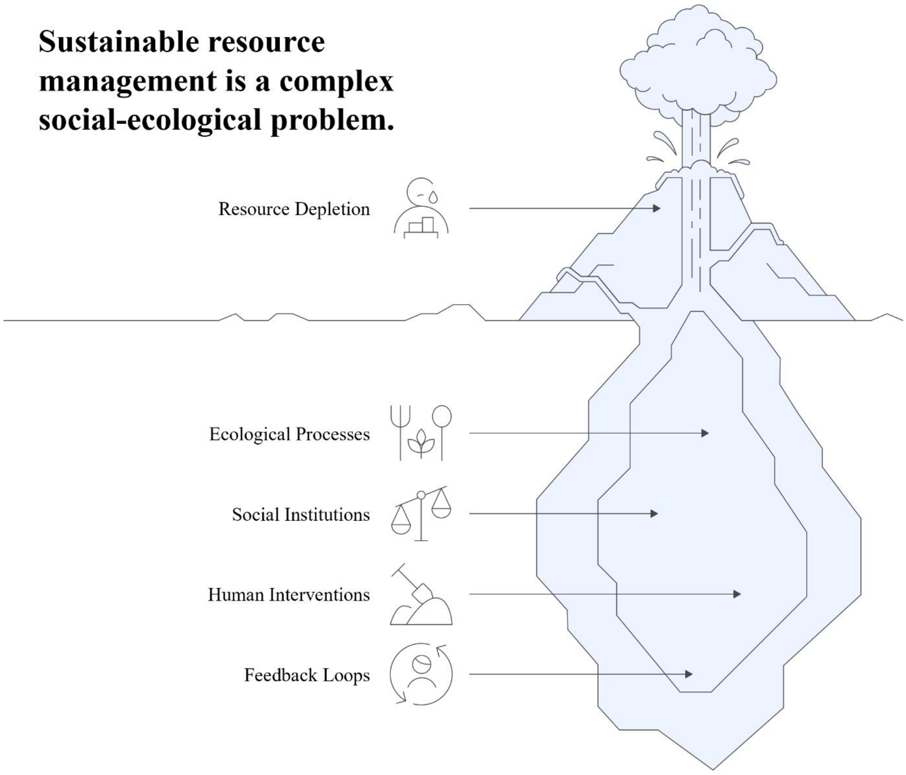

Figure 1. Conceptual framework linking ecosystem integrity and human development in a social ecological system.

The social ecological system frame stresses the fact that sustainability is not an endpoint but a dynamic ability to continue desired functions despite conditions of change. There is a constant disruption created by climate variability, economic shock, technological change, and demographic transitions. Here, sustainability relies on how effectively ecological systems can take a shock without major functions, as well as how effectively societies can learn, coordinate, and adapt in ways that do not entrap them on fragile pathways. This reframing also explains why those best practice solutions are not easily transferable to different contexts. The results are determined by biophysical limits, regional livelihood, effective governance, power, and the cross-scale interrelations between the local resource mobilization and the remote markets and policies [23,24].

2.2. Ecosystem Integrity as a Boundary Condition for Development

Ecosystem integrity is defined as the level of the ecosystem maintaining its typical makeup, structure, as well as functionality, and can support these properties over time [25]. When it comes to the issue of resource management, the concept of integrity is occasionally discussed as one of the goals to be sacrificed for the benefit of developing gains. Nevertheless, there is a growing literature on sustainability that has considered ecosystem integrity as a condition: as a precondition to the presence of the ecological processes that sustain development as such. This does not support the notion of justifying the freezing of landscapes or seascapes in some perceived pristine state. Instead, it acknowledges that at some stage(s) of degradation, ecosystems might experience regime shifts, e.g., eutrophication in lakes, desertification in drylands, coral reef collapse, or fisheries depletion, which radically lower the services and are untenable or costly to restore [26,27].

Considering integrity as a condition of the boundary is operational. It is a change in decision-making that no longer focuses on maximizing near-term outputs (i.e., extraction, yield), but instead on ecological functionality and resilience. It also redefines restoration and conservation as discretionary environmental lavishness, to being basic measures of risk management in the protection of water security, food production, disaster protection, and human health. Cumulative impacts also need consideration in the process of integrity-based thinking. Single projects can seem manageable on a one-to-one basis, but combined can push systems to the edge.

To this end, integrity needs to be addressed with suitable spatial and time scales, such as landscape connectivity, watershed dynamics, as well as multi-decadal soil, forest, and hydrological system dynamics [28,29].

2.3. Human Development as a Multidimensional and Distribution-Sensitive Objective

The growth of human beings in the context of sustainable resource management could not be channeled down to income growth. The concept of well-being is multidimensional, which covers topics such as health, nutrition, education, energy availability, safety, as well as being able to engage in preferred livelihoods. The effects of resource interventions tend to create disequilibrium of benefits and burdens affecting groups, places, and time. A dam can boost the electricity production and strengthen national indicators and resettle communities and fisheries; an agricultural intensification program can boost average yields and expose people to the dangers of chemicals, or destabilize land tenure with regard to smallholders. These results are not by chance; they are often predetermined by those involved in decision-making, the manner in which rights are respected, and which priorities are taken into consideration [30].

Distribution-sensitive vision of development is particularly critical since environmental degradation and lack of resources impact marginalized populations (low-income households, women, pastoralists, and Indigenous people) more disproportionately and with fewer shock buffers. On the other hand, the cost of interventions that are planned in the capacity of conservation may also become costs when these interventions are restrictive and do not offer equal alternatives or reparations. Consequently, the balance between integrity and development does not merely concern the amount of all benefits and all costs, but is essentially an issue of who will be better off, who will take more risks, and whose rights and knowledge will be considered in the measure of success [31].

2.4. Understanding Trade-Offs, Synergies, and the Conditions That Shape Them

Trade-offs can occur in situations where an intervention enhances one thing and harms another, like maximizing production but decreasing biodiversity or maximizing infrastructure but eroding watershed processes. When the intervention generates co-benefits, i.e., the wetland can be restored to enhance water quality, reduce the risk of flooding, and support livelihoods, synergies are achieved. In the real world, trade-offs and synergies are relative to forms of interventions, and not inherent to them, depending on choices of design, governance, and the biophysical context. As an illustration, nature-based solutions can provide robust co-benefits by restoring native habitat and as long as they are coupled with local livelihood approaches, but fail to provide benefits when they are based on monocultures, drive out food production, or overlook tenure realities. Likewise, technological efficiency can suppress the pressure on resources, but this also has the possibility of generating rebound through an increase in aggregate consumption in the case of lower costs [20,32].

Three forms of trade-offs recurrently occur. The trade-offs in space take place where local benefits are earned at the expense of the environment in other locations by leakage or shifts in the supply chain. Temporal trade-offs are those in which the short-term benefit is pursued at the cost of long-term sustainability, such as the soil being degraded, groundwater over-drafted, or a habitat being fragmented. Distributional trade-offs are a situation where aggregate outcomes appear beneficent, yet there is a disproportionate distribution of burdens on less powerful communities. Being aware of these trends can be used to understand why certain sustainability programs seem to be thriving in the headline indicators and collapsing on the legitimacy, equity, or durability levels [33].

The main takeaway is that the management of sustainable resources ought to be set on setting portfolios of interventions, where the root causes of degradation are altered instead of the symptoms being simply counteracted. This usually involves integrating ecological measures (protection, restoration, connectivity), demand-side measures (efficiency, circularity, behavioral change), and instability that are able to monitor, enforce, learn, and resolve conflicts. Increased probabilities of synergies occur when interventions are formulated based on constraints of the system, the local priorities, when they alleviate pressure at the source, and when they provide accountability and adaptation mechanisms [34,35].

2.5. Design Principles for Moving from Balancing to Co-Optimizing

The transformation in balancing to co-optimization of integrity and development relies on the design principles that are strong across sectors. To begin with, caution is necessary when ecosystems are at thresholds in situations of high uncertainty; preventing irreversible damage is usually less expensive than trying to clean up after the damage. Second, a structured approach to the prioritization of integrity by avoiding impacts where they can be avoided, minimizing the impacts that are not avoidable, restoring damaged systems, and offsets as a last resort, the mitigation hierarchy offers a structured approach to the prioritization of integrity to allow the development where it is needed socially. Third, subsidiarity and polycentric governance help make decisions on the lowest level of efficiency and allow coordination between scales to facilitate such issues as watershed management, migratory species, and transboundary pollution [36].

Participation, transparency, and legitimacy are other principles that are equally important. Significant engagement of the affected communities enhances the quality of knowledge, trade-offs, and compliance and stewardship. Opening up assumptions, surveillance, and sharing of the benefits minimizes the possibility of greenwashing and assists in creating trust, especially where market-based instruments or the use of personal finance is concerned. Adaptive management, the management of policies and projects as learning processes, no longer as fixed plans, offers the operational interface between no longer certain and action. It must have clear goals, believable signals, and prearranged conditions under which it may need to readjust itself in the case of a result that is not expected [37].

Lastly, equity can be considered as not only an ethical periphery but a practical necessitates of a sustainable world. Rights undermining, benefit concentration, and livelihood destruction interventions are prone to be met with opposition, ineffective implementation, and subsequent failure despite resulting in a positive change in ecological indicators. On the other hand, those strategies that match integrity objectives with well-being gains in the form of secure tenure, diversified livelihoods, reduced exposure to risk, and equitable compensation have a high possibility of surviving both political and economic cycles. In this regard, social justice and ecological resilience are complementary to one another: each of them requires institutions that can cope with conflicts, share benefits equally, and sustain ecological underpinnings of development [38].

2.6. Implications for the Structure of This Review

This theoretical basis inspires the construction of the review on two aspects. First, it warrants arranging the concept of innovation not as a list of tools, but rather as avenues that work under specific mechanisms, including technological, nature-based, circular, governance, and financial, the results of which are conditional on the context of a system and institutional design. Second, it encourages the analysis of interventions in the paired outcome perspectives: ecosystem integrity and multidimensional human development, and specific consideration of spatial, temporal, and distributional trade-offs. The most promising approaches under this framing include those that uphold improvements of integrity levels, lessen pressure sources, and introduce adaptive as well as equitable governance frameworks that can learn and adapt to change [39].

2.7. Review Methodology

This review adopts a narrative (semi-systematic) approach to synthesise evidence on innovative strategies for sustainable resource management that balance ecosystem integrity and human development. A structured literature search was performed in March 2025 across four databases: Web of Science Core Collection, Scopus, Google Scholar, and ScienceDirect. The search timeframe covered January 2000 to March 2025, capturing both foundational concepts and recent innovations.

Keyword strings combined terms related to sustainable resource management (“sustainable resource management”, “natural resource governance”), ecosystem integrity (“ecosystem integrity”, “ecological resilience”, “biodiversity conservation”), human development (“human well-being”, “sustainable development goals”, “livelihoods”), and innovation pathways (“technological innovation”, “nature-based solutions”, “circular economy”, “payments for ecosystem services”, “adaptive governance”, “social innovation”).

Inclusion criteria were: (i) peer-reviewed articles, book chapters, or authoritative grey literature (e.g., UN, World

Bank, IPBES, IPCC reports); (ii) English language; (iii) explicit focus on the interplay between ecological integrity and human development in resource management. Exclusion criteria were: conference abstracts, editorials without new analysis, and studies addressing only biophysical or only socioeconomic dimensions without integration.

After removing duplicates, 481 records were screened by title/abstract. Full-text assessment was performed on 162 articles, from which 113 core references were retained. Additional references were identified through forward/backward citation tracking and expert recommendations. The synthesis does not aim for quantitative meta-analysis but instead identifies recurring themes, trade-offs, synergies, and innovation bundles across sectors. This methodology ensures transparency and reproducibility while allowing integration of diverse evidence types.

3. Innovation Pathways for Sustainable Resource Management

3.1. Framing Innovation as Pathway Bundles Rather than Standalone Solutions

Sustainable resource management innovation is frequently introduced as a collection of very clear-cut instruments new technologies, restoration initiatives, new or new financial instruments, or policy reforms [40]. As a matter of fact, long-term results are seldom achieved when only a single intervention is carried out. The drivers are interacting, such as demographic change, market incentives, institutional capacity, and climate variability, and the systems of the available resources are formulated at scale, ranging from houses to global supply chains. It is due to this that it is best to think of innovation as a series of possibilities that can be packaged into bundles in response to local limitations and opportunities. Bundling is different, as the pathways would be more likely to cover different aspects of the problem. Technology advances can lessen resource intensity, but will not necessarily solve tenure problems or poor enforcement; the ecological role of nature can be restored by natural means, but in a situation where funding and participation are not established, then purposely with unstable investment and determined eagerness; and the market mechanism becomes available, but is inequitable, because rights to obtain and protect are lacking. One such perspective is known as a pathway perspective that focuses on complementarity, sequencing, and alignment of governance, with an aim aimed at returning systems to persistent co-benefits to support ecosystem integrity and human well-being [41,42].

3.2. Technological and Digital Innovations

Innovative technological solutions have become popular in the domains of water, food, energy, and conservation, and the most popular have been applications to information-based management and real-time decision support [43]. Precision methods, applied in agriculture and water management, are precision techniques used to deliver water, fertilizers, and pesticides in a more controlled form, minimizing losses and pollution and ensuring the same yields. Smart infrastructure and metering can be applied in cities to enhance leak detection, demand management, and the effectiveness of systems. Vessel monitoring systems, electronic logbooks, and machine learning to detect illegal activities can enhance regulations in areas with ineffective or expensive conventional surveillance in fisheries and other marine settings. In these sectors, remote sensing is used in the spatially explicit tracking of land cover change, vegetation condition, and water dynamics on the surface and certain proxies of ecosystem disturbance so that the risk can be detected earlier and more accountable [44].

Digital innovation is another one that transforms the evidence-generating and using processes. Climate forecasts, hydrological forecasts, and socioeconomic indicators can be incorporated in decision-support platforms to inform allocation regulations, reservoir activities, or provide a warning of drought and floods [45]. Newer methods known as digital twins of cities or watersheds seek to develop dynamic models of cities or watersheds that can be tested and their trade-offs visualized, and plans updated. These tools can enhance the speed and inclusiveness of the decisions made when they convert non-interpretable data to meaningful information for the stakeholders. Nonetheless, online strategies are not always fair and viable. Their performance is based on the quality of data, their maintenance capacity, and institutional preparedness. They can intensify exclusion in situations with low connectivity, in cases of lopsided technical literacies, or in cases where the control of data is taken by the directives of vested interests. Additionally, rebound effects may be created in response to efficiency gains in case reduced costs lead to a rise in aggregate consumption. Such technological tracks thus demand clear regulation of data rights, transparency, visibility, and complementary demand-side measures and governance, which do not permit efficiency to just facilitate increased extraction [46].

3.3. Nature-Based and Regenerative Strategies

Regenerative and nature-based approaches strive to restore, protect, or manage the ecology to maintain biodiversity, enhance resilience, and provide ecosystem services sufficient to sustain human progress. Forest and wetland conservation efforts can also yield stabilized flows, better water quality, and less sedimentation in watersheds and often cost-effectively supplement built infrastructure by reducing treatment expenditures, as well as mitigating extremes. On the coast, mangroves, salt marshes, and seagrasses should be restored in order to decrease the effects of storm surges, improve fisheries habitat, and help store carbon. Agroforestry and regenerative farming methods can enhance the soil composition, nutrient circulation, and water absorption in the farmland, making the soil less susceptible to drought and sustaining diversified livelihoods. Green and blue infrastructure, which includes parks, permeable surfaces, riparian corridors, and indicatively built wetlands, can alleviate heat stress, stormwater, and well-being in an urban setting [47,48].

Even though based on promise, nature-based strategies are very narrow in design integrity. Interventions described as restoration may compromise the ecosystem integrity in cases where they homogenize ecosystems to monocultures and when they value carbon measurements more than biodiversity, and where they force the local food production out of the area without offering equivalent compensations. Ecology is a factor of species selection, landscape situation, and long-term management. The tenure security, benefit-sharing, as well as the research of local knowledge into planning and management are all what social outcomes will rely on. Ecological regenerative strategies are also limited to scale since recovery can take a long time, and the costs incurred in ecological recovery may be non-uniform with time. The ecological technique is, however, a critical innovation in this pathway as is the institutional structure that perpetuates management, community stewardship, co-management agreements, and tangible long-term financing models that perpetuate interventions that go beyond short project cycles [49,50].

3.4. Circular Economy and Demand-Side Innovation

Circular economy strategies aim to alleviate the pressure on ecosystems through altering the way that materials and products are designed, used, and recovered. Instead of considering extraction and waste to be inevitable, circular methods focus on extending the life of products by improving the durability and reuse, remanufacturing, and enhancing collection and recycling procedures to reuse the resources. Circular design in the construction industry can de-emphasize high-impact materials and make them reusable. Industrial symbiosis is an industrial association between waste streams produced by a process used as the input of another process to generate reduced resource needs and pollution. Circularity is applied in agriculture and food systems via nutrient recovery, compost production, and minimization of food loss and waste throughout supply chains to ease land conversion pressure and reduce the emissions related to production [51,52].

Circularity requires demand-side innovation due to the fact that the improvement of efficiency alone is hardly sufficient to cover the growth of consumption. Such strategies that influence demand comprise sustainable procurement criteria, product-service structures that no longer associate utility and ownership, and social innovations that redistribute preferences towards reduced-impact diets and cut waste. Nonetheless, the movement of burdens among life cycles or geographies can bring new trade-offs to the transitions of circular economies [53]. Recycling mechanisms can either be based on energy-consuming procedures, or workers are exposed to toxins, or centralized pollution in disadvantaged communities. Unless reforms are introduced that allow exploitation of fair transitions and restrictions on labor, the informal sectors that handle high levels of recycling nowadays can be removed. Besides, circularity in no way excludes the necessity of governance: it needs material quality, traceability, and responsibility standards, and policy tools like extended producer responsibility that coordinate the interests of the firms with the societal objectives [54].

3.5. Governance, Policy, and Institutional Innovation

Governance innovation focuses on the institutional circumstances where technological, ecological, and market interventions are made or not. A large number of resource challenges exist and remain unresolved, not due to a lack of solutions but due to the inability to implement them because of the lack of a single point of authority, enforcement mechanisms, conflicting rights, or disadvantageous incentives. Adaptive style of governance engages in trying to enhance performance through focusing on learning, flexibility, and cross-actor, cross-level collaboration. In fisheries, forests, and rangelands, especially, co-management arrangements, such as those integrating state power with local expertise and legitimacy, can be used. Polycentric structures of governance decentralize decision-making in two or more sources of authority, making it possible to experiment and be responsive to the environment, yet still coordinated in a way that gaps and conflicts can be prevented [55].

The issue of policy innovation is more inclined towards integrated planning, both in sectors and scales. The spatial planning tools can be used to map out areas to be conserved, restored, and farmed, and provide infrastructure in a manner that minimizes conflict and will not sever connections. The integrated watershed and landscape strategies seek to align land and water decision-making inside and outside jurisdictions. Rights-founded and Indigenous-led paradigms of stewardship have shown that acknowledgment of tenure and governance power in a particular area can enhance ecologically favorable and socially advantageous methods, particularly where the customary methods of governance have long held sustainable practices. Nevertheless, contrary to this, governance reforms have the issue of the capture of the elite, whereby the gains are captured by the strong groups, and the other way, where the governance arrangements fail to fit with the ecological demarcations, or the living systems. Well-being of respondent governance pathways thus relies on accountability, conflict-resolution, capacity creation, and the capacity to maintain collaboration across the transforming political situations [56–58].

3.6. Financial and Market-Based Innovations

Financial innovations are intended to allocate funds towards conservation, restoration, and environmentally responsible production and change incentives towards degradation. Ecosystem services Payments Ecosystem Payments connect the compensation to the action of stewardship or their results, which may be useful in diversifying livelihoods and promoting conservation in areas with a high opportunity cost. Green bonds and blended finance are aimed at significant reductions in risks and higher returns to attract the private capital, on projects in infrastructure and on land-based projects with environmental benefits. Natural capital accounting and disclosure frameworks are an effort to incorporate ecological risks and dependencies into an economic decision-making process and change the way governments and firms assess investments and policy trade-offs [59,60].

However, challenges of credibility and justice are common to the financial mechanisms. The outcomes of environmental factors have to be measurable, extra, and lasting, yet the ecological systems are fluid, and they are tough to attribute. The markets of biodiversity credits, or offsets, may induce perverse incentives as long as they make a normalized avoidance of damage, or as long as they work off poor baselines and imprecision regarding equivalence between harmed ecosystems and those being compensated. The presence of financial pathways can also be one of the sources of control to be concentrated in external actors and the emergence of conflicts and legitimacy crises in such cases, when communities lack bargaining power, or where rights are ambiguous. Strong risk management mechanisms must therefore be taken into account, such as transparent measurements, independent auditing, grievance channels, and benefit-sharing contracts, which are locally prioritized. Finance can be used to facilitate long-term stewardship that most governmental budgets cannot afford; nevertheless, it can be used to increase inequality and distrust towards sustainability efforts when designed poorly [61–63]. **Figure 2** demonstrates that the six innovation pathways to sustainable resource management (SRM) are connected, and they work more effectively jointly.

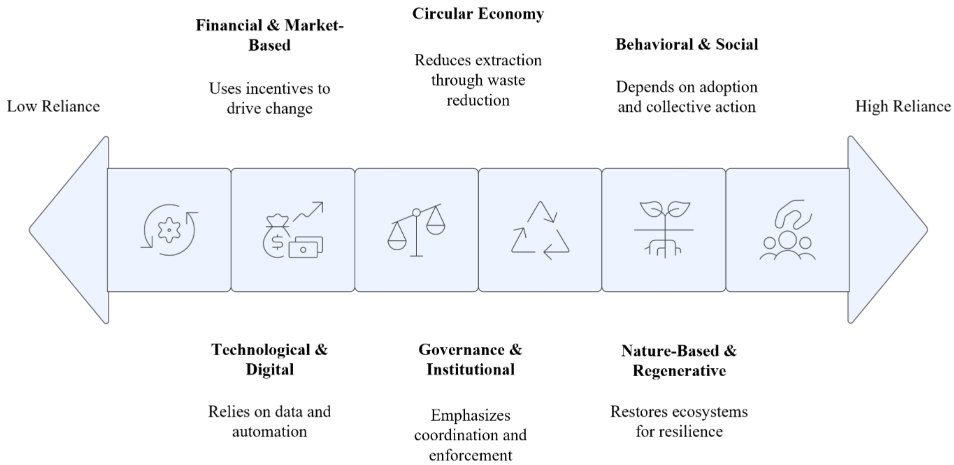

Figure 2. Innovation pathway map and bundling logic.

3.7. Behavioral and Social Innovation as the Connective Tissue across Pathways

Behavioral and social innovation may be viewed as a secondary element, but it is the core of the success of each of the mentioned pathways. The shifts in technology adoption, adherence to regulations, eagerness to endorse restoration, and acceptability of new economic tools are finally a social procedure that is determined by the acceptance, social interdependence, and apprehension of peril, sharing of risks and advantages. Community monitoring, participatory planning, as well as co-production of knowledge may enhance the relevance of interventions and legitimacy of the results as well. Adaptive capacity and conflict reduction can be enhanced through social innovations that empower local organizations, enlarge women and youth leadership opportunities and networks within and between communities. In consumption areas, dietary shifts, movement patterns, and waste culture can bring tremendous positive environmental results, even though these transformations are inclined to endure only in case supported by facilitating infrastructure, policy incentives, and culturally memorable discourses [64,65].

By framing social innovation as connective tissue, it is emphasized as well that numerous technical approaches to innovation have been unhelpful socially: a lack of trust, misfit to livelihoods, or apparent unfairness. On the other hand, low-level technical sophistication of interventions may be effective when the governance has legitimacy, when the benefits are visible and distributed fairly, and when communities are really involved in the process of decision-making. Innovation as a form of sustainable resource management is hence more concerned with changing relations and institutions than it is with applying new tools [66].

3.8. Synthesis: Pathways, Trade-Offs, and the Logic of Bundling

In all the technological, nature-based, circular, governance, financial, as well as social routes, the common theme is that results are determined by how they interact and whether integrity and equity are considered found on design slats as opposed to optional co-benefits. Pathways vary by their common strength's technologies tend to enhance efficiency, and monitoring nature-based strategies tend to restore ecological provision. No upstream pressure tends to place a reduced strain on the instrument. Circularity should build governance to create coordination and enforcement. Finance tends to sustain long-term action social innovation tends to develop legitimacy and adoption. They are also different in their weaknesses, and through bundling, can offset their weaknesses when a plan is the basis of the bundling. Restoration projects in conjunction with secure tenure, stable financing, and participatory monitoring are more long-term. Combined with demand management and permanent limits, there are fewer chances of rebound effects with efficiency technologies. Market instruments are more justifiable when they are installed in rights-based governance and accountability transparency [67].

This route production forms the foundation of the subsequent stages to explore the performance of these innovations within particular nexus settings, including water-food-energy dynamics, cities, and coastal and marine resources. It also gives impetus to the twin assessment prism that is applied during the review: the degree to which bundles of innovation uphold the integrity of the ecosystem and promote multidimensional human development, without causing harm in the space, time, or social categories [68]. **Table 1** gives a typology of the six major ways of innovation to sustainable resource management and where they are most commonly used, as well as the possible risks.

Table 1. Typology of innovation pathways and design considerations.

Innovation Pathway	Primary Mechanism	Typical Application Contexts	Expected Co-Benefits (Integrity + Development)	Common Risks/Failure Modes	Design Requirements to Reduce Risk
Technological & digital	Efficiency, detection, decision support	Precision ag, smart water systems, enforcement, MRV	Reduced losses, improved compliance, faster response to shocks	Rebound effects; data exclusion; high O&M needs	Caps/allocations; data governance; capacity & maintenance plans
Nature-based & regenerative	Restore function, buffer hazards	Watersheds, coasts, rangelands, urban green-blue	Resilience, biodiversity recovery, risk reduction, livelihood diversification	Monoculture "restoration"; land competition; impermanence	Native diversity; tenure clarity; long-term stewardship financing
Circular economy & demand-side	Reduce upstream extraction	Construction, industry, food systems	Lower land/mineral pressures; waste reduction; job creation	Burden shifting; toxic recycling; informal-sector displacement	LCA/MFA screening; labor safeguards; EPR + traceability
Governance & institutional	Coordination, legitimacy, enforcement	Shared basins, landscapes/seascapes, commons	Durable compliance, conflict reduction, adaptive capacity	Elite capture; weak enforcement; institutional mismatch	Participation; accountability; polycentric coordination; grievance mechanisms
Financial & market-based	Incentives and capital mobilization	PES, green bonds, blended finance	Sustained funding; conservation incentives; risk-sharing	Weak additionality; leakage; measurement gaming	High-integrity baselines; independent audit; benefit-sharing; "avoid-first" rules
Behavioral & social	Adoption, norms, collective action	Community stewardship, consumption shifts	High durability when aligned with values and livelihoods	Low persistence without enabling conditions	Co-production, enabling infrastructure, credible local benefits

4. Nexus and Sector Applications: Where Strategies Succeed or Fail

4.1. Water Systems: Integrating Ecosystem Protection with Water Security

One of the most important areas of the discussion of sustainable resource management involves water resources because they become the point of intersection of the ecosystem and human development. Freshwater systems are vital sources of ecosystem services, which include habitat, water purification, and flood management, and at the same time satisfy agricultural, industrial, and domestic water requirements. Nevertheless, rising requirements for water, climate variability, and pollution have exerted tremendous effects on water resources. Simultaneously, the destruction of freshwater ecosystems by means of over-extraction, damming, pollution, and land-use change only exacerbates those issues with the reduction in the resilience of the ecosystems, the deterioration of the quality of the water, and the increase in risks associated with droughts and floods [69,70]. As **Figure 3** shows, total interconnectedness of the five main areas of the watch in sustainable resource management is here and paramount in terms of planning and sectoral interconnections in the process.

The innovative approach to watershed control is typically aimed at reaching the equilibrium between these opposing demands through combining environmental safety measures and the human factor. The application of integrated water resources management (IWRM) frameworks such as to bring water, land, and other associated resources under management in a manner that maximally optimizes the economic and social values of water whilst also ensuring the sustainability of the ecosystem. The adaptive management approaches are frequently stressed by these strategies, and they permit flexibility in the condition of uncertainty and evolving hydrological conditions. Also, reviewed are examples of nature-based solutions (NbS) of water systems, which include wetland restoration, forest conservation in watersheds, and riparian buffer zones, that have proven to decrease the cost of water treatment, improve water quality, and mitigate against flooding, in addition to supporting biodiversity [71,72].

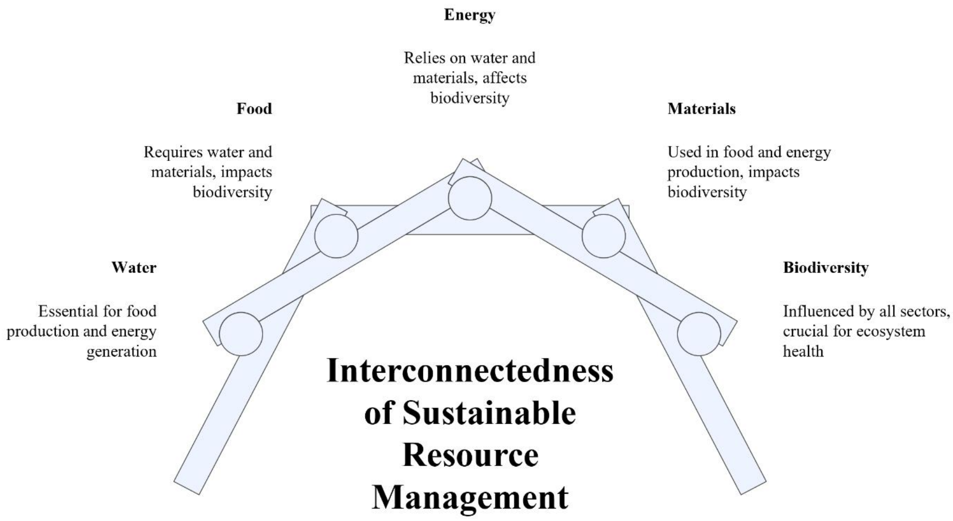

Figure 3. Nexus interaction schematic across sectors (water–food–energy–materials–biodiversity).

These strategies, however, depend on good governance and appreciation of the entire gamut of ecosystem services delivered by water bodies. Water management systems that focus on the short-term economic benefit: the over-extraction of water to irrigate land or serve industrial processes generally overlook the long-term ecological processes that sustain the water quality and supply. Furthermore, the governance issues like conflicting interests of stakeholders, laxity of regulations, and unfairness in sharing water rights can drive the success of the most apt water management plans. Effective approaches should thus take into account the ecological capacity of freshwater systems and social processes that deal with water distributions, as well as encourage collaboration among the government agencies, communities, and the private sector.

4.2. Land and Food Systems: Navigating Trade-Offs in Agriculture and Conservation

One of the most enduring and thorny issues in sustainable resource management is the conflict between agricultural growth and conservation. Demand for food and land is increasing at a high pace as the world population keeps increasing and food habits change. At the same time, massive production processes of agricultural goods in large-scale agriculture and raising livestock, in particular, monoculture and livestock production, are some of the key contributors to deforestation, loss of biodiversity, soil erosion, and greenhouse gases. To balance between the necessity to advance food production and reduce the harm to the environment, innovative strategies that combine the intensification of agriculture with the preservation of the ecosystem must be developed [73,74].

Two major areas are agroecology and sustainable intensification, which aim to counter this challenge. The agroecological practices are designed to promote agricultural yields and, at the same time, ecological resilience through crop diversification, agroforestry, limited application of pesticides, and effective management of soil health. These not only keep the ecosystem services intact, like pollination, soil fertility, and water storage, but also require minimal external inputs in production, reducing the carbon footprint of agriculture. Sustainable intensification, on the other hand, aims at intensifying food production on a unit of land by the use of better management practices, technological inputs, and better utilization of resources instead of an expansive agricultural front [75].

Though the presented strategies could provide a great number of advantages, their effectiveness is usually dependent on the local conditions, the support of policies, and economic factors. Smallholder farmers operating in most of the developing regions are struggling to find markets, credit facilities, and technologies that can help them adopt more sustainable practices. Based on economic motivation and global supply chains, large-scale agricultural systems might be unwilling to undergo agroecological transition because of profitability and competitive issues. In addition, conservation goals do not receive unanimous support as conservation policies restrict land-use, or farmers feel that their livelihood is at risk. Overcoming these obstacles takes a mixture of policy changes to encourage sustainable activities, capacity-enhancing activities of smallholder farmers, and new sources of finance like payments to ecosystem services (PES), which have the power to offer explicit financial assistance to agricultural conservation [76,77].

4.3. Energy Systems: Balancing Renewable Transitions with Ecosystem Preservation

It is a well-known fact that the introduction of renewable energy is an important step to reduce the impact of climate change, yet it also poses a threat to ecosystems when not done with professionalism. Although renewable energy sources like wind, solar, and hydropower can considerably decrease carbon emissions and energy reliance, these sources also may create serious ecological effects, namely land-use change, habitat fragmentation, and water utilization. An example is that extensive solar farms and wind turbines consume a substantial amount of land, blocking out natural habitats or agricultural lands. Although hydropower projects offer renewable energy sources, they disturb the river ecosystem, alter the water in the river, and affect biodiversity [78].

One of the most important strategies for reducing these impacts is renewable energy siting. Renewable energy projects may be located in locations that do not have a high impact on the environment by taking generous ecological considerations like biodiversity hotspots, migratory routes, and water systems. In this case, solar farms can be located in degraded or unproductive lands, thus putting pressure on agricultural lands. The wind farms can be placed in regions with low ecological value, and the hydropower plant can be adopted with fish-friendly technologies and an important flow regime to conserve aquatic life [79].

As well as the issue of siting, it is possible to consider off-grid renewable energy systems, including small-scale solar or wind-powered systems, that can lower the requirements on large, centralized energy infrastructure development projects that have significant environmental footprints. Off-grid systems can decrease the use of fossil fuels in energy production, thus generating electricity to poorly served rural populations without the adverse environmental effects of large-scale energy initiatives. Nevertheless, these systems have not been proven to be scalable, and there are still issues concerning how they can be integrated with the national grids, especially in the infrastructurally and financing-deficient regions. Finally, energy systems should be operated in a wider expansion of the energy-water-food nexus model, where interdependences between energy production systems, water reservoirs, and food systems are properly taken into account to prevent the creation of additional contradictions or the worsening of the contrasts [80]. In **Table 2**, a sectoral breakdown of the sustainable resource management strategies has been provided with highlighting the bundle strategies that are quite common and the trade-off to be made in various areas.

Table 2. Nexus/sector applications and recommended bundle strategies.

Sector/Nexus Domain	Dominant Pressures	High-Performing Strategy Bundle (Illustrative)	Ecosystem Integrity Focus	Human Development Focus	Frequent Trade-Offs to Manage
Water systems	Over-allocation, pollution, climate extremes	Environmental flows + watershed restoration + smart demand management + enforcement	River connectivity, water quality, habitat condition	Reliability, affordability, drought/flood risk reduction	Upstream–downstream conflicts; equity in allocations
Land & food systems	Deforestation, soil loss, input pollution	Regenerative practices + deforestation-free supply chains + tenure security + incentives	Habitat connectivity, soil function, biodiversity	Yield stability, income resilience, nutrition	Land competition; short-term yield risks; labor burdens
Energy & minerals	Siting impacts, extraction frontiers	Strategic siting + mitigation hierarchy + circular minerals + just transition policy	Avoid hotspots, reduce fragmentation	Energy access, jobs, local development benefits	"Green" buildout vs habitat; mining vs rights/health
Urban systems	Heat, floods, material demand	Green-blue infrastructure + circular construction + transit-oriented planning	Reduced runoff impacts, urban biodiversity	Health, safety, service access	Gentrification/displacement; unequal access to green space

Table 2. *Cont.*

Sector/Nexus Domain	Dominant Pressures	High-Performing Strategy Bundle (Illustrative)	Ecosystem Integrity Focus	Human Development Focus	Frequent Trade-Offs to Manage
Coastal & marine	Overfishing, habitat loss, sea-level rise	Co-managed fisheries + MPAs + mangrove/seagrass restoration + monitoring	Nursery habitats, trophic structure	Food security, income, storm protection	Access restrictions; compliance costs; tourism capture
Cross-sector supply chains	Leakage, outsourcing impacts	Traceability + procurement standards + verification + local benefit-sharing	Avoid displaced deforesta-tion/degradation	Stable markets, fair value distribution	Impact displacement; verification loopholes

4.4. Urban Systems and Infrastructure: Designing Cities for Sustainability

City centers contribute to environmental decline, as well as being the possible centers of ecologically friendly innovations. With the continuing population increase in cities around the world, cities are facing more and more pressure to supply housing, transportation, and power with as little impact as possible on nature. The causes of urban sprawl, inefficient infrastructures, and excessive consumption are leading to a huge ecological degradation, which includes deforestation, air and water pollution, and carbon emissions. Meanwhile, cities can also be innovation centers, which encourages the use of new technologies and policies that will lead to sustainability.

Green infrastructure constitutes one such innovation that has received much attention over the last couple of years. The green infrastructure can deliver many related benefits that include, among others, better air quality, decreased urban heat islands, and stormwater management, as green infrastructure incorporates natural features within urban landscapes, including parks, green roofs, urban forests, and wetlands. Green infrastructure may also enhance the quality of life of urban dwellers, besides giving them space to recreate and induce mental and physical well-being, which has ecological benefits [81].

Furthermore, sustainable city planning is interested in compact and transit-oriented city planning that minimizes sprawl, which is car-dependent, energy conservation, and the ecological impact of the cities. By encouraging the development of mixed-use districts, energy-efficient buildings, and transportation systems that are environmentally friendly, cities can substantially diminish their environmental footprint, as well as improving the viability of cities against the impacts of climate change. The adoption of these measures is, however, usually limited by economic and political issues such as insufficient funding, conflicting interests in the automobile and construction sectors, as well as institutional fracturing. Consequently, the city planning and sustainability agenda must have effective governance, policy alignment, and collaboration with the non-governmental actors to ensure that development objectives are coherent as well as consistent with the requirements of the ecological and social environment [82].

4.5. Coastal and Marine Resources: Integrating Conservation with Livelihoods

Coastal and marine ecosystems happen to be one of the most productive as well as biologically varied on earth, which perform vital services like carbon absorption, coastline safeguarding, and sea fishing resources. Simultaneously, these ecosystems face direct danger of overfishing, coastal development, pollution, and other threats. The communities that live in the coastal regions are usually very dependent on the sea as a means of livelihood, and the destruction of these ecosystems poses a threat to their sources of food and earnings [83].

Two new approaches, which strive to balance conservation and human development aspects in coastal areas, are marine protected areas (MPAs) and fisheries co-management. Properly structured and implemented MPA can offer biodiversity reserves, fish boosters, and sustainable tourism. Nevertheless, MPAs can only be effective when they involve the local communities in their management and design and when connected to a larger marine spatial planning, which would take into account the interdependencies existing between terrestrial activities and marine life. Compliance can be improved through the co-management models that include the local communities in the decision-making process with the government and industry stakeholders; they help to manage all the resources as well as to ensure that conservation efforts are matched with local development priorities.

Blue carbon programs that enable restoration and conservation of coastal ecosystems, e.g., mangroves, seagrasses, and salt marshes, also promise as a way of mitigating climate change as well as adapting to it. These ecosystems absorb vast levels of carbon and provide important ecosystem services like wave break protection, water purification, and a home to marine animals. The effectiveness of these plans, however, would rest on finding long-term funding, sharing benefits fairly, and defeating the obstacles of using massive restoration projects on politically and economically unfriendly coastal regions [84–87].

4.6. Cross-Cutting Lesson: The Need for Bundled Approaches

Although sector-specific strategies are necessary to deal with specific issues, the real potential for sustainable resource management is based on integrated, cross-sectoral solutions. This is because water, land, food, energy, and biodiversity are all interconnected and therefore solutions provided must consider these interdependencies. An example of this is that water management cannot be isolated and independent of the land-use decisions, and that energy production should not ignore the effects of using it on the ecosystem and communities. Bundling interventions—combining technological, nature-based, governance, financial, and social strategies—allows for the optimization of synergies and the reduction of trade-offs across sectors. These bundled approaches are more likely to ensure that ecosystem integrity is maintained while advancing human development fairly and sustainably [88].

5. Measuring Outcomes, Managing Risks, Ensuring Equity, and Setting Future Research Directions

5.1. Why Measurement Is Central to Balancing Integrity and Development

Measurement with sustainable resource management is not merely an appraisal exercise undertaken following the interventions undertaken, but rather, it influences the kind of interventions undertaken, finances, regulations, and the magnitude of such undertakings. What is measured will be what is managed, and what is rewarded will be what is given priority. The measures of ecosystem integrity and human development are multidimensional, so the use of single measures of environment brought about by hectares restored, tons of carbon sequestered, water-use efficiency, and gross income can give false signals and promote perverse behavior. Interventions can be effective in small terms and obscure a simplification of biodiversity, displacement of risk, precarity of livelihood, or unequal distribution of gain. This is why plausible appraisal should consider both integrity and development as outcome domains effects and directly monitor whether in one part of the domain being attained to the detriment of the other, or it is being accomplished by moving a burden abroad, among populations, or over time [89,90].

Another governance role of measurement is that it allows transparency and accountability. Government bodies need indicators to apply rules and determine propriety. Credible monitoring is needed by investors and financiers to allow them to justify the claims of performance and control risk. Societies need the available information to balance the benefits of sharing, oppose degrading proposals, and maintain stewardships. The weak, opaque, or overly technical measurement systems may contribute to the lack of legitimacy and conflict when present. They should be strong, inclusive, and transparent so that they can promote adaptive management when assumptions are shown to be failing, and when interventions should be changed [91].

5.2. Paired Outcome Domains: Ecosystem Integrity and Human Development

To operationalize elementary ecosystem integrity, it is necessary to identify more indicators other than land cover and vegetation greenness [92]. Integrity consists of the state of habitats, stability of biodiversity, and preservation of ecological processes, e.g., nutrient cycling, hydrological regulation, and disturbance recovery. In terrestrial systems, integrity has been commonly taken to mean habitat connectivity, fragmentation, structural complexity, and a native species assemblage as opposed to biomass. The measures of ecological condition and cumulative pressures may be used in assessing integrity in freshwater and marine systems in terms of water quality, flow regimes, trophic structure, availability of spawning habitat, and measures of ecological integrity. Notably, there should be indicators of integrity that are both sensitive to initial degradation as well as sensitive to collapse, since the price of recovery rises exponentially when limits are exceeded [93].

The results of human development should also be considered as multidimensional. Income and employment are still important proxies of well-being, but only to a limited extent, especially in a resource-dependent context in which subsistence production, informal employment, and ecosystem services play material roles in livelihoods. The food and water security, health burden, elements of exposure, energy and service accessibility, and stability of options of livelihood in the face of climate variability and market shocks are outcomes of relevance in development. Most of the interventions cannot change the total number of such outcomes but change the distribution of such outcomes, making them better in terms of averages but more dangerous to certain populations. In this connection, it will be necessary that the disaggregated assessment, that is, disaggregated by gender, age, ethnicity, wealth, and tenure status, be undertaken to determine the effects of distribution, which dictates legitimacy and long-term sustainability [94].

An effective implication of paired assessment is that minimum acceptable levels in each area necessarily have to be defined. Ecosystem integrity standards can be based on the imperative habitat needs, the flow necessities in the environment, or target connectivity. Thresholds Development thresholds can represent a minimum access to services, a minimum livelihood, or a minimum exposure to risk. In the absence of such thresholds, assessment may rapidly head in the direction of trading off the ecological functions that are difficult to restore or towards accepting chronic deprivation as an inevitability of conservation. The concept of measuring measurement as a boundary condition stands along with the development being a rights/capabilities-sensitive goal, and thereby, the threshold-based thinking measures the aspects of integrity [95]. **Figure 4** describes how to measure, monitor, and report on the outcomes of the ecosystem and development, making it possible to connect this process with adaptive management and accountability.

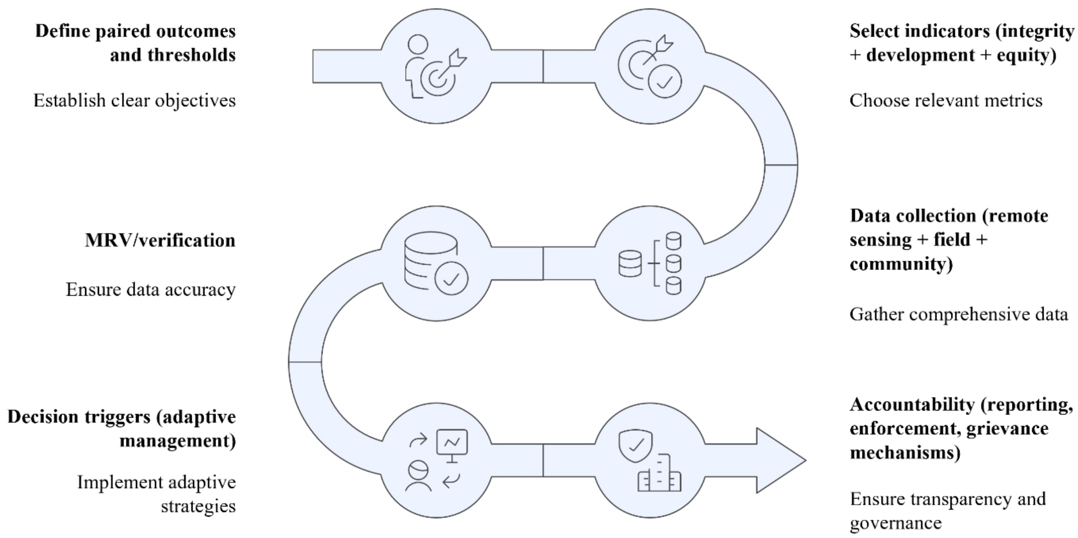

Figure 4. Measurement-to-governance workflow: Indicators, MRV, adaptive management, accountability.

5.3. Integrated Assessment and Monitoring Architectures

Since the outcomes cut across sectors and scales, it follows that integrated assessment cannot be achieved by applying the same set of analytical tools, but that it must be a combination of complementary techniques. The assessment of the ecosystem services can serve to clarify that the ecological condition can be converted into the benefits, which are relevant to the development aspects, yet the application of the ecological assessment needs to be careful to not convert all the values to a financial concept and lose the cultural and relational values that might be valuable to communities. The burden shifting can be uncovered in life cycle strategies and material flow thinking, e.g., when the so-called green infrastructure depends on supply chains that emit lots of emissions or when the transition of the circular economy puts the burden of pollution on the recycling centers. Trade-offs in a scenario analysis and the multi-criteria decision can define the trade-offs, which can be deliberated by stakeholders, and the impact of alternative value weighting on selected strategies, which is especially relevant in the contentious decisions [96].

Architectures in monitoring are becoming more and more incorporated with remote sensing, field ecological data, administrative data, as well as community-based observations. Scalability and transparency of land cover change, some vegetation measures, surface water dynamics, and disturbance detection are steadily becoming viable by remote sensing. Field-based ecological surveillance cannot be replaced by satellites with respect to biodiversity and species composition, as well as various functional pointers that cannot be reliably drawn out by satellites. Community monitoring and participatory mapping can fill such data gaps, enhance the ownership of the local people, and reflect on the livelihood impacts and local knowledge of the ecological systems, which are generally overlooked by these formal systems. The plausible monitoring schemes are the ones that compile such streams and are clear on uncertainty, baselines, and counterfactuals, since attribution is hardly simple in complicated systems [97–99]. This is detailed in **Table 3**, which gives indicators and data sources to measure the outcome of both ecosystem integrity and human development, with the associated caution towards the measures.

Table 3. Measurement and monitoring toolbox (integrity and development).

Outcome Domain	Indicator Family (Examples)	What It Captures	Typical Data Sources	Scale & Frequency	Cautions
Ecosystem integrity	Habitat condition & fragmentation	Structural integrity, edge effects	Remote sensing + field validation	Landscape; quarterly–annual	Land cover ≠ biodiversity; validate locally
Ecosystem integrity	Biodiversity (species, abundance trends)	Composition and persistence	Field surveys, eDNA, citizen science	Site–region; seasonal–annual	Sampling bias; need baselines
Ecosystem integrity	Functional integrity (flows, trophic structure, soil function)	Ecosystem processes/resilience proxies	Gauges, water quality, soil tests	Watershed; monthly–annual	Harder attribution; climate variability
Human development	Livelihood resilience	Income diversity, shock recovery	Household surveys, admin data	Community; annual	Disaggregate by groups/tenure
Human development	Food/water/energy security	Access, reliability, affordability	Surveys, utility data	Household–city; monthly–annual	Seasonal variability matters
Human development	Health & risk exposure	Heat/flood exposure, waterborne disease risk	Public health data, hazard maps	City–region; seasonal–annual	Underreporting; privacy constraints
Cross-cutting	Equity/justice process metrics	Participation, consent, grievance use	Process documentation	Project–program; continuous	Avoid tokenism; ensure accessibility

One of the key predictors of trust-based versus conflict-based monitoring is data governance. In cases of data extraction without the authorization of the population, inabilities to share or understand the discoveries by the communities, or when the selection of indicators is made exclusively by foreign actors, monitoring may turn into an instrument of control in lieu of accountability. On the other hand, under conditions of data rights observation, tracking methods, and communicating results in usable forms, monitoring can facilitate the negotiation process, adaptive activities, and legitimacy. This is particularly important at a time when digital MRV systems are increasingly used in the context of climate and biodiversity finance, where the claims of measurement can influence the key financial flows and land-use choices [100].

5.4. Risk, Trade-Off Management, and Recurrent Failure Modes

Sustainability strategies that are otherwise intended to work can fall flat in cases where they neglect the normal risk corridors. Leakage or displacement is one of the most common failures, when one location experiences a divergence in local conservation or local efficiency, at the expense of other locations, that is, in most cases, the achievement of the gains through supply chains or spatial spillovers. One more is temporal fragility, where brief project periods, changing political priorities, or inadequate maintenance were causing a quick disappearance of ecological benefits. One of them is rebound effects, where total consumption is encouraged because of the lower cost of units in using a resource. Other forms of failure are elite seizure of gains, corruption during enforcement, and the loss of trust when one fails to occur in terms of the promised development co-benefits.

One way to cope with such risks is to govern through arrangements that consider trade-offs as design variables and not as surprises. The reduction of spatial leakage can be conducted through the coordination of interventions with more expansive planning areas, integrating jurisdictions, and integrating local action plans with demand-side policies and supply-chain responsibility. Temporal weaknesses may be tackled by investing in structures that assist in long-term stewardship by providing legal protection that initiates over political loops and institutionalizing maintenance obligations. The effect of rebounds can be countered by capping, allocation policies, or price regimes that do not allow efficiency to be used to facilitate free growth. In all these risks, the trustworthiness of sacrifices lies in transparency, supervisory capability, and the existence of grievance and conflict-resolution systems where the informed groups can challenge the detrimental results [101].

One such risk that is potentially important in modern practice is the replacement of integrity by the proxies that are more easily measured, e.g., interventions can be carbon-oriented and disregard biodiversity and ecosystem functioning, or they can think of green cover as ecological recovery. This is a proxy problem that is heightened on market-based schemes seeing how complex ecological realities are reduced to standardized credits through tradable units. In all areas where simplification is necessary, we must put in place those safeguards which prevent the proxy taking the character of a loophole whereby harm avoidable is justified. This brings us to the hierarchy of mitigation: mitigation by its nature is more trustworthy alongside minimization, rather than trying to recover the losses by making unpredictable equivalences [102–104]. **Table 4** identifies the typical failure modes associated with sustainable resource management and gives the safety measures and mitigation solutions.

Table 4. Risks, failure modes, and safeguards (operational checklist).

Failure Mode	How It Typically Appears	Early Warning Signals	Integrity Impacts	Development Impacts	Safeguards/Mitigation
Leakage/displacement	Reduced local impact, increased elsewhere	Supply-chain shifts; new frontiers	Net biodiversity loss persists	Benefits overstated; conflict increases	Regional planning; demand-side measures; traceability
Rebound effects	Efficiency lowers costs, raises total use	Rising total extraction/consumption	Continued pressure on ecosystems	Short-lived savings	Caps/quotas; pricing; enforceable limits
Short project cycles	Gains fade after funding ends	Maintenance lapses; staff turnover	Regeneration stalls	Livelihood promises fail	Long-term finance; stewardship agreements; O&M plans
Proxy-driven greenwashing	Carbon/cover improves, biodiversity declines	Monocultures; poor baselines	Simplified ecosystems	Local costs without real benefits	Multi-metric integrity standards; independent audits
Elite capture	Benefits accrue to powerful actors	Exclusion from decisions; opaque contracts	Weak stewardship	Inequity, displacement	Tenure security; transparency; grievance mechanisms
Weak legitimacy/compliance	Rules ignored or resisted	Low participation; enforcement conflict	Protection/restoration undermined	Conflict, insecurity	Co-management; participatory monitoring; fair benefit-sharing

5.5. Equity, Justice, and Legitimacy as Functional Requirements

Equity considerations dictate the existence of interventions that can be maintained as socially sustainable, hence, the ecological gains. Distributional justice deals with the allocation of costs and benefits, compensation for limits on the use of resources, project revenues, as well as the distribution of risks like displacement or exposure to polluted air. Procedural justice is about who is to be involved in the decision-making process, whose opinion is significant, and whether the agreement is more than formal. Recognition justice deals with the issue of whether the identities, rights, and systems of governance, especially those of Indigenous peoples and local communities, are recognized and honored [105].

These dimensions of justice are not outside ecological performance; they define compliance, stewardship, and conflict. Illegitimate conservation restrictions are likely to stimulate rule violations, sabotage, or even political retaliation that weaken conservation zones and restoration efforts. However, on the contrary, with rights in place and benefits-sharing being believable, communities usually become long-term custodians of ecosystems and watchdogs of illicit exploitation. Equity should thus be seen more as a design constraint that enhances chances of sustainable results. In practice, it would require that tenure security, the clarity of benefit-sharing arrangements, and the availability of grievance systems are regarded as the main infrastructure of the sustainable management of the resources, along with the ecological and technical ones [105].

There is also the intersection between equity and knowledge systems. The management of resources sustainably often relies on the local ecological knowledge, recollection of past environmental change, and cultural practices that create the landscapes over time. Knowledge co-production has the potential to enhance the design of interventions and relevance of monitoring, although it needs to be protected by extraction and misappropriation precautions. The complicating issue is to establish institutions in which several knowledge systems can be put to work to inform decisions on the same footing as opposed to being selectively applied to justify already existing agendas [106].

5.6. Future Research Directions for an Integrity-and-Development Agenda

There is a crucial gap in the research, as one of the primary ones is the reinforcement of long-term evidence on ecological and social outcomes. Most of the interventions are also assessed on short time scales, which are in line with the funding cycles and not with ecological recovery and institutional learning. This leaves one in doubt on persistence, delayed gains, and whether the initial gains are maintained during shocks. Future research should thus give more emphasis on longitudinal designs and tracking approaches in tracking both integrity and well-being across the period of pertinent time spans, such as the dynamics of maintenance, governance change, and climate variability [107].

The second requirement is better causal attribution of complex systems. Such interventions of sustainable resources are commonly carried out together with other types of change, including market changes, policy changes, and climate changes, and it is hard to distinguish what follows. The inference can be reinforced by improvements of quasi-experimental designs, counterfactual methods, and mixed integration of methods, but the methods have to be modified to the ethical and practical reality in the field. The comparison between different regimes of governance and ecological settings can also assist in determining which institutional attributes are always conducive to providing co-benefits [107].

A third requirement is that of standardization of measurement without oversimplification. The discipline needs stronger, similarity measures of integrity, which track biodiversity and functionality, rather than carbon or land cover. Meanwhile, standardization should not be too unconcerned with the situation but must take care not to become an instrument of marginalization of the values of all the local communities. The research should come up with modular, scalable indicator sets, contractively measure uncertainty, and be incorporated in transparent MRV systems deployed by governments and finance participants [108].

A fourth requirement is to comprehend scaling paths not subject to leakage and injustice. Numerous innovations look promising during pilots but produce evils when implemented on a large scale, particularly when the value of land alters, an outside party participates, or the process of governance is centralized. Studies need to concentrate on ways of scaling interventions using institutional replication, learning networks, and policy alignment instead of the naive expansion of project footprints. This involves research on how benefit-sharing, tenure security, and participation are possible under the scale and commercialization pressure.

A fifth requisite is greater integration of just transition views of resource governance, particularly where sustainability policies are tied to energy transitions, mining, and industrial restructuring [109]. The low-carbon technologies have material needs that can result in new frontiers of extraction and conflicts. Studies need to explore the models of governance that can organize mineral circularity, responsible sourcing, local development payoffs, and biodiversity protection, and should not use the discourse according to which ecological damage is an acceptable side effect of climate control [110–113].

Lastly, the prospective studies should be invested in the institutional design of landscapes and seascapes with multiple defensible claims within them, and where there is a high degree of uncertainty. This comes with deliberation, conflict-resolution, and adaptive rule-making mechanisms that are resistant to change of political turnover. The key to gaining an understanding of how trust is established and sustained, in this way, by transparency, accountability, and mutual monitoring, can be just as consequential as technological or financial progress. In this respect, the sustainable resource management frontier is not necessarily the new interventions, but the establishment of frameworks of governance that will be able to learn, fairly share benefits, and safeguard the ecological bases of development.

6. Conclusion

One of the urgent issues of our age is to reach the sustainable management of resources that would bring the integrity of the ecosystem with human development. With the growing pressure on natural resources in the world and the destruction of the ecosystems, it is now evident that business-as-usual strategies are not enough anymore. Rather, there is a pressing necessity for new approaches that can help to preserve the ecological systems upon which we rely as well as serve the economic, social, and developmental demands of the increasing human populations. This review has discussed the major avenues to such a balance with a focus on technological, nature-based, financial, governance, and social innovations, which provide new prospects of managing resources.

With the synthesis of the literature, it is clear that no particular solution or single intervention can be used to reach the desired results. Instead, the best strategies are those that acknowledge the interdependence of the ecological systems and human development and functions on a variety of scales and sectors. Technological innovations, including precision agriculture and digital surveillance technology, nature-based strategies, including ecosystem restoration and agroecology, and financial instruments, such as ecosystem services payments and green bonds, are all important towards the enhancement of sustainability. Their success, however, hinges upon their incorporation into sound governance systems that emphasize equity, transparency, and local participation and close observation so that the trade-offs are reduced and benefits shared fairly.

One of the most important findings of this review is that it is necessary to manage trade-offs and encourage synergies between development goals and ecosystem integrity. Although trade-offs in the form of spatial, temporal, and distributional are an unavoidable part of life, the secret of success is to implement interventions that are thoughtful and strategic in dealing with trade-offs. This implies that the ecological integrity is not an optional objective, but a prerequisite of human prosperity. In this light, the long-term ecological thresholds must be kept in mind when developing the resource management strategies, and also, ecological services are known to be very important, and they offer important services which support human wellbeing, and thus, when they are lost or damaged, recovery may be expensive and even impossible.

Besides, this review highlights the necessity to have both comprehensive and context-specific measurement and monitoring systems. Monitoring results in various areas, such as ecological, social, and economic, is necessary to ensure that interventions are not only efficient in maintaining ecosystems but also bring real and fair utility to communities. Moreover, the monitoring systems should be democratic and open, with all stakeholders at every level being incorporated in the evaluation, learning, and adaptation process. It is just through such a form of inclusive and data-driven governance that we can be assured that any sustainability efforts are both legitimate and responsible.

Equity also plays an important role in determining the future of sustainable resource management. Since the marginalized communities are disproportionately impacted by the lack of resources and environmental degradation, any strategy aimed at balancing the ecosystem health with human growth should take into account the social aspect of justice. There is a need to address distributional, procedural, and recognition justice to create legitimacy, cooperation, and the distribution of benefits equally. The sub-elements of Indigenous knowledge systems, local community leadership, and rights approaches will play an important role in making sure the sustainability efforts can meet the needs and aspirations of all the affected groups.

As to the future, some major areas where research and innovation should take place are as follows. The cross-disciplinary research should be conducted in the long term to gain a clearer insight into the long-term effects of various approaches, as well as to determine how the effects of interventions can be sustained over time. The dynamics of successful interventions in scaling, leakage prevention, and maintenance of ecological and social protection should also be researched so that the large scale remains at large scales. Moreover, the development of tools and techniques of the measurement of ecological integrity and the outcomes of human development will be essential to enhance the decision-making process, promote cooperation, and make the sustainability efforts legitimate.

To sum it up, sustainable resource management is on the way to a complex integrated system that incorporates technology innovation and nature-based solutions, governance reforms, and finance systems based on equity and social justice principles. Although major obstacles still exist, the possibilities of developing mutually reinforcing products in the ecosystems and human communities are enormous. With the help of the synergetic approach in place of the old-time trade-off mentality, we can make sure that the ecological integrity and human development no longer conflict but do go hand in hand. Such a balance will take collective action, the long-term commitment, and a willingness to adapt to the changing world, but the payoff is more than worth the cost: resilient ecosystems, flourishing communities, and a more sustainable future.

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References

[1] Macy, J., 2021. World as Lover, World as Self: Courage for Global Justice and Planetary Renewal. Parallax Press: Berkeley, CA, USA.

[2] Qureshi, F., 2024. Sustainable Resource Management: Balancing Human Needs and Environmental Protection. Frontiers in Environmental Science and Sustainability. 1(1), 1–19.

[3] Putnam, L., Martin, J., 2025. Everything new is old again: The coming metaverse, platforms as premises, and addressing harms that occur behind the veil of scale. Yale Journal of Law and Technology. 27, 151.

[4] Bhambri, P., Kautish, S., 2024. Technological advancements in promoting ecosystem health. In Digital Technologies to Implement the UN Sustainable Development Goals. Springer: Cham, Switzerland. pp. 413–432.

[5] Hussain, S., Sharma, S., Sobti, R., et al., 2025. Science, technology, and novelty for sustainable development goals: Perspectives and challenges from environment, ecology, and human society in a changing world. In Role of Science and Technology for Sustainable Future. Springer: Cham, Switzerland. pp. 3–21.

[6] Olorunsogo, T.O., Ogugua, J.O., Muonde, M., et al., 2024. Environmental factors in public health: A review of global challenges and solutions. World Journal of Advanced Research and Reviews. 21(1), 1453–1466.

[7] Ugwu, C.N., Ugwu, O.P.C., Alum, E.U., et al., 2025. Sustainable development goals (SDGs) and resilient healthcare systems: Addressing medicine and public health challenges in conflict zones. Medicine. 104(7), e41535.

[8] Aiguobarueghian, I., Adanma, U.M., Ogunbiyi, E.O., et al., 2024. An overview of initiatives and best practices in resource management and sustainability. World Journal of Advanced Research and Reviews. 22(2), 1734–1745.

[9] Xuan, S., Song, D., You, G., 2024. Financial risk prevention and corporate green innovation: A quasi-natural experiment based on the new asset management regulation. Pacific-Basin Finance Journal. 88, 102566.

[10] Adeoba, M.I., Odjegba, E.E., Pandelani, T., 2025. Nature-based solutions: Opportunities and challenges for water treatment. In Smart Nanomaterials for Environ-

mental Applications. Springer: Cham, Switzerland. pp. 575–596.

[11] Ogwu, M.C., Kosoe, E.A., 2025. Environmental Economics: Valuing Ecosystem Services and Green Technologies. In Evaluating Environmental Processes and Technologies. Springer: Cham, Switzerland. pp. 487–511.

[12] Ntawuhiganayo, E.B., Dobie, P., 2025. Incentives and Financing Mechanisms for Improved Landscape Management, Biodiversity Conservation, Nature-Based Solutions and Livelihood Development. CIFOR: Bogor, Indonesia; ICRAF: Nairobi, Kenya.

[13] Gayer, T., Horowitz, J.K., 2006. Market-Based Approaches to Environmental Regulation. Foundations and Trends in Microeconomics. 1(4), 201–326.

[14] Andrae, S., 2025. Financing Mechanisms for the Conservation of Biodiversity: A Multi-Country Comparison. In Biodiversity Finance: The Economic, Operational, and Societal Impacts of Biodiversity Loss. Springer: Cham, Switzerland. pp. 269–299.

[15] Sarioguz, O., Miser, E., 2024. Integrating AI in financial risk management: Evaluating the effects of machine learning algorithms on predictive accuracy and regulatory compliance. International Journal of Science and Research Archive. 13(2), 789–811.

[16] Helgeson, J.F., Al Kajbaf, A., Fung, J.F., 2025. Co-benefits of resilience planning: A review of analysis tools and methods. Frontiers in Climate. 7, 1539858.

[17] Herath, P., Bai, X., 2024. Benefits and co-benefits of urban green infrastructure for sustainable cities: six current and emerging themes. Sustainability Science. 19(3), 1039–1063.

[18] D'Adamo, I., Di Carlo, C., Gastaldi, M., et al., 2024. Economic performance, environmental protection and social progress: A cluster analysis comparison towards sustainable development. Sustainability. 16(12), 5049.

[19] Amorocho-Daza, H., van der Zaag, P., Sušnik, J., 2024. Ethical considerations of using system dynamics in participatory settings: A social-ecological-systems perspective. System Dynamics Review. 40(2), e1755.

[20] He, J., Zhou, Y., Pandey, R., et al., 2025. Characteristics and Framework for Assessing Supply and Demand Relationship for Ecosystem Services Using a Trade-off and Synergy Lens. Land Degradation & Development. 36(6), 1771–1786.

[21] Smith, G., Atkins, J., Gregory, A., et al., 2025. The minimum complexity necessary: The value of a simple Social-Ecological systems analysis in holistic marine environmental management. Sustainable Futures. 9, 100476.

[22] Zhang, J., Ji, Q., Skene, K.R., et al., 2025. Bridging resilience and sustainability: A reconciled framework for navigating social-ecological systems. Regional Environmental Change. 25(3), 106.

[23] Gomez-Jaramillo, Y., Berrouet, L., Villegas-Palacio, C., et al., 2024. Conceptual framework for analyzing the sustainability of socio-ecological systems with a focus on ecosystem services that support water security. Sustainable Development. 32(3), 2298–2313.

[24] Angeon, V., Casagrande, M., Navarrete, M., et al., 2024. A conceptual framework linking ecosystem services, socio-ecological systems and socio-technical systems to understand the relational and spatial dynamics of the reduction of pesticide use in agrifood systems. Agricultural Systems. 213, 103810.

[25] Cao, J., Deng, Z., Huang, Z., et al., 2025. Identifying Conservation Priority Areas of China: A methodological framework for ecosystem integrity and authenticity. Biological Conservation. 302, 110924.

[26] Wang, H.-Z., 2024. Assessments and diagnoses of aquatic ecosystem integrity based on integrity requirements of ecosystem service targets. Water Biology and Security. 3(1), 100230.

[27] Liu, R., Gao, W., Yang, F., 2025. Authenticity, Integrity, and Cultural–Ecological Adaptability in Heritage Conservation: A Practical Framework for Historic Urban Areas—A Case Study of Yicheng Ancient City, China. Buildings. 15(8), 1304.

[28] Islam, F.S., 2025. Artificial intelligence-driven optimization of nature-based carbon sequestration: A scalable architecture for urban climate resilience. International Journal of Environment and Climate Change. 15(7), 252–277.

[29] Ma, L., Xu, Z., Fan, L., et al., 2025. Multi-Source Data Integration and Model Coupling for Watershed Eco-Assessment Systems: Progress, Challenges, and Prospects. Processes. 13(9), 2998.

[30] Özkan, F.H., Gürbüz, İ.B., 2024. The Influence of Inflation, Human Development Index, and Poverty. Contemporary Research in Social, Human and Administrative. 21.

[31] Fonchingong Che, C., Bang, H.N., 2024. Towards a "Social Justice Ecosystem Framework" for Enhancing Livelihoods and Sustainability in Pastoralist Communities. Societies. 14(11), 239.

[32] Allouche, J., 2024. Nexus framing of sustainability issues: Feasibility, synergies, and trade-offs in terms of water-energy-food. Annual Review of Environment and Resources. 49(1), 501–518.

[33] Zhang, Q., Avraamidou, S., Paulson, J.A., et al., 2025. Navigating the Trade-offs and Synergies of Economic and Environmental Sustainability Using Process Systems Engineering. In Proceedings of the 2025 American Control Conference (ACC), Denver, CO, USA, 7–10 July 2025.

[34] Jain, S.K., Tiwari, M., Choubey, S., 2024. Environmental Degradation and Management for Healing

through Collective Efforts—A Comprehensive Study. International Journal of Pharmacology & Biological Sciences. 18(2).
[35] Kealy, T., 2024. Review of the Interlinked Environmental, Economic and Social Realms of Sustainability. In Empirical Evaluation of Renewable Energy Projects for Sustainable Development. Springer: Cham, Switzerland. pp. 1–33.
[36] Sorrentino, M., Cirillo, V., Nappi, L., 2019. Development of flexible procedures for co-optimizing design and control of fuel cell hybrid vehicles. Energy Conversion and Management. 185, 537–551.
[37] Muhdiarta, U., 2025. The Role of Community Participation in Shaping Policies and Its Implications for Government Legitimacy. The Journal of Academic Science. 2(4), 1109–1117.
[38] Vargas, C.M., Cooper, P.J., 2024. Implementing Sustainable Development: From Global Policy to Local Action. Bloomsbury Publishing USA: New York, NY, USA.
[39] Katsou, E., Nika, C.-E., Buehler, D., et al., 2020. Transformation tools enabling the implementation of nature-based solutions for creating a resourceful circular city. Blue-Green Systems. 2(1), 188–213.
[40] Raffaelli, R., Glynn, M.A., Tushman, M., 2019. Frame flexibility: The role of cognitive and emotional framing in innovation adoption by incumbent firms. Strategic Management Journal. 40(7), 1013–1039.
[41] Schot, J., Steinmueller, W.E., 2018. Three frames for innovation policy: R&D, systems of innovation and transformative change. Research Policy. 47(9), 1554–1567.
[42] Bessant, J., Öberg, C., Trifilova, A., 2014. Framing problems in radical innovation. Industrial Marketing Management. 43(8), 1284–1292.
[43] Zhai, Z., Martínez, J.F., Beltran, V., et al., 2020. Decision support systems for agriculture 4.0: Survey and challenges. Computers and Electronics in Agriculture. 170, 105256.
[44] Sajib, M.M.H., Sayem, A.S.M., 2025. Innovations in Sensor-Based Systems and Sustainable Energy Solutions for Smart Agriculture: A Review. Encyclopedia. 5(2), 67.
[45] Kennedy, M.A., 2016. Adaptive practice: Next generation evidence-based practice in digital environments. In Nursing Informatics 2016. IOS Press: Amsterdam, The Netherlands. pp. 417–421.
[46] Westfall-Greiter, T., Dienhofer, H., 2017. From Evidence-Based to Evidence Generating Practice: Implications for Education Research in the Context of Innovation. In Erfahrungen deuten–Deutungen erfahren: Vignettes and Anecdotes as Research, Evaluation and Mentoring Tool. StudienVerlag: Innsbruck, Austria. pp. 77–94.
[47] King, C., 2022. Beyond sustainability: A global study of nature-based solutions in regenerative tourism. Travel and Tourism Research Association: Advancing Tourism Research Globally. 38, 219–227.
[48] Cheng, C., Li, F., 2024. Ecosystem restoration and management based on nature-based solutions in China: Research progress and representative practices. Nature-Based Solutions. 6, 100176.
[49] Lindenmayer, D.B., Likens, G.E., Andersen, A., et al., 2012. Value of long-term ecological studies. Austral Ecology. 37(7), 745–757.
[50] Sibanda, N., 2024. Eco-Social Contracting for Environmental Justice: Assessing the Effectiveness of Community-Based Natural Resource Management. UNRISD: Geneva, Switzerland.
[51] Yang, M., Chen, L., Wang, J., et al., 2023. Circular economy strategies for combating climate change and other environmental issues. Environmental Chemistry Letters. 21(1), 55–80.
[52] Gaustad, G., Krystofik, M., Bustamante, M., et al., 2018. Circular economy strategies for mitigating critical material supply issues. Resources, Conservation and Recycling. 135, 24–33.
[53] Khanna, N.Z., Zhang, J., Lu, H., et al., 2023. Conceptualizing demand-side technological and social innovations in modeling pathways to carbon neutrality. Energy Research & Social Science. 100, 103115.
[54] Note, O.C.P.R.B., 2023. Competition in the Circular Economy. OECD Publishing: Paris, France.
[55] Droste, N., Hansjürgens, B., Kuikman, P., et al., 2016. Steering innovations towards a green economy: Understanding government intervention. Journal of Cleaner Production. 135, 426–434.
[56] Agrawal, A., Lemos, M.C., 2007. A greener revolution in the making?: Environmental governance in the 21st century. Environment: Science and Policy for Sustainable Development. 49(5), 36–45.
[57] Bodin, Ö., 2017. Collaborative environmental governance: Achieving collective action in social-ecological systems. Science. 357(6352), eaan1114.
[58] Lebel, L., Anderies, J.M., Campbell, B., et al., 2006. Governance and the capacity to manage resilience in regional social-ecological systems. Ecology and Society. 11(1), 19.
[59] Chapman, B., Lindenmayer, D.B., 2019. A novel approach to the sustainable financing of the global restoration of degraded agricultural land. Environmental Research Letters. 14(12), 124084.
[60] Akhtar-Schuster, M., Thomas, R.J., Stringer, L.C., et al., 2011. Improving the enabling environment to combat land degradation: Institutional, financial, legal and science-policy challenges and solutions. Land Degradation & Development. 22(2), 299–312.
[61] Ghobakhloo, M., Iranmanesh, M., Grybauskas, A., et al., 2021. Industry 4.0, innovation, and sustainable development: A systematic review and a roadmap

to sustainable innovation. Business Strategy and the Environment. 30(8), 4237–4257.

[62] Chang, Y.-Y., Chiang, F.-Y., Hu, Q., et al., 2025. From green HRM to SDG success: Pathways through exploratory innovation and developmental culture. Review of Managerial Science. 19(6), 1711–1741.

[63] Thrane, S., Blaabjerg, S., Møller, R.H., 2010. Innovative path dependence: Making sense of product and service innovation in path dependent innovation processes. Research Policy. 39(7), 932–944.

[64] Maturo, M.G., Soligo, M., Gibson, G., et al., 2020. The greater inflammatory pathway—High clinical potential by innovative predictive, preventive, and personalized medical approach. EPMA Journal. 11(1), 1–16.

[65] Oeij, P.R.A., van der Torre, W., Vaas, F., et al., 2019. Understanding social innovation as an innovation process: Applying the innovation journey model. Journal of Business Research. 101, 243–254.

[66] Fischer, A., Petersen, L., Feldkötter, C., et al., 2007. Sustainable governance of natural resources and institutional change—An analytical framework. Public Administration and Development: The International Journal of Management Research and Practice. 27(2), 123–137.

[67] Lavorel, S., Grigulis, K., 2012. How fundamental plant functional trait relationships scale-up to trade-offs and synergies in ecosystem services. Journal of Ecology. 100(1), 128–140.

[68] Leitner, K.-H., Warnke, P., Rhomberg, W., 2016. New forms of innovation: Critical issues for future pathways. Foresight. 18(3), 224–237.

[69] Pahl-Wostl, C., Knüppe, K., 2016. Water security and environmental water needs: The role of the ecosystem services concept and transformation of governance systems. In Handbook on Water Security. Edward Elgar Publishing: Cheltenham, UK. pp. 226–238.

[70] Qin, K., Liu, J., Yan, L., et al., 2019. Integrating ecosystem services flows into water security simulations in water scarce areas: Present and future. Science of the Total Environment. 670, 1037–1048.

[71] Vargas, D.C.M., Hoyos, C.d.P.Q., Manrique, O.L.H., 2023. The water-energy-food nexus in biodiversity conservation: A systematic review around sustainability transitions of agricultural systems. Heliyon. 9(7), e17016.

[72] Pulighe, G., Pirelli, T., 2023. Assessing the sustainability of bioenergy pathways through a land-water-energy nexus approach. Renewable and Sustainable Energy Reviews. 184, 113539.

[73] Lu, N., Liu, L., Yu, D., et al., 2021. Navigating trade-offs in the social-ecological systems. Current Opinion in Environmental Sustainability. 48, 77–84.

[74] Garnett, T., Godfray, C., 2012. Sustainable Intensification in Agriculture. Navigating a Course through Competing Food System Priorities. University of Oxford: Oxford, UK. pp. 51.

[75] Vikas, Ranjan, R., 2024. Agroecological approaches to sustainable development. Frontiers in Sustainable Food Systems. 8, 1405409.

[76] Bigger, P., Dempsey, J., Rojas-Marchini, F., et al., 2021. Beyond the Gap: Placing Biodiversity Finance in the Global Economy. The University of British Columbia: Vancouver, BC, Canada.

[77] Mery, G., Katila, P., Galloway, G., et al., 2010. Forests and Society: Responding to Global Drivers of Change. IUFRO: Vienna, Austria. pp. 441–486.

[78] Pacifici, M., 2025. Ecologically sound strategies for renewable energy transition: Balancing conservation and energy development in coal plant conversions. Ecological Solutions and Evidence. 6(2), e70001.

[79] Raj, R., Sharma, S., 2025. Green Energy, Greener Earth: Innovations in Renewable Energy and Ecosystem Conservation. In Green Equilibrium: Deciphering Earth's Ecosystems for Sustainable Tomorrow. Springer: Cham, Switzerland. pp. 255–279.

[80] Özcan, Z., Willaarts, B., Klessova, S., et al., 2024. From nexus thinking to nexus implementation in South Europe and beyond: Mutual learning between practitioners and policymakers. Sustainability Nexus Forum. 32, 6.

[81] Joss, S., 2011. Eco-cities: The mainstreaming of urban sustainability—Key characteristics and driving factors. International Journal of Sustainable Development and Planning. 6(3), 268–285.

[82] Riffat, S., Powell, R., Aydin, D., 2016. Future cities and environmental sustainability. Future Cities and Environment. 2(1), 1.

[83] Yanda, P.Z., Mabhuye, E., Johnson, N., et al., 2019. Nexus between coastal resources and community livelihoods in a changing climate. Journal of Coastal Conservation. 23(1), 173–183.

[84] Di Franco, A., Hogg, K.E., Calò, A., et al., 2020. Improving marine protected area governance through collaboration and co-production. Journal of Environmental Management. 269, 110757.

[85] Alongi, D.M., 2018. Blue Carbon: Coastal Sequestration for Climate Change Mitigation. Springer: Cham, Switzerland.

[86] Hejnowicz, A.P., Kennedy, H., Rudd, M.A., et al., 2015. Harnessing the climate mitigation, conservation and poverty alleviation potential of seagrasses: Prospects for developing blue carbon initiatives and payment for ecosystem service programmes. Frontiers in Marine Science. 2, 32.

[87] Jahan, F., 2025. A Systematic Review of Blue Carbon Potential in Coastal Marshlands: Opportunities for Climate Change Mitigation and Ecosystem Resilience. Frontiers in Applied Engineering and Technology. 2(1), 40–57.

[88] Vaughan, M., Jernigan, J., Pitt Barnes, S., et al., 2017. Evaluating cross-cutting approaches to chronic disease prevention and management: Developing a comprehensive evaluation. Preventing Chronic Disease. 14, E131.

[89] Bieker, T., Waxenberger, B., 2002. Sustainability balanced scorecard and business ethics—Developing a balanced scorecard for integrity management. In Proceedings of the 10th International Conference of the Greening of Industry Network, Göteborg, Sweden, 23–26 June 2002.

[90] Bennett, M., James, P., Klinkers, L., 2017. Sustainable Measures: Evaluation and Reporting of Environmental and Social Performance. Routledge: London, UK.

[91] Hilliard-Boone, T., Firminger, K., Dutta, T., et al., 2022. Stakeholder-driven principles for advancing equity through shared measurement. Health Services Research. 57, 291–303.

[92] LaPaix, R., Freedman, B., Patriquin, D., 2009. Ground vegetation as an indicator of ecological integrity. Environmental Reviews. 17, 249–265.

[93] Reining, C.E., Lemieux, C.J., Doherty, S.T., 2021. Linking restorative human health outcomes to protected area ecosystem diversity and integrity. Journal of Environmental Planning and Management. 64(13), 2300–2325.

[94] Smith, L.M., Case, J.L., Smith, H.M., et al., 2013. Relating ecoystem services to domains of human well-being: Foundation for a US index. Ecological Indicators. 28, 79–90.

[95] Waylen, K.A., Blackstock, K.L., 2017. Monitoring for Adaptive Management or Modernity: Lessons from recent initiatives for holistic environmental management. Environmental Policy and Governance. 27(4), 311–324.

[96] Weyant, J., Davidson, H., Dowlatabadi, H., et al., 1995. Integrated assessment of climate change: An overview and comparison of approaches and results. In Climate Change. Cambridge University Press: Cambridge, UK.

[97] Avello, P., Allakulov, U., Barreto-Dillon, L., et al., 2023. The integrity management toolbox in action: A study of 22 urban water service cases. Journal of Water, Sanitation and Hygiene for Development. 13(12), 952–961.

[98] Wurtzebach, Z., Schultz, C., 2016. Measuring ecological integrity: History, practical applications, and research opportunities. BioScience. 66(6), 446–457.

[99] Tierney, G.L., Faber-Langendoen, D., Mitchell, B.R., et al., 2009. Monitoring and evaluating the ecological integrity of forest ecosystems. Frontiers in Ecology and the Environment. 7(6), 308–316.

[100] Macleod, K., 2021. Increasing Demands for Environmental Monitoring Data, Reporting, and Verification Due to Changes in Corporate Sustainability Reporting and Financial Disclosure Related to the Climate and Biodiversity Crises. The James Hutton Institute: Aberdeen, UK.

[101] Gregory, A., Spence, E., Beier, P., et al., 2021. Toward best management practices for ecological corridors. Land. 10(2), 140.

[102] Wijeratne, W., Perera, B., De Silva, L., 2014. Identification and assessment risks in maintenance operations. Built Environment Project and Asset Management. 4(4), 384–405.

[103] Erdil, A., Erbıyık, H., 2023. Failures prevention methods for sustainability of production-failure modes and effect analysis in a business: A case study. Research Journal of Business and Management. 10(3), 134–151.

[104] Carlson, C.S., 2012. Effective FMEAs: Achieving Safe, Reliable, and Economical Products and Processes Using Failure Mode and Effects Analysis. John Wiley & Sons: Hoboken, NJ, USA.

[105] Leach, M., Reyers, B., Bai, X., et al., 2018. Equity and sustainability in the Anthropocene: A social–ecological systems perspective on their intertwined futures. Global Sustainability. 1, e13.

[106] Löfqvist, S., Kleinschroth, F., Bey, A., et al., 2023. How social considerations improve the equity and effectiveness of ecosystem restoration. BioScience. 73(2), 134–148.

[107] Collins, S.L., Carpenter, S.R., Swinton, S.M., et al., 2011. An integrated conceptual framework for long-term social–ecological research. Frontiers in Ecology and the Environment. 9(6), 351–357.

[108] Brown, E.D., Williams, B.K., 2016. Ecological integrity assessment as a metric of biodiversity: are we measuring what we say we are? Biodiversity and Conservation. 25(6), 1011–1035.

[109] Bainton, N., Kemp, D., Lèbre, E., et al., 2021. The energy-extractives nexus and the just transition. Sustainable Development. 29(4), 624–634.

[110] Redman, C.L., Grove, J.M., Kuby, L.H., 2004. Integrating social science into the long-term ecological research (LTER) network: Social dimensions of ecological change and ecological dimensions of social change. Ecosystems. 7(2), 161–171.

[111] Kuebbing, S.E., Reimer, A.P., Rosenthal, S.A., et al., 2018. Long-term research in ecology and evolution: A survey of challenges and opportunities. Ecological Monographs. 88(2), 245–258.

[112] Hughes, B. B., Beas-Luna, R., Barner, A. K., et al., 2017. Long-term studies contribute disproportionately to ecology and policy. BioScience. 67(3), 271–281.

[113] Sovacool, B. K., Ali, S. H., Bazilian, M., et al., 2020. Sustainable minerals and metals for a low-carbon future. Science. 367(6473), 30–33.