sustainability

MDPI

Article

Circular-ESG Model for Regenerative Transition

Tariqullah Khan

School of Graduate Studies, INCEIF University, Jalan Tun Ismail, Kuala Lumpur 50480, Malaysia; tariqullah.khan@gmail.com

Abstract: This paper presents a novel circular-ESG framework integrating circular economy (CE) principles with environmental, social, and governance (ESG) criteria to address the lack of uniform sustainability measures. We introduce normalized sustainability coordinates (NSCs) as a comprehensive metric for sustainability performance, reconciling economic development with environmental balance. The circular-ESG model employs a four-quadrant Cartesian system to map business model impacts on natural and socio-economic systems, ranging from linear open-loop to circular closed-loop ESG models. This framework enables empirical analysis through data-driven NSCs (−1 to 1) and establishes temporal key performance indicators. By incorporating the Human Development Index within ecological limits, the model promotes regenerative development aligned with planetary boundaries. The circular-ESG approach offers a practical tool for businesses, households, organizations, and policymakers to navigate sustainable development complexities. This integrated framework fosters innovation and supports a just transition towards regenerative practices, providing a roadmap for high human development within ecological limits. The circular-ESG model advances sustainability science and management, contributing to the discourse on measuring and implementing sustainable practices across sectors and scales. The model is currently conceptual; we encourage empirical validation and further research to explore its practical applications and effectiveness in real-world scenarios. While the provided examples of use cases serve as conceptual demonstrations, future research could empirically apply the model to real-world data.

Keywords: circular-ESG; normalized sustainability coordinates; sustainability management; regenerative development; business models innovation

Citation: Khan, T. Circular-ESG Model for Regenerative Transition. *Sustainability* **2024**, *16*, 7549. https://doi.org/10.3390/su16177549

Academic Editor: Matteo Rossi

Received: 14 July 2024
Revised: 10 August 2024
Accepted: 28 August 2024
Published: 31 August 2024

1. Introduction

The growing body of credible data underscores the worsening state of planetary health [1] and its severe impacts on critical life-sustaining systems [2]. This awareness has catalyzed proactive, multilateral initiatives like the Paris Agreement and the Sustainable Development Goals [3]. Significant governmental and regulatory actions, such as the European Green Deal and taxonomies [4], are being implemented. Various sustainability disclosure standards, including the Principles of Responsible Investments (PRIs) [5], Global Reporting Initiative (GRI) [6], the International Sustainability Standards Board (ISSB) [7], and the Task Force on Climate-Related Financial Disclosures (TCFD) [8], have been introduced. Green technologies, such as renewable energy and electric vehicles, are already transforming markets. Investor and consumer preferences are shifting toward sustainability, as evidenced by Environmental, Social, and Governance (ESG) [9] reporting by companies. Circular economy (CE) [10] business models are being adopted and promoted through public initiatives like the EU Green Deal [4]. This unprecedented transformation driven by sustainability is positively reshaping global economies [11]. These examples highlight the numerous drivers of sustainability disruptions.

While the transition offers significant long-term advantages, or "Green Swans", ref. [12] also poses short-term socio-economic uncertainties and transition and physical risks [13]. This warrants a robust economic model and coherent conceptual framework capable of discussing and analyzing the complexities involved in sustainability transition and its management.

Historically, there has been a significant conflict between human development, as measured by the Human Development Index (HDI), and the health of environmental systems. Developed countries have often attained high HDI levels, which include factors such as life expectancy, education, and per capita income, but this progress has frequently come at the expense of severe environmental degradation [14]. This pattern of development has led to the depletion of natural resources, increased pollution, and substantial biodiversity loss.

As we move forward with the transition, it is crucial to address and resolve this conflict. Future development must aim to achieve high levels of HDI without compromising the integrity of our environmental systems. This means that human development should occur within the "safe operating boundaries" of the planet, ensuring that we do not exceed the ecological limits that sustain life on Earth [15]. By adopting sustainable practices and integrating environmental considerations into development and business strategies, we can work towards a regenerative future where human well-being and environmental health coexist in harmony [12,16].

The existing business sustainability approaches can be broadly categorized into the ESG [17] approach and the CE [10] approach. Both frameworks aim to achieve sustainability but often operate independently and sometimes even in competition with each other. ESG focuses on incorporating environmental, social, and governance factors into business strategies, emphasizing responsible management and reporting. In contrast, the CE approach aims to eliminate waste, extend resource life, and continually use resources through regenerative practices. In addition to these two frameworks, there are a growing number of sustainability disclosure templates focusing on different aspects of sustainability.

While both approaches and the different disclosure frameworks strive for sustainability, their independent application can lead to fragmented efforts of sustainability governance and missed opportunities for synergy. This paper aims to bridge this gap by merging the ESG and CE frameworks through a two-dimensional and four-quadrant Cartesian coordinate system.

The primary objective of the paper is to present "circular-ESG" as an integrated, multidisciplinary, versatile, and dynamic framework that leverages the strengths of both approaches. The unified circular-ESG framework can be used for studying, monitoring, and managing the transition towards humane and regenerative sustainability. The interrelated secondary objectives of the paper are as follows:

(a) To review significant sustainability models and identify points of divergences and convergences;
(b) To create a holistic, dynamic, and robust Cartesian four-coordinate mathematical framework that integrates various business model innovations;
(c) To establish a unified measure of circularity and ESG;
(d) To propose a comprehensive framework for equitable risk-sharing between present and future generations.

We propose a single, comprehensive metric of circularity and ESG, namely the normalized sustainability coordinates (NSCs)—to leverage on the strengths of both approaches for a robust assessment of sustainability performance. This new framework is expected to provide a comprehensive strategy for sustainability transition and its management, promoting collaboration over competition and ensuring a more cohesive and effective path toward sustainable and regenerative transition.

In Section 2, we undertake a review of key sustainability models and the relevant lead literature and discuss the methodology. In Section 3, we formally discuss the proposed circular-ESG framework. In Section 4, we discuss the risks and opportunities. Section 5 discusses the NSCs and their hypothetical use cases. Section 6 summarizes the conclusions, limitations, and future research pathways.

2. Review of Concepts and Literature

The pivot of our research is the integration of CE and ESG and developing NSCs as a unified measure of circularity and ESG. With this narrow focus, in what follows we review the most relevant concepts and the related literature. Table 1 summarizes the salient features of the different sustainability models. The models converge on the shared purse but diverge in the details and processes to achieve sustainability.

Table 1. Convergence and divergence of sustainability models.

Model	Core Focus	Approach	Metrics	Scope	Sustainability Integration	Application
Circular Economy (CE)	Resource life extension/efficiency, waste reduction, closed-loop systems	Emphasizes "Re" and "De," innovation, closed-loop production	Waste reduction, recycling rates, material efficiency	Product design, industrial product, biological and technical, supply chains, operations	High focus on resource efficiency, less on social and governance aspects	Circular business models, technical and biological analysis for product longevity
Environmental, Social, and Governance (ESG)	Sustainability in E, S, and G dimensions	Risk management, regulatory compliance	Carbon footprint, water usage, governance standards	Investment decisions, corporate reporting	Balanced focus across E, S, and G	Focus on meeting regulatory standards and risk mitigation
Triple Bottom Line (TBL/PPP)	Balance of planet, people, and profit	Broader business strategy guiding operations	Economic performance, environmental, and social impacts	Overall business strategy and performance	Emphasizes economic benefit alongside sustainability	Strategic business decisions with a sustainability focus
Doughnut Economics (DE)	Balancing social foundations and ecological boundaries	Holistic rethinking of economic goals and structures	Dashboard of social and environmental indicators	Global and systemic change	Social and ecological balance within planetary limits	Policy changes and global cooperation
Regenerative Economy (RE)	Restoration and regeneration of ecosystems and societies	Biomimicry, circularity, regenerative practices	Ecological health, biodiversity, community resilience	Local, community-level transformations. Nature-based solutions	Prioritizes regeneration of natural and social systems	Community-driven initiatives and sustainable practices

Source: Prepared by author through literature reviewCE and the Era of R and D.

2.1. Convergences

The sustainability models outlined in Table 1 share common ground in their overarching goals of promoting sustainable practices across various sectors and scales. A notable convergence among these models is their emphasis on balancing environmental, social, and economic factors, albeit with different approaches and focal points. For example, both the Triple Bottom Line (TBL/PPP) [18] and ESG frameworks [19] emphasize a balanced consideration of environmental and social dimensions alongside economic performance, even though from distinct operational perspectives. Similarly, CE and DE models converge on the need for resource efficiency and the systemic integration of environmental considerations, advocating for a shift towards closed-loop systems and holistic rethinking of economic goals. These shared principles reflect a broad consensus on the importance of integrating sustainability into decision-making processes across different levels, from corporate operations to global economic structures.

2.2. Divergences

Despite their shared sustainability goals, these models diverge significantly in their core focuses, approaches, and applications. The circular economy (CE) model, for instance, centers on resource life extension and waste reduction through innovation and closed-loop production, primarily applied to product design and industrial operations. In contrast, the Doughnut Economics (DE) model takes a more global and systemic view, focusing on balancing social foundations and ecological boundaries to guide policy changes and global cooperation. The ESG model diverges by emphasizing risk management and regulatory compliance, with a strong focus on investment decisions and corporate reporting, making it distinct from the broader strategic and performance-driven focus of the TBL/PPP framework. Moreover, the Regenerative Economy (RE) model stands out by prioritizing local and community-level transformations, emphasizing the regeneration of ecosystems and societies through biomimicry, circularity, and nature-based solutions (NBSs), which contrasts with the more corporate-centric and operational scope of the other models.

2.3. Integration for Strength

Integrating the strengths of these models can lead to a more comprehensive and robust approach to sustainability. For example, combining the resource efficiency and waste reduction focus of the CE with the holistic, systemic change advocated by DE can foster innovation in both product design and global policy frameworks, ensuring that economic activities remain within planetary boundaries while meeting social needs. Similarly, the ESG model's emphasis on regulatory compliance and risk management can complement the broader strategic focus of the TBL/PPP, ensuring that business operations not only perform well economically but also adhere to sustainability standards. Finally, incorporating the local and regenerative focus of the RE into broader sustainability strategies can enhance community resilience and ecological health, creating a more integrated and multi-dimensional approach to sustainable development. This integration allows for a nuanced application of sustainability principles, addressing both local and global challenges while leveraging the strengths of each model.

2.3.1. The CE and ESG

The focus of the current paper is CE [20] and ESG [21] integration. In Figure 1, we summarize the differences and convergences of the two approaches.

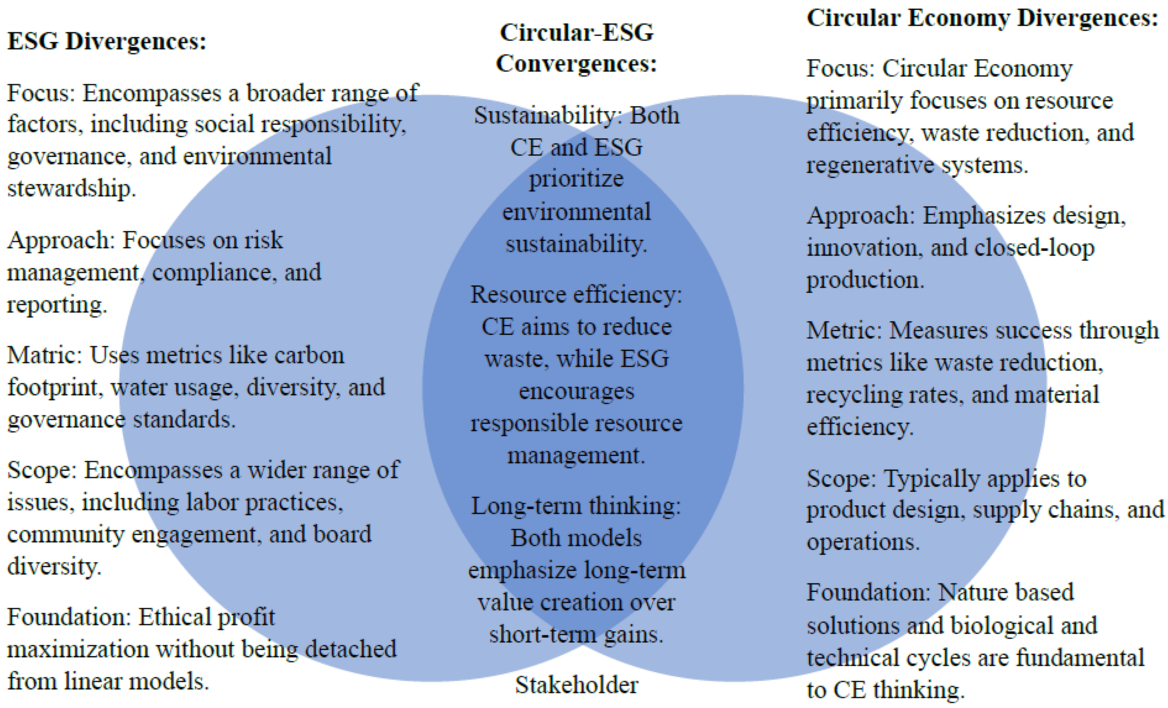

Figure 1. Divergence and convergence of CE and ESG models. Source: Drawn by author.

While both models share sustainability goals, CE focuses on resource efficiency and nature-based regenerative systems [10]. ESG takes a broader approach, incorporating social responsibility, governance, and environmental stewardship but still focusing on profit maximization [19]. The summary simplifies the two models' main features, but in practice, the degree of overlap or divergence can vary depending on how these concepts are implemented. In addition, there can be more nuanced interactions between CE and ESG principles. It is worth noting that both CE and ESG are evolving concepts. This diagram represents a current understanding, but the relationship between these approaches may change over time.

The CE has emerged as a prominent concept in sustainability literature, offering a closed-loop alternative to the traditional open-loop linear economic model of "take-make-dispose" [22]. The concepts of R (refuse, reduce, reuse, etc.) and D (design) are key to the nature-based approaches of the CE through the biological and technical cycles as visually presented in the "butterfly" diagram.

The CE literature extensively discusses the "R" [20–22] principles, which have evolved from the initial 3Rs (Reduce, Reuse, Recycle) [22] to more comprehensive frameworks covering concepts of Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover [23]. These principles form the core of CE behavioral expectations and corporate strategies, aiming to minimize waste and maximize resource efficiency.

The concept of "D" for Design [20,22,24,25] has gained increasing attention in recent years, emphasizing its importance in enabling CE practices. Design for durability, repair, and recyclability is seen as crucial for extending product lifecycles and facilitating material recovery. Design out waste, design taxonomies, policies, incentive systems, and design sustainable financial contracts to support CE transitions—the scope of design is vast, covering almost all systems, products, and services.

2.3.2. CE and Social/Governance Themes

While CE literature is rich in environmental and economic considerations, with a focus on closing the loops of waste, emissions, biodiversity loss, and extending the life of resources, there is a notable lack of emphasis on social and governance aspects [26]. In fact, the CE core literature does not pay the desirable attention to social and governance themes.

2.3.3. Regenerative and Doughnut Economics

The CE [10], Doughnut Economy (DE) [16], and Regenerative Economy (RE) [27–29] form a triumvirate of innovative economic frameworks that converge to redefine the pursuit of sustainable regenerative development. The CE's focus on waste reduction and resource efficiency lays the groundwork for the DE's vision of a safe and just space for humanity, balancing social and environmental boundaries. RE builds upon these foundations, emphasizing the restoration and revitalization of ecosystems and human societies through biomimicry, circularity, and regenerative practices. Together, these interconnected frameworks offer a comprehensive approach to transforming the traditional economic paradigm, prioritizing human well-being, social justice, and environmental stewardship to create a thriving, resilient, and regenerative future.

Both Regenerative [26,28] and Doughnut Economics [16] offer compelling alternatives to traditional economic models, addressing crucial environmental and social challenges. While they diverge in their specific approaches and metaphors, they converge on fundamental principles of sustainability, human well-being, and respect for ecological boundaries [16]. These models provide valuable frameworks for reimagining economic systems that can thrive within planetary limits while ensuring social equity. As global challenges intensify, the insights from both of these approaches could prove instrumental in shaping more resilient, just, and sustainable economies for the future.

2.3.4. Circular and Doughnut Economics

The CE and DE intersect as complementary frameworks, redefining sustainable development. While the CE focuses on circular flows, waste reduction, and resource efficiency, the DE envisions a safe and just space for humanity, balancing social and environmental boundaries.

While both the CE and DE aim to create sustainable and resilient systems, they approach the challenge from different angles. The CE focuses on optimizing resource use and minimizing waste within the existing economic framework. The DE proposes a more comprehensive rethinking of economic goals and structures to ensure both ecological sustainability and social equity. Together, they create a powerful synergy, driving transformative change towards regenerative, distributive, and CE.

2.3.5. Circular and Regenerative Economics

The CE and RE converge as interconnected paradigms, revolutionizing traditional economic models. The CE focuses on circular flows, waste reduction, and resource efficiency, while RE prioritizes the regeneration of natural systems, human societies, and economic vitality. There are divergencies, but together they form a powerful synergy, driving transformative change towards a restorative, resilient, and thriving economy.

The CE and RE both aim to create sustainable and resilient systems but approach the challenge from different angles. Integrating and embracing this fusion enables a holistic transition towards a regenerative CE, where economic vitality is intertwined with environmental stewardship and social justice.

The divergence and convergence across various sustainability models, such as PPP, CE, RE, DE, and ESG, highlight the complexity and diversity in approaches to sustainable development. Each model presents unique strengths and perspectives, yet their convergences suggest an underlying shared vision of a sustainable future. Integrating these models through a unified measure, like normalized sustainability coordinates (NSCs), as aimed in this paper, could harmonize their efforts, providing a holistic and comprehensive framework for evaluating and advancing sustainability goals.

NSCs offer a robust and flexible tool for capturing the multifaceted nature of sustainability by normalizing impacts across social, economic, and environmental dimensions. Such a unified measure will allow for comparability and integration of different sustainability strategies, recognizing their unique contributions while aligning them towards common objectives. By utilizing NSCs, policymakers, businesses, and communities can better understand and balance trade-offs, ensuring that actions in one area do not undermine progress in another. Such an integrated approach will foster synergy and innovation, driving systemic change towards a regenerative and resilient global economy.

Moreover, the adoption of NSCs can enhance transparency and accountability, as it provides a clear and consistent metric for tracking progress across diverse initiatives. This promotes greater collaboration and shared learning, as stakeholders can benchmark their efforts against a unified standard. Ultimately, the integration of CE, RE, DE, and ESG models through NSCs can accelerate the transition to sustainable development, ensuring that economic growth, social well-being, and environmental stewardship are achieved in harmony. Such a holistic perspective is essential for addressing the complex and interconnected challenges of the 21st century, paving the way for a more sustainable and equitable future.

3. Methodological Flow

The methodological flow of the research is presented in Figure 2. The problem statement is how to transition to a high HDI world for everyone, but within the safe natural limits of our planet! Several sustainability models and efforts are ongoing, including CE and ESG. Their strengths can be enhanced by integration as their purpose is shared. To integrate the CE and ESG models and to develop the NSCs as unified measures of circularity and ESG, we first identify the key differences and similarities between the two approaches. The key barrier to integration CE and ESG is the absence of a robust and versatile mathematical framework. To overcome this barrier and to present a novel circular-ESG unified framework for studying and managing sustainability transitions, the methodology of this research adopts a Cartesian coordinate system. The framework maps the impacts of various business model innovations, policies, and practices on natural and socio-economic systems using normalized sustainability coordinates (NSCs) from −1 to 1 on both axes.

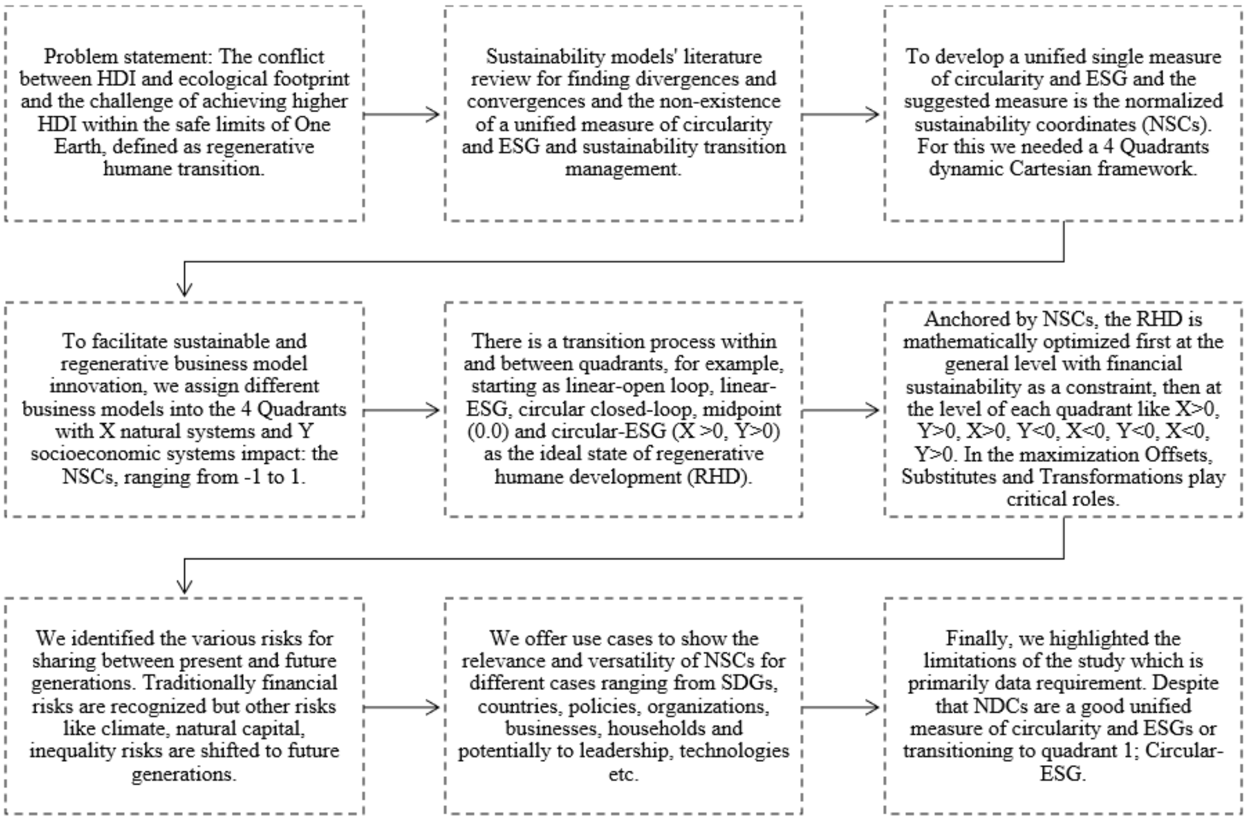

Figure 2. Methodological flow.

The X-axis represents impacts on natural systems, while the Y-axis represents impacts on socio-economic systems. This creates four quadrants: circular-ESG (Q1), circular (Q2), linear open-loop (Q3), and linear-ESG (Q4). The framework allows for quantitative assessment and visual representation of sustainability performance. The methodology introduces the concept of normalized sustainability coordinates (NSCs) as a measure of negative and positive externalities. These coordinates serve as a unified, dynamic, and comprehensive measure of sustainability performance, allowing for standardized comparison across different entities and time periods. Positive coordinates indicate net positive externalities (regenerative practices), while negative coordinates represent net negative externalities (degenerative practices). The framework incorporates the concepts of substitution (S) and transformation (T) to analyze pathways for transitioning between quadrants. It also integrates offsets for negative externalities (ONEs) to account for mitigating actions.

The methodology enables the setting of temporal key performance indicators as specific coordinates within quadrants. A key innovation of this framework is the introduction of regenerative humane development (RHD) as an alternative to traditional utility maximization. The RHD concept aims to achieve high human development indices within the planet's safe ecological boundaries. The paper presents an RHD maximization model that replaces conventional utility functions, incorporating environmental and social dimensions alongside economic considerations. The paper presents hypothetical use cases for various entities like households, businesses, and policies. The methodology aims to provide a comprehensive, data-driven approach for sustainability assessment and transition management across different scales and contexts.

4. The Circular-ESG Framework

The "circular-ESG" framework is presented in Figure 3 and comprises four segments. We first discuss the different segments of the framework, and then discuss the risks and opportunities of the sustainability transition and add some concluding remarks.

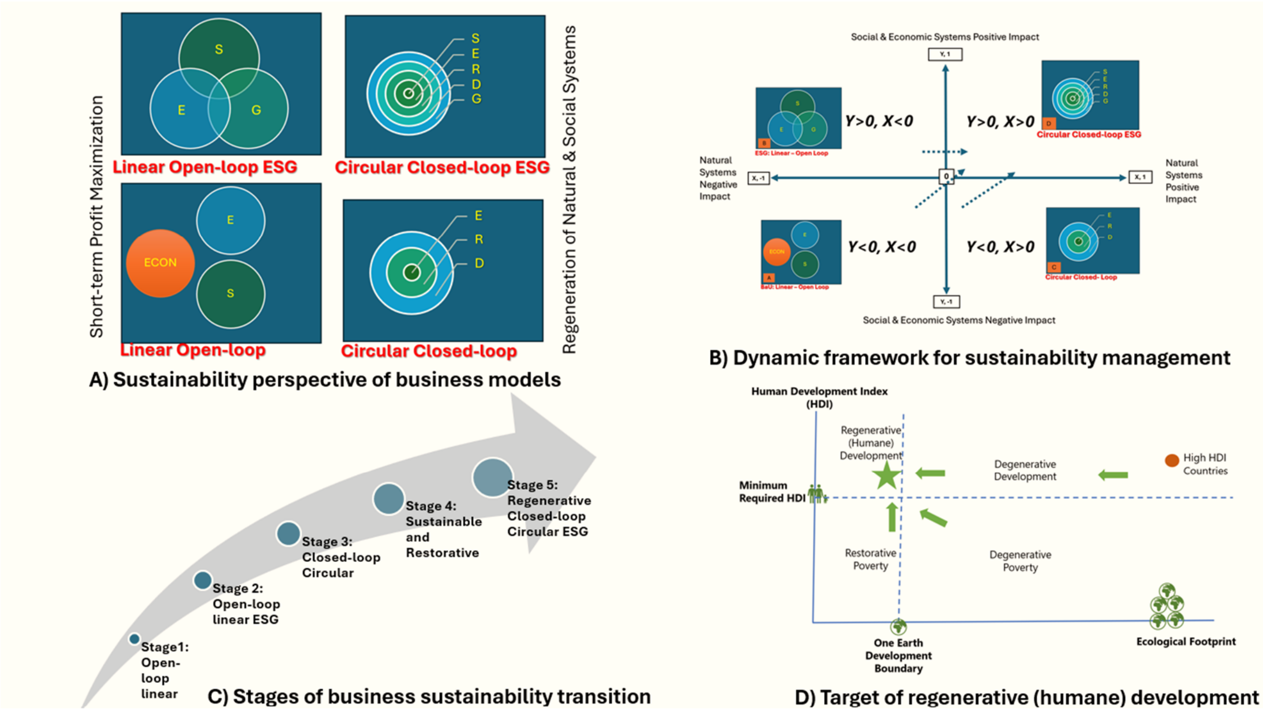

Figure 3. Integrated, multidisciplinary, and dynamic framework for sustainability studies. **Notations:** Era of R: Refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover. Era of D: Design to facilitate the Rs, design to durability, design to reduce emissions and pollutants, design financial contracts to support the transition, design supportive policies, design supportive technologies. S: social, G: governance, E: environment. **Source**: developed by author.

4.1. *Figure 3, Segment A: Business Models: Market-Driven Sustainability vs. Sustainability-Driven Markets*

Segment A of Figure 3 delineates the sustainability perspective of business models, highlighting the evolution from linear open-loop models, which prioritize short-term profit maximization, to circular closed-loop models, which focus on the regeneration of natural and social systems. This transition underscores the shift from a traditional mere economic focus of the business to a more holistic approach that integrates the closed-loop CE paradigm with ESG criteria—pivots summarized in Table 2.

Table 2. Pivots of business models.

Markets Driven Sustainability (Motivation Short-Term Profit Maximization)	Sustainability-Driven Markets (Motivation and Regeneration of Natural and Social Systems)
Linear open-loop—weak social, governance, and environmental sustainability	Circular closed-loop—strong environmental sustainability but weak social and governance sustainability
Linear open-loop ESG—stronger social and governance sustainability but weak environmental sustainability	Circular closed-loop ESG—ideal state of circular closed-loop supplemented with strong social and governance sustainability

The four distinct business models are arranged along the axes of short-term profit maximization on the left side of the panel, and the regeneration of natural and socio-economic systems on the right side of the panel. These models simultaneously exist in any location, region, or country at a given time. The models can be generalized to individual and household behaviors, organizations, policies, technologies, etc., as explained in later sections of the paper. The models include the following:

(a) Linear open-loop: represents a traditional business model focused on economic gain (ECON) with minimal consideration of environmental (E), social (S), and governance (G) factors. It is characterized as being based on resource extraction, production, consumption, emissions, and waste generation—negative externalities are tolerated as inevitable outcomes of markets. This is the dominant neoclassical economic paradigm, well known as the shareholders' capitalism.

(b) Linear open-loop ESG: integrates ESG factors into the linear model but maintains a focus on short-term profit maximization—this can be termed as an attempt to achieve sustainability through markets. There's a careful attempt at market-driven incentive-based internalization of negative externalities, but often it leads to moral hazard in the form of greenwashing [30].

(c) Circular closed-loop: adopts CE principles, emphasizing resource reuse and waste reduction—ideally waste elimination by closing the loop in the linear system by biological (composting) and technical (design and resource reuse) processes. However, some recent studies highlight that this model bypasses the social and governance considerations of ESG.

(d) Circular closed-loop ESG: combines CE principles of zero-waste and resource conservation and regeneration with strong ESG integration, with robust financial, social, and governance taxonomies aiming for comprehensive sustainability—this can be termed as *sustainability-driven markets*.

4.2. Figure 3, Segment B: Dynamic Framework for Sustainability Management

Segment B of Figure 3 introduces the dynamic framework for sustainability governance/management, summarized in Table 3, utilizing a Cartesian coordinate system to map the impact of different business models on natural and socio-economic systems. The horizontal axis (X) represents the impact on social and economic systems, ranging from negative/degenerative (−1) to positive/regenerative (1), while the vertical axis (Y) captures the impact on natural systems, also spanning from negative (−1) to positive (1). This quadrant-based approach allows for a nuanced analysis of how different models, such as linear open-loop ESG and circular closed-loop ESG, perform in terms of their sustainability outcomes. By plotting these impacts, businesses can identify pathways to move from degenerative practices towards regenerative ones. This dynamic framework uses a Cartesian plane to map the impacts of different business models on natural and socio-economic systems.

Table 3. Model specification.

Closed-Loop ESG	**Closed Loop**	**Linear Open-Loop**	**Midpoint Balance**	**Open-Loop ESG**
PEs + ONEs − NEs > 0. Y > 0, X > 0 (1, 1)	PEs + ONEs − NEs ≥ 0. Y < 0, X > 0 (−1, 1)	PEs + ONEs − NEs < 0. Y < 0, X < 0 (−1, −1)	PEs + ONEs − NEs = 0. Y = 0, X = 0 (0, 0)	PEs + ONEs − NEs ≤ 0. Y > 0, X < 0 (1, −1)

Notations: PEs: positive externalities, NEs: negative externalities, ONEs: offsets for social and environmental NEs representing effectiveness of institutions and governance.

It is noticeable that we are labeling the four quadrants unconventionally to suit our netting requirement of the quadrants. Business models are positioned in quadrants based on their impacts:

Upper right quadrant (Y > 0, X > 0): positive impacts on both systems (e.g., circular closed-loop ESG).

Upper left quadrant (Y > 0, X < 0): positive social/economic impact but negative natural impact.

Lower right quadrant (Y < 0, X > 0): negative social/economic impact but positive natural impact.
Lower left quadrant (Y < 0, X < 0): negative impacts on both systems (e.g., linear open-loop).

The framework's use of coordinate limits from -1 to 1 significantly enhances its versatility and data-driven capabilities by providing a normalized, standardized scale for evaluating and comparing sustainability performance across diverse contexts. This range allows for a clear and concise representation of impacts on both natural and social systems, with negative values indicating detrimental effects and positive values signifying beneficial outcomes.

The bounded scale facilitates the setting of temporal key performance indicators (KPIs) as normalized coordinates within each quadrant, enabling precise tracking of progress for specific activities, businesses, or policies. By situating sustainability performance within this coordinate system, stakeholders can easily identify current positions and desired targets, thereby fostering a dynamic approach to sustainability management. The normalized coordinates ensure consistency and comparability over time, supporting robust empirical studies and informed decision-making. Additionally, this dynamic value allows for adaptive management practices, where interventions can be regularly adjusted based on real-time data and evolving conditions, driving continuous improvement towards sustainability goals.

Natural systems and capital are fundamental to sustaining life and businesses, providing essential resources such as clean air, water, fertile soil, and biodiversity that underpin economic activities and human well-being. Our model emphasizes the restoration and regeneration of these natural systems, integrating nature-based solutions (NBSs) as a crucial pathway in the sustainability transition. By adopting circular closed-loop ESG principles, businesses can shift from exploiting natural resources to enhancing their resilience and regenerative capacities. This approach not only mitigates environmental degradation but also promotes long-term sustainability, ensuring that natural capital continues to support both current and future generations.

Substitution and transformation effects

Substitution (S) and Transformation (T) are critical processes of the sustainability transformation and require some elaboration.

Substitution (S):

Substitution refers to the process of replacing less sustainable or more harmful practices, materials, or technologies with alternatives that have a lower environmental impact or are more socially responsible. This approach directly impacts the natural capital axis (X) of the framework by improving or sustaining environmental resources. Examples of substitution include the following:

Energy sources: switching from fossil fuels to renewable energy sources such as solar or wind power.

Materials: using recycled or biodegradable materials instead of virgin plastic or other non-renewable resources.

Processes: adopting water-efficient technologies in manufacturing to reduce water use and wastewater generation.

Product Design: designing products for disassembly and recycling, substituting materials or components that facilitate CE practices.

Impact: Substitution typically aims to directly reduce environmental degradation or enhance resource efficiency. It can also indirectly impact social externalities by contributing to a healthier environment and reducing the social harms associated with pollution and resource depletion.

Transformation (T):

Transformation involves more profound changes that redefine an organization's fundamental practices, including its business models, operational processes, and cultural or strategic frameworks. This change targets both the environmental and social dimensions, aiming to create systemic improvements that align with sustainable development goals. Examples of transformation include the following:

Business models: moving from single-use product models to service-based models (like product-as-a-service), where the focus shifts from selling physical products to offering the functionality of the product as a service.

Corporate culture: developing a corporate culture that prioritizes sustainability, ethical behavior, and social responsibility, which can permeate all levels of decision-making.

Supply chain: transforming the supply chain to include only suppliers who adhere to strict environmental and social standards, ensuring sustainability is maintained from source to sale.

Stakeholder engagement: changing the way an organization interacts with its stakeholders to ensure their needs and rights are proprietarily considered, promoting transparency and accountability.

Impact: Transformation is aimed at creating long-lasting changes that not only improve the current state but also ensure sustainability is integrated into the core strategic decisions of an organization. By doing so, it helps sustain positive social externalities (Y-axis) and can improve or mitigate negative impacts on natural capital (X-axis).

Table 4 provides a comparative analysis of different business models in terms of their effectiveness in addressing social and environmental negative externalities (NEs). The table categorizes the models into five types: linear, linear-ESG, circular, mid-point, and circular-ESG business models. Each model is evaluated on its explicit destination for closing the loop of social and environmental NEs, with a scoring system where "NONE: 0" indicates no explicit destination, "PARTIAL: > 0 < 1" indicates a partially clear destination, and "FULL: 1" indicates an explicitly clear destination. Linear business models have no clear destination for closing the loop on either type of NEs. Linear-ESG and mid-point models only partially address these externalities. Circular business models fully address environmental NEs but only partially address social NEs. The circular-ESG business model stands out as the only model that explicitly aims to close the loop on both social and environmental negative externalities, achieving full scores in both categories. This table underscores the comprehensive approach of the circular-ESG model in fostering holistic sustainability.

Table 4. Destinations of closing the loop of negative externalities.

	Linear Business Models	**Linear-ESG Business Models**	**Circular Business Models**	**Mid-Point**	**Circular-ESG Business Models**
Destination for Closing the Loop of Social Negative Externalities	NONE: 0 There is no explicit destination to close the loop of negative social externalities	PARTIAL: > 0 < 1 There is only a partially clear destination to close the loop of negative social externalities	PARTIAL: > 0 < 1 There is only a partially clear destination to close the loop of negative social externalities	PARTIAL: > 0 < 1 There is only a partially clear destination to close the loop of negative social externalities	FULL: 1 There is an explicitly clear destination to close the loop of negative social externalities
Destination for Closing the Loop of Environmental Negative Externalities	NONE: 0 There is no explicit destination to close the loop of negative environmental externalities	PARTIAL: > 0 < 1 There is only a partially clear destination to close the loop of negative environmental externalities	FULLY: 1 There is a explicitly clear destination to close the loop of negative environmental externalities	PARTIAL: > 0 < 1 There is only a partially clear destination to close the loop of negative environmental externalities	FULL: 1 There is a explicitly clear destination to close the loop of negative environmental externalities

4.3. *Figure 3, Segment C: Stages of Business Sustainability Transition*

Segment C of Figure 3 outlines the stages of the business sustainability transition, detailing a five-stage journey from open-loop linear models to regenerative closed-loop circular ESG models. The stages progress from basic sustainability measures, such as refuse and rethink (Stage 1), through intermediate steps like repair and refurbishment (Stages 2 and 3), to advanced practices such as sustainable and restorative processes (Stage 4), culminating in the fully regenerative models (Stage 5). Each stage emphasizes increasing levels of environmental and social responsibility, encouraging businesses to continually improve their sustainability practices. This segment outlines a progression through five stages of sustainability:

(a) Stage 1: open-loop linear: businesses operate in a traditional linear model with minimal sustainability considerations.
(b) Stage 2: open-loop linear ESG: integrates ESG factors into the linear model, enhancing sustainability awareness.
(c) Stage 3: closed-loop circular: adopts CE practices, emphasizing resource efficiency and waste reduction.
(d) Stage 4: sustainable and restorative: combines circular practices with strong ESG considerations, aiming to restore natural and social systems.
(e) Stage 5: regenerative closed-loop circular ESG: achieves the highest level of sustainability, focusing on regenerative practices that enhance both natural and social systems.

Deeper Stages of Regenerative Transition

The sustainability transition involves stages of deeper levels of transformation, as depicted in Figure 4, based on the model and the required policies and initiatives. Key features of deeper levels of sustainability are as follows:

(a) ESG integration: environmental, social, and governance disclosures.
(b) Reduction of resource use: implement strategies to minimize resource extraction and consumption, promoting the use of sustainable materials.
(c) Extension of product lifespan: encourage the design and production of durable goods, emphasizing reuse, repair, refurbishment, and remanufacture.
(d) Improvement of recycling and waste management: enhance recycling processes and the utilization of production and consumption residues.
(e) Institutional reform and effectiveness: taxonomies for financial, social, educational, and administrative transformation
(f) Integration of social finance: philanthropic social safety net, community institutions, income support, and empowerment initiatives for the underprivileged
(g) Regenerative focus: implement nature-based solutions (NBS) with regenerative focus
(h) Stakeholders: The various stakeholders are engaged meaningfully.

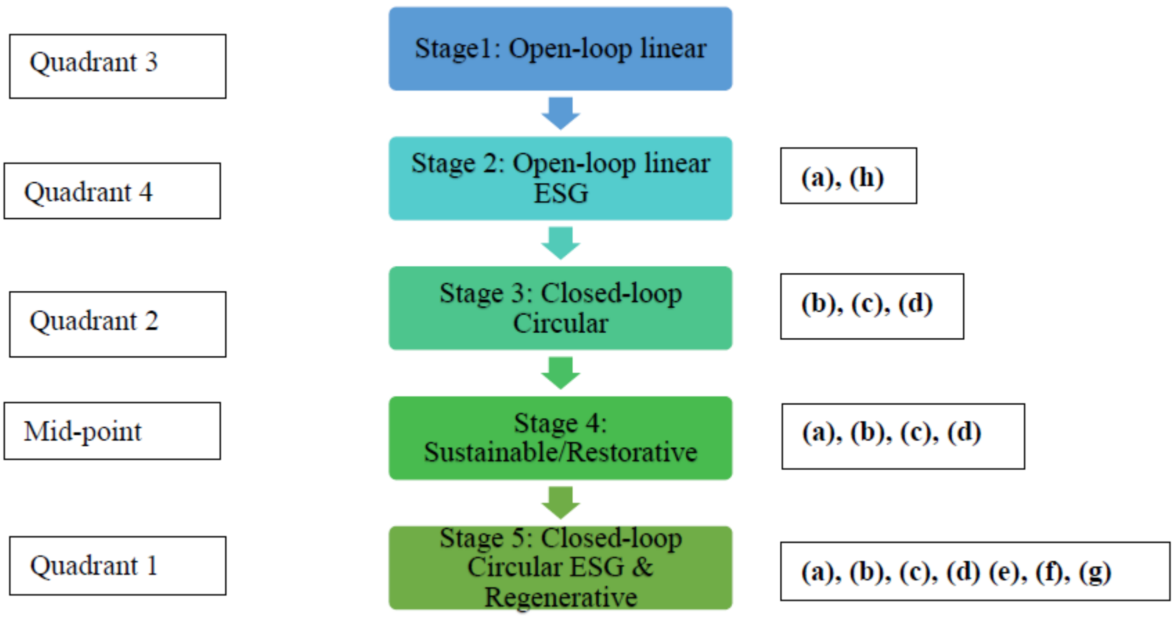

Figure 4. The deeper stages of sustainability transition. Source: prepared by author.

4.4. Figure 3, Segment D: Regenerative Humane Development (RHD)

Segment D of Figure 3 adopts the approach of the Global Footprint Network and sets the target of regenerative (humane) development, integrating the Human Development Index (HDI) within the ecological limits of one Earth. Safe planetary boundaries are emphasized by several studies. This segment emphasizes the importance of achieving high HDI, which reflects improved living standards and social well-being, while staying within the planet's ecological boundaries. The framework uses a similar coordinate system to Segment B, with the HDI plotted against ecological impact, demonstrating the balance required to achieve sustainable human development. The goal is to attain a positive impact on both axes, ensuring that development is both humane and ecologically sustainable. The 2023–2024 UNDP Human Development Report offers an optimistic finding that the emerging economies are showing signs of performing better on HDI with a lesser consequential ecological footprint as compared with the developed countries. This positive sign is the result of the efforts and technologies that we mentioned in the introduction of this paper.

This segment sets the goal of RHD—achieving high human development indices (HDI) within the planet's safe ecological boundaries. It presents a two-dimensional graph where the following are true:

The X-axis represents the ecological footprint, with a boundary indicating the planet's safe limits.

The Y-axis represents HDI, with a minimum threshold required for humane development.

The goal is to achieve a high HDI within the safe ecological footprint, avoiding scenarios of degenerative development (high HDI with unsustainable ecological impact) and aiming for regenerative development (high HDI with sustainable ecological practices).

RHD Maximization—General Form

In the framework, regenerative humane development (RHD) maximization replaces the traditional utility maximization. Here we discuss the maximization of the general objective function for the model.

Objective Function

$$\text{RHD (X, Y, ONEs)} = \alpha X + \beta Y - \omega.\ \text{OptimalONEs (ONEs)}$$

where

X: enhancement of natural capital.
Y: improvement in social externalities.
OptimalONEs (ONEs): a function representing strategic application of environmental and social offsets to minimize reliance on offsets while maximizing positive externalities.
α, β, ω: weights indicating the importance of each component, where higher weights reflect a greater priority in the RHD framework.
$\dot{X} = f\ (S, EnvONEs) - \gamma X$: shows natural capital improvement influenced by sustainable practices (S) environmental offsets.
$\dot{Y}$: $g\ (T, SocONEs) - \delta Y$: captures social externality improvement driven by transformation efforts (T) and social offsets.
$\dot{ONEs} = h\ (S, T, X, Y) - \varepsilon ONEs$: models the optimization of offset usage based on the current environmental and social states.

Financial Sustainability Constraint and Convexity

The above model clearly defines a structure that balances the dynamic interactions between natural systems and socio-economic systems and the strategic use of offsets. In general, there are two fundamental considerations that need to be addressed:

(a) Incorporating financial constraints: adding a constraint to ensure that the costs associated with S, T, and ONEs do not exceed a predefined budget. This ensures that the RHD maximization efforts are financially sustainable.
(b) Enhancing objective function with convexity: Assuming convex relationships in f, g, and h functions might help in emphasizing the increasing returns on investment in sustainability efforts, making the model even more robust in driving significant

enhancements in both X and Y. In general, there are increasing returns associated with investment in education (Y axes) and planting trees (X axes).

This extension enriches the model by ensuring that financial resources are utilized efficiently, aligning economic feasibility with ecological and social benefits, thereby providing a comprehensive and practical framework for sustainable regenerative development. This extended model provides a robust framework for analyzing and maximizing regenerative and humane development under financial constraints. It not only retains the core principles of the RHD maximization model but also enhances its analytical and practical capabilities, making it a powerful tool for sustainable development planning and implementation. This model is particularly useful for policymakers and planners seeking to optimize resource allocation in a way that maximizes both ecological and social welfare within financial limits.

Objective Function

Financial sustainability is now assumed to be a constraint rather than being the objective itself. The objective now is the maximization of regenerative human development (RHD) continuously in a dynamic equilibrium environment.

The goal is to maximize f (X, Y).

X and Y are indices or levels of natural and social capital, respectively.

The function f (X, Y) is assumed to be convex, potentially a Cobb-Douglas or another form that shows increasing return as X and Y increase. This reflects the concept that greater investments in social (education) and natural capital (planting trees) yield progressively larger benefits.

Financial Sustainability Constraint

The model includes a financial constraint $g(X, Y, C) \leq B$, where

C represents the cost of investing in natural capital and social capital.
B is the budget or financial resources limit.
g (X, Y, C) is a function that captures the cost associated with given levels of X and Y.

This constraint ensures that the expenditure on RHD initiatives does not exceed the financial resources available, emphasizing the importance of maintaining financial sustainability.

Covex Optimization

The problem is formulated to maximize f (X, Y) subject to $g(X, Y, C) \leq B$.

The convex nature of X simplifies the optimization, ensuring that local maxima are also global maxima, which facilitate finding the optimal solution.

Solution Methodology

Solutions might be explored using Lagrange multipliers, particularly if f and g are differentiable. This involves setting up the Lagrangian:

$$L(X, Y, \lambda) = f(X, Y) - \lambda(g(X, Y, C) - B)$$

here, λ is the Lagrange multiplier associated with the financial constraint. Solving this equation gives the values of X, Y, and λ that maximize f (X, Y) while ensuring that the cost does not exceed the budget B.

RHD Maximization for Quadrant 1 (X > 0, Y > 0)

In quadrant 1, both socio-economic and environmental impacts are positive. The focus of RHD maximization involves enhancing these already positive impacts while strategically utilizing and reducing dependence on offsets for negative externalities (ONEs). We can set the model for RHD maximization, which replaces the traditional utility maximization.

Objective Function5

$$RHD(X, Y, ONEs) = \alpha X + \beta Y - \omega(ONEs)$$

where

X: enhancement of natural capital.
Y: improvement in social externalities.

α and β are weights reflecting the importance of enhancing natural capital and social externalities, respectively.
ω is the weight assigned to the cost or impact of utilizing offsets, indicating a strategic aim to minimize these wherever possible.

Dynamic Equations

$$\dot{X} = f\,(S, EnvONEs) - \gamma X.$$

f (S, EnvONEs) shows natural capital improvement influenced by sustainable substitute practices (S) and environmental offsets.

$-\gamma X$ is the natural depreciation or consumption of natural capital over time.

$$\dot{Y} = g\,(T, SocONEs) - \delta Y.$$

g (T, SocONEs) captures social externality improvement driven by transformation efforts (T) and social offsets.

δY represents the potential decline of social benefits over time without continuous improvement efforts.

$$\dot{ONEs} = h\,(S, T, X, Y) - \varepsilon ONEs.$$

Models the strategic reduction of ONEs, aiming to decrease reliance on these offsets as direct improvements in X and Y are achieved.

RHD Maximization for Quadrant 2 (X > 0, Y < 0)

In quadrant 2, socio-economic impacts are weaker; they could even be negative, but environmental impacts are positive. The focus of RHD maximization involves overcoming the social negative externalities and enhancing the already positive environmental impacts while strategically utilizing offsets for overcoming social negative externalities (ONEs). We can set the model for RHD maximization, which replaces the traditional utility maximization.

Objective Function

$$RHD\,(X, Y, ONEs) = \alpha X - \beta\,|Y| - \omega(ONEs)$$

where

X: enhancement of natural capital.
Y: improvement in social externalities.
α weights reflect the importance of enhancing natural capital.
β weights reflect the importance of improving social positive externalities.
ω is the weight assigned to the cost or impact of utilizing offsets, indicating a strategic aim to minimize these wherever possible through effective social improvements.

Dynamic Equations

$$\dot{X} = f\,(S, EnvONEs) - \gamma X.$$

f (S, EnvONEs) shows natural capital improvement influenced by sustainable substitute practices (S) and environmental offsets.

$-\gamma X$ is the natural depreciation or consumption of natural capital over time.

$$\dot{Y} = g\,(T, SocONEs) - \delta Y.$$

g (T, SocONEs) captures social externality improvement driven by transformation efforts (T) and social offsets; these become priorities given Y < 0.

δY represents the potential decline of social benefits over time without continuous improvement efforts, a priority concern given Y < 0.

$$\dot{ONEs} = h\,(T, Y) - \varepsilon ONEs.$$

Models the strategic reduction of social ONEs, aiming to decrease reliance on these offsets as direct improvements in Y are achieved.

RHD Maximization for Quadrant 3 (X < 0, Y < 0)

In quadrant 3, both X (environmental conditions) and Y (socioeconomic conditions) are in degenerative stages. The focus of RHD maximization involves overcoming the social negative externalities as well as the environmental negative impacts while strategically utilizing social offsets (SocONEs) and environmental offsets (EnvONEs). We can set the model for RHD maximization, which replaces the traditional utility maximization.

Objective Function

$$\text{RHD (X, Y, ONEs)} = -\alpha \mid X \mid -\beta \mid Y \mid - \omega(\text{ONEs})$$

where

X: stopping the degeneration of natural capital and its enhancement.
Y: stopping the degeneration of social systems and their improvement.
α weights reflect the urgency of stopping the degeneration of natural capital and enhancing it.
β weights reflect the urgency of stopping the degeneration of social systems and improving those systems.
ω is the prioritized weight assigned to the cost or impact of utilizing offsets, indicating a strategic aim to minimize these wherever possible through effective social and environmental improvements.

Dynamic Equations

$$\dot{X} = f\ (\text{S, EnvONEs}) - \gamma X.$$

f (S, EnvONEs) to show strong natural capital improvement programs influenced by sustainable substitute practices (S) and environmental offsets, given the already degraded condition of $X < 0$.

$-\gamma X$ is the natural depreciation or consumption of natural capital over time.

$$\dot{Y} = g\ (\text{T, SocONEs}) - \delta Y.$$

g (T, SocONEs) captures strong social rehabilitation and improvement programs driven by transformation efforts (T) and social offsets, as these become priorities given $Y < 0$.

δY represents the potential decline of social benefits over time without continuous improvement efforts, a priority concern given $Y < 0$.

$$\dot{\text{ONEs}} = h\ (\text{S, T, X, Y}) - \varepsilon\text{ONEs}.$$

Models the strategic reduction of SocONEs, aiming to decrease reliance on these offsets as direct improvements in Y are achieved.

RHD Maximization for Quadrant 4 (X < 0, Y > 0)

In quadrant 4, both X environmental conditions are negative, but Y socioeconomic conditions are positive. The focus of RHD maximization involves overcoming the negative environmental externalities and preserving and enhancing the positive socioeconomic impacts while strategically utilizing environmental offsets (EnvONEs) as a priority and social offsets (SocONEs). We can set the model for RHD maximization, which replaces the traditional utility maximization.

Objective Function

$$\text{RHD (X, Y, ONEs)} = \alpha \mid X \mid +\beta \mid Y \mid - \omega(\text{ONEs})$$

where

X: stopping the degeneration of natural capital and its enhancement.
Y: preserving positive impacts on social systems and their improvement.
α weights reflect the urgency of stopping the degeneration of natural capital and enhancing it.

β weights reflect the positive state of social systems and improving those systems.
ω is the prioritized weight assigned to the cost or impact of utilizing offsets, indicating a strategic aim to minimize these wherever possible through effective environmental improvements and maintaining social systems' positive impacts.

Dynamic Equations

$$\dot{X} = f\,(S, EnvONEs) - \gamma X.$$

f (S, EnvONEs) to show strong natural capital improvement programs influenced by sustainable substitute practices (S) and environmental offsets, given the already degraded condition of $X < 0$.

$-\gamma X$ is the natural depreciation or consumption of natural capital over time.

$$\dot{Y} = g(T) - \delta Y.$$

g(T) captures efforts to maintain and further improve the positive social externalities through continued transformative actions (T), given $Y > 0$.

δY represents the potential decline of social benefits over time without continuous improvement efforts.

$$O\dot{N}Es = h\,(S, X) - \varepsilon ONEs.$$

Models the strategic application and eventual reduction of environmental ONEs as the natural capital improves.

5. Risks and Opportunities

How many of the risks of a business are the owners taking responsibility for, and how many of the risks do they shift to future generations? In the open-loop linear system, the focus is predominantly on financial risks such as credit risk, market risk, operational risk, and liquidity risk, with these risks being borne directly by shareholders—Figure 5. However, this system fails to recognize and address broader environmental, social, and governance (ESG) risks, as well as climate, natural capital, and inequality risks. Consequently, these unrecognized risks are effectively transferred to future generations as unintended and underpriced social costs. This transfer results in significant negative externalities that future generations must bear, highlighting a fundamental flaw in the sustainability of the open-loop linear business model.

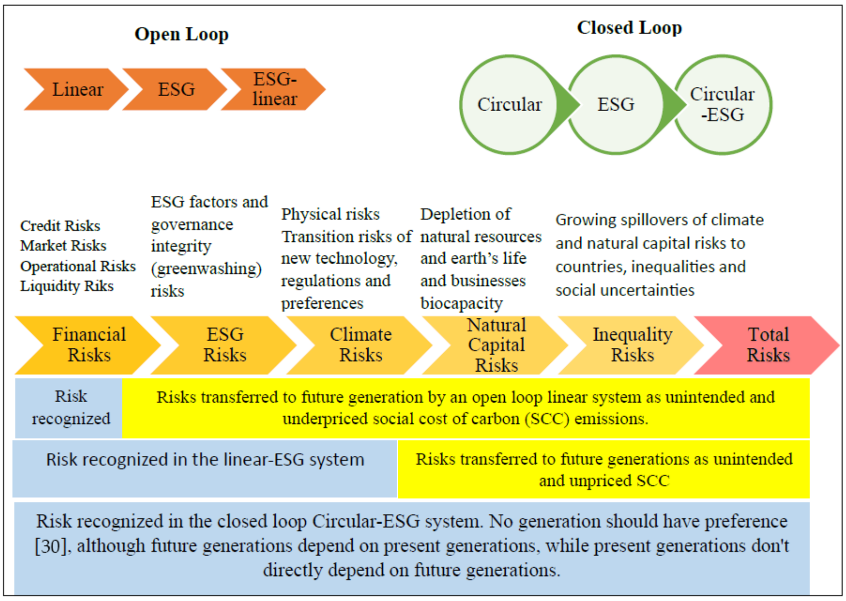

Figure 5. Risks of alternative business models. Source: prepared by author.

Conversely, the closed-loop ESG system incorporates a comprehensive approach to risk management, emphasizing risk-sharing between present and future generations. This system recognizes a wide spectrum of risks, including financial, ESG, climate, natural capital, and inequality risks.

Since linear-ESG is primarily focused on regulatory compliance rather than a genuine business model innovation, concerns about integrity (greenwashing) risks are increasing [30]. This approach often prioritizes meeting minimum standards over authentic sustainability efforts, leading to potential misrepresentation. In contrast, circular-ESG represents a genuine business model innovation that can address the integrity-first call by embedding transparency and accountability into its core practices.

By integrating ESG principles into a CE framework, the closed-loop ESG system aims to balance the immediate financial interests with long-term sustainability goals. This inherent feature of risk-sharing is crucial for effective sustainability transition management, as it promotes the regeneration of natural and social systems, ensuring that the negative externalities are minimized, and the benefits of sustainable practices are maximized for both current and future stakeholders.

Table 5 outlines the uncertainties, hidden disruptive opportunities, and risks associated with sustainability transitions across various domains. Climate change presents uncertainties such as severe weather events and economic loss but also offers opportunities through advancements in renewable energy technologies and climate-resilient agriculture. Businesses that fail to seize these opportunities risk facing significant economic losses and habitat destruction. Similarly, water scarcity can be mitigated by innovations in purification, desalination, and smart irrigation. Companies that neglect these innovations may encounter water shortages, agricultural decline, and associated health impacts.

Table 5. Challenges of mankind; disruptive opportunities of transition and risks.

Challenge and Hidden Opportunities	Potential Scientific Innovation and Positive Disruption	Risks of Missing Out the Opportunities
Climate Change: Renewable energy technologies, job creation, climate modeling advancements.	Advanced renewable energy technologies, carbon capture, climate-resilient agriculture.	Severe weather events, economic loss, habitat loss.
Water Scarcity: Growth in water technology industries, improved agricultural productivity.	Efficient purification/desalination, smart irrigation, water recycling.	Water shortages, agricultural decline, health impacts.
Biodiversity Loss: Eco-tourism, sustainable agriculture, new pharmaceuticals.	Conservation technologies, habitat restoration, genetic diversity preservation.	Ecosystem collapse, loss of ecosystem services.
Food Security: Increased efficiency, reduced wastage, sustainable supply chains.	Vertical farming, precision agriculture, resilient GM crops.	Food shortages, price spikes, malnutrition.
Health Impacts: Improved health outcomes, digital health market growth.	Advanced treatments, telemedicine, disease prediction/prevention tech.	Increased disease burden, healthcare costs, reduced life expectancy.
Energy Transition: Energy independence, reduced emissions, new clean energy	Advanced batteries, hydrogen fuel, smart grids.	Continued reliance on fossil fuels, climate impact.
Ocean Degradation: Sustainable fisheries, marine biotechnology, coastal protection.	Pollution control, sustainable aquaculture, ocean monitoring.	Marine ecosystem damage, economic loss for coastal communities.
Urbanization and Infrastructure: Improved urban living, efficient public transport.	Smart city tech, sustainable urban planning, resilient infrastructure.	Urban sprawling, water and sewage infrastructure strain, environmental degradation.
Economic Inequality: Empowerment, social entrepreneurship, poverty reduction.	Inclusive financial tech, digital inclusion, education access tools, equitable models.	Social unrest, economic disparity, missed growth opportunities.
Waste Management: Circular economies, sustainable packaging, landfill reduction.	Zero-waste CE prospects Advanced recycling, waste-to-energy, biodegradable materials.	Increased pollution, resource depletion, economic loss.
Biocapacity Degradation: Enhanced ecosystem services, carbon sequestration, productivity.	Sustainable land management, reforestation, soil restoration.	Reduced agricultural yields, increased emissions, habitat loss.
Resource Depletion: Conservation, alternative materials, sustainable supply chains.	Efficient extraction, CE business models, and efficient resource management.	Resource scarcity, economic instability, environmental damage.
Conflict between Growth and Environment: Balanced growth, sustainable industries, environmental protection.	Green economic models, sustainable policies, impact assessments. Growth and high human development within the planetary capacity of earth.	Environmental degradation, unsustainable growth, social conflict.

Table 5. *Cont.*

Challenge and Hidden Opportunities	Potential Scientific Innovation and Positive Disruption	Risks of Missing Out the Opportunities
Antibiotic Resistance: Medical research advancements, improved health outcomes.	New antibiotics, alternative treatments, rapid diagnostics.	Increased morbidity/mortality, higher healthcare costs, pandemics.
Political and Social Instability: Global cooperation, peace promotion, crisis management.	Conflict resolution tech, tech in humanitarian aid delivery, resilience programs.	Prolonged conflicts, migration crises, economic instability.

Source: Compiled by author based on [2].

Biodiversity loss, food security, and health impacts are other areas with substantial disruptive opportunities. Conservation technologies, vertical farming, and advanced health treatments can address these challenges while providing new market opportunities. Failing to innovate in these areas could lead to ecosystem collapse, food shortages, price spikes, and increased healthcare costs. Additionally, the energy transition towards advanced batteries and hydrogen fuel represents a critical shift. Companies that do not invest in these clean energy solutions may continue to rely on fossil fuels, exacerbating climate impacts.

Urbanization, waste management, and biocapacity degradation highlight the need for sustainable urban planning, zero-waste economies, and sustainable land management. Embracing these opportunities can lead to improved urban living and reduced environmental degradation. On the contrary, businesses that overlook these innovations risk contributing to urban sprawl, increased pollution, and resource depletion. Overall, the table emphasizes that the transition to sustainable practices is not only essential for environmental health but also presents significant opportunities for innovation and economic growth, while the failure to adapt poses substantial risks to long-term business viability and societal well-being.

6. Normalized Sustainability Coordinates and Hypothetical Use Cases

Normalized sustainability coordinates (NSCs) offer a unified measure of sustainability by integrating various sustainability impacts into a standardized range, typically from -1 to 1. The NSCs system utilizes a four-quadrant Cartesian coordinate system, representing different dimensions and states of sustainability of any entity.

Axes and Quadrants

X-axis (environmental impacts): Reflects the effects of an activity on the natural systems.
Y-axis (socio-economic impacts): Reflects the effects of an activity on the human, social, and economic systems.

The Cartesian coordinate system divides sustainability into four quadrants:

Quadrant I (Q1): positive environmental and social impacts of an activity (circular-ESG).
Quadrant II (Q2): positive environmental but negative social impacts of an activity (circular closed-loop).
Quadrant III (Q3): negative environmental and social impacts of an activity (linear open-loop).
Quadrant IV (Q4): positive social but negative environmental impacts of an activity (linear-ESG).

Applications of NSCs

The NSCs are versatile and can be applied at micro and macro levels. The examples of potential applications are given below.

SDGs Performance

NSCs serve as a versatile tool, useful for stakeholders ranging from households to nations. This system provides a comprehensive measure of sustainability by integrating the impacts of the Sustainable Development Goals (SDGs) into a standardized framework.

Axes Definition and Grouping of SDGs

X-axis (environmental impacts): includes environmental SDGs:

SDG 6: Clean Water and Sanitation.
SDG 7: Affordable and Clean Energy.

SDG 12: Responsible Consumption and Production.
SDG 13: Climate Action.
SDG 14: Life Below Water.
SDG 15: Life on Land.

Y-axis (socio-economic impacts): includes socio-economic SDGs:

SDG 1: No Poverty.
SDG 2: Zero Hunger.
SDG 3: Good Health and Well-Being.
SDG 4: Quality Education.
SDG 5: Gender Equality.
SDG 8: Decent Work and Economic Growth.
SDG 10: Reduced Inequalities.
SDG 11: Sustainable Cities and Communities.
SDG 16: Peace and Justice Strong Institutions.

Normalization and Calculation of NSCs

Step-by-Step Calculation:

Assessment of impacts: measure progress or shortfall in each SDG, assigning scores based on target achievement.

Normalization: convert scores into a standardized range from −1 to 1:

−1: Significant shortfall from the target.
0: Target met.
+1: Significant excess beyond the target.

Aggregation: combine normalized scores for environmental SDGs to form the X-coordinate and socio-economic SDGs to form the Y-coordinate.

Example calculation: assume a country has the following scores for selected SDGs:

SDG 6 (Clean Water and Sanitation): 0.8.
SDG 13 (Climate Action): −0.4.
SDG 3 (Good Health and Well-being): 0.5.
SDG 8 (Decent Work and Economic Growth): −0.3.

Environmental X-axis: (0.8 for SDG 6 + (−0.4) for SDG 13)/2 = 0.2.
Socio-economic Y-axis: (0.5 for SDG 3 + (−0.3) for SDG 8)/2 = 0.1.

The coordinates (0.2, 0.1) place this country in Quadrant I (Q1), indicating positive impacts on both environmental and socio-economic dimensions, with room for improvement.

Other Hypothetical Use Cases and Versatility of NSCs

Electric Vehicles (EVs) and Solar Energy:

Linear open-loop: (−0.2, −0.5) reflects moderate negative impacts (because of life cycle concerns of solar panels, inverters, and batteries).
Circular: (0.5, −0.3) improved environmental impacts with social challenges (circularity adopted but social and governance concerns remain).
ESG: (−0.2, 0.5) strong social governance, less environmental emphasis (ESG adopted but life cycle concerns not addressed).
Circular-ESG: (0.5, 0.5) positive impacts on both dimensions (life cycle concerns addressed by circularity and social and governance concerns addressed by ESG).

Vehicles:

Linear: (−0.5, −0.5) significant negative impacts.
Circular: (0.2, −0.3) improved environmental practices, ongoing social issues.
ESG: (−0.3, 0.5) positive social, negative environmental impacts.
Circular-ESG: (0.2, 0.5) balanced improvements.

Banks:

Linear: (−0.5, −0.5) negative impacts for traditional banks.
Circular: (0.4, −0.3) improved environmental impacts, ongoing social issues.

ESG: (0.2, 0.5) positive social impacts, less environmental focus.
Circular-ESG: (0.3, 0.3) balanced positive impacts.

Households:

Linear: (−0.3, −0.3) moderate negative impacts.
Circular: (0.5, −0.3) positive environmental impacts, social challenges.
ESG: (−0.3, 0.5) positive social, negative environmental impacts.
Circular-ESG: (0.5, 0.5) positive impacts on both dimensions.

Charities:

Linear: (−0.3, 0.5) positive social, negative environmental impacts (charities have strong social focus but often may ignore environmental concerns).
Circular: (0.5, 0.5) positive impacts on both dimensions.
ESG: (−0.2, 0.7) high positive social impact, less environmental focus.
Circular-ESG: (0.7, 0.7) strong positive impacts (addressing environmental concerns) charities make a significant contribution to humane transition.

Policies:

Linear: (−0.7, −0.7) significant negative impacts (policies have significant influence on incentive systems and institutional quality, both negative and positive).
Circular: (0.6, −0.4) positive environmental, negative social impacts.
ESG: (−0.5, 0.7) high positive social impact, negative environmental impacts.
Circular-ESG: (0.7, 0.7) strong positive impacts (policies addressing socio-economic and environmental concerns in a balanced manner can play a highly positive role in humane transition).

Potential Use of NSCs in Sustainability Studies and Transition

Unified framework: NSCs integrate diverse sustainability aspects into a single, coherent measure.
Enhanced comparability: NSCs offer a consistent and comparable measure across entities and time periods.
Holistic approach: NSCs provide a comprehensive understanding of sustainability impacts and interdependencies.
Dynamic and temporal measurement: continuous tracking and adjustment of sustainability efforts are possible.
Practical applicability: NSCs are designed for real-world application, bridging theory and practice.
Ethical and intergenerational equity: NSCs ensure current sustainability efforts do not compromise future generations' needs.

Regenerative and Degenerative Businesses

Quadrant I (Q1)—Circular-ESG: strong CE practices and ESG integration.
Quadrant II (Q2)—Circular: strong CE practices, weaker ESG integration.
Quadrant III (Q3)—Open-Loop Linear: no CE practices or ESG integration.
Quadrant IV (Q4)—ESG-Open-Loop Linear: strong ESG practices, no CE integration.

Lifecycle Impacts:

Consideration of the entire lifecycle of businesses is crucial for sustainability. Strategies for improvement involve substitution, transformation, and offsets for negative externalities.

Role of Technology and Innovations

Substitution: innovations in materials science and renewable energy are vital for reducing the environmental footprint.
Transformation: technological advancements enable redesigns for enhanced sustainability.
Transition to Q1: continuous technological advancements and innovative solutions are essential for transitioning to Q1.

Strengths of the Cartesian Framework in Sustainability Studies and Transition Management

(a) Multidimensional integration: incorporates both environmental and socio-economic dimensions.
(b) Quantification and precision: allows for precise quantification of sustainability impacts.
(c) Visual representation: offers an intuitive visual representation of sustainability concepts.
(d) Comparative analysis: facilitates easy comparison between entities, strategies, or time periods.
(e) Dynamic tracking: enables dynamic tracking of progress over time.
(f) Flexibility and scalability: can be applied at various scales and contexts.
(g) Goal setting and strategic planning: aids in setting concrete, quantifiable sustainability goals.
(h) Identification of trade-offs and synergies: helps identify potential trade-offs and synergies.
(i) Compatibility with data-driven approaches: aligns with modern data-driven decision-making.
(j) Standardization potential: could standardize sustainability reporting across sectors.
(k) Educational tool: effective for teaching complex sustainability concepts.
(l) Policy formulation aid: assists in assessing policy impacts.
(m) Integration of business models: provides a unique perspective on organizational strategies.
(n) Transition pathway visualization: allows clear visualization of sustainability transitions.

The Cartesian framework and NSCs offer powerful tools for advancing sustainability studies and transition management by providing clear, quantifiable, and visually intuitive representations of complex sustainability concepts.

7. Conclusions

As the timeline for the SDGs approaches its conclusion and the UN marks the current decade as the Decade on Ecosystem Restoration, this research aims to provide a few original insights. We framed the problem by addressing the conflict between the Human Development Index (HDI) and the ecological footprint, focusing on the challenge of achieving higher HDI within the safe boundaries of our planet, a concept we define as the regenerative humane transition.

We undertook a comparative review of the main sustainability models and the related literature and found convergence of purpose but divergence of methods and processes. Since the shared purpose is obtaining sustainable development, there should have been one unified measure of progress in achieving the goal. The non-existence of a unified measure of circularity and ESG and sustainability transition management offers an opportunity to leverage and develop synergies.

The research has tried to suggest a conceptual framework for normalized sustainability coordinates (NSCs) as a dynamic, comprehensive, and unified measure of circularity, ESG, and the sustainability transition. For developing the NSCs, the research utilized a four-quadrant dynamic Cartesian framework. To facilitate sustainable and regenerative business model innovation, we assigned different business models into the four quadrants with their impacts on X natural systems and Y socio-economic systems measured by the NSCs, ranging from -1 to 1.

There is a transition process within and between quadrants. For example, starting as a linear open-loop model ($X < 0$, $Y < 0$), a business can transform to become a linear-ESG model ($X < 0, Y > 0$) and/or a circular closed-loop model ($X > 0$, $Y < 0$), midpoint (0.0), and circular-ESG ($X > 0$, $Y > 0$) as the ideal state of regenerative humane development (RHD).

Anchored by NSCs, the RHD is mathematically optimized first at the general level with financial sustainability as a constraint. Then, at the levels of each quadrant, like $X > 0$, $Y > 0$, $X > 0$, $Y < 0$, $X < 0$, $Y < 0$, $X < 0$, $Y > 0$. In the maximization of RHD, offsets, substitutes, and transformations play critical roles.

Sharing of risks between present and future generations is of critical importance for sustainable development. Traditionally only financial risks are recognized and borne by owners under regulatory surveillance, but other risks like climate, natural capital, and inequality risks are not recognized and unintentionally shifted to future generations. We identified the various risks for sharing between present and future generations.

We offered different use cases to show the relevance and versatility of the NSCs for different cases ranging from SDGs, countries, policies, organizations, businesses, households, and potentially to leadership, technologies, etc. For example, a country might be represented in the Upper Left Quadrant ($Y > 0$, $X < 0$) with coordinates like (0.8, −0.6), indicating strong socio-economic development but significant environmental impacts. A household practicing minimal composting and recycling might fall in the lower left quadrant with coordinates like (−0.4, −0.3). An organization implementing green technologies but lacking strong social policies might be in the lower right quadrant with coordinates like (0.5, −0.2).

The integrated, multidisciplinary, and dynamic framework for anchoring sustainability studies is designed to navigate the complex interplay between economic growth, environmental sustainability, and social equity. This framework is articulated through four key segments, each addressing a vital aspect of sustainable development.

The framework addresses potential criticisms by balancing economic growth with sustainability. It emphasizes innovation and technological advancements as key drivers of sustainable development, countering concerns that ecological limits may restrict economic progress. By showcasing examples where sustainable practices have led to economic benefits, the framework advocates for a transition that enhances long-term resilience, reduces environmental risks, and fosters equitable growth. This approach ensures that sustainability is seen not as a constraint but as an opportunity for innovation and prosperity.

The framework provides a comprehensive roadmap for businesses, organizations, and policymakers to navigate the complexities of sustainable development. It underscores the need for a balanced approach that integrates economic, social, and environmental dimensions, promoting a just transition towards regenerative practices. By setting clear targets and stages, and using a dynamic coordinate system to map impacts, the framework offers a practical tool for achieving high human development within the planet's ecological limits. This holistic perspective encourages continuous improvement and innovation, ensuring that sustainability becomes an integral part of business strategy and societal progress.

Limitations and Future Research Pathways

While this study presents a novel, comprehensive, and dynamic conceptual framework for sustainability studies and transition management, it is important to acknowledge its limitations. Firstly, the Circular-ESG model, while theoretically sound, has not yet been empirically validated on a large scale. The practical application and effectiveness of the framework across diverse real-world scenarios require further testing and refinement.

As the model is currently conceptual, we encourage empirical validation and further research to explore its practical applications and effectiveness in real-world scenarios. While the provided examples of use cases serve as conceptual demonstrations, future research could empirically apply the model to real-world data.

Secondly, the quantification of sustainability impacts into normalized coordinates (−1 to 1) may oversimplify complex sustainability issues. The process of translating multifaceted environmental and social impacts into single numerical values risks losing nuanced information and context-specific factors. However, the limitation can be overcome by using the NSCs and complementing the other available sustainability rubric. For example, NSCs can be used alongside SDGs, GGI, Sis, and ESGs. NSCs can be used to normalize these existing rubrics for comparability in a unified manner.

Thirdly, the framework assumes a linear relationship between positive and negative impacts, which may not always reflect real-world complexities. Some sustainability aspects might have non-linear or threshold effects that are not fully captured by the current model.

The Regenerative Humane Development (RHD) maximization concept, while innovative, requires further development and testing to ensure its practical applicability and effectiveness as an alternative to traditional utility maximization models.

Additionally, the framework's reliance on accurate and comprehensive data for plotting coordinates and tracking progress may be challenging in practice, especially in contexts where sustainability data are limited or unreliable.

Refinement of the Cartesian framework can involve further validating and calibrating the coordinate system across different sectors and scales. Developing standardized metrics for measuring and plotting various sustainability aspects will enhance the framework's precision. Additionally, conducting large-scale empirical studies to test its applicability across diverse industries and geographical regions will provide valuable insights. Analyzing longitudinal data will help assess the model's effectiveness in tracking sustainability transitions over time.

Integration with Existing Tools and Technologies

Investigating how the Cartesian framework can complement or enhance existing sustainability assessment tools like Life Cycle Assessment (LCA) or Environmental, Social, and Governance (ESG) ratings can offer new perspectives and synergies. The potential for integrating this framework with emerging technologies like blockchain for transparent sustainability reporting is also promising. Furthermore, exploring the use of artificial intelligence and machine learning to predict sustainability trajectories based on current coordinates will advance data-driven decision-making processes.

Policy Impact Analysis and Sector-Specific Adaptations

Exploring the framework's potential for assessing the impact of different policy interventions on sustainability outcomes is crucial. Developing case studies on how policymakers can use this tool for evidence-based decision-making will enhance its practical relevance. Tailoring the framework for specific sectors, such as energy, agriculture, and manufacturing, will address unique sustainability challenges and opportunities, providing sector-specific insights.

Stakeholder Engagement and Educational Applications

Studying how different stakeholders, including businesses, governments, and NGOs, interpret and use the framework will shed light on its influence on decision-making processes. Developing educational modules and case studies based on the framework for sustainability education at various levels will enhance its educational value and broaden its impact.

Interdisciplinary Expansion and Dynamic Systems Modeling

Exploring how the framework can bridge gaps between different disciplines in sustainability science will foster more integrated approaches. Incorporating dynamic systems modeling to capture the complex interactions between different sustainability dimensions over time will provide a more comprehensive understanding of sustainability transitions.

Scenario Planning and Cultural Contextual Factors

Utilizing the framework for scenario planning and forecasting future sustainability states under different conditions will enhance strategic planning capabilities. Investigating how cultural and contextual factors influence the interpretation and application of the framework in different global settings will ensure its adaptability and relevance in diverse contexts.

Alignment with SDGs and Comparative Analysis

Exploring how the framework can be aligned with or used to track progress towards the UN Sustainable Development Goals (SDGs) will enhance its strategic relevance. Conducting comparative studies between this Cartesian approach and other sustainability frameworks will identify strengths, weaknesses, and potential synergies, contributing to the ongoing development of sustainability assessment tools.

These future research pathways will help refine, validate, and expand the application of the Cartesian framework in sustainability studies and transition management, enhancing its effectiveness and utility in various contexts.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: This work has benefited from numerous feedback by my students in the MBA course on Sustainability Management at INCEIF University Malaysia, my peers and anonymous reviewers. I thankfully acknowledge their contributions.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. SRC. Planetary Boundaries. Stockholm Resilience Center. 2023. Available online: https://www.stockholmresilience.org/research/planetary-boundaries.html (accessed on 9 August 2024).
2. IPCC. Panel on Climate Change Sixth Assessment Report (AR6). 2023. Available online: https://www.ipcc.ch/report/sixth-assessment-report-cycle/ (accessed on 9 August 2024).
3. United Nations. The Sustainable Development Goals Report 2024. 2024. Available online: https://unstats.un.org/sdgs/report/2024/ (accessed on 9 August 2024).
4. European Union. EU Green Deal. 2024. Available online: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (accessed on 9 August 2024).
5. Principles of Responsible Investment (PRI). Principles for Responsible Investment. Available online: https://www.unpri.org/ (accessed on 9 August 2024).
6. Global Reporting Initiative (GRI). Global Reporting Standards. Available online: https://www.globalreporting.org/standards/ (accessed on 9 August 2024).
7. IFRS Foundation. IFRS Sustainability Standards. Available online: https://www.ifrs.org/issued-standards/ifrs-sustainability-standards-navigator/ (accessed on 9 August 2024).
8. Task Force on Climate-Related Financial Disclosures (TCFD). Climate-Related Financial Disclosures. Available online: https://www.fsb-tcfd.org/ (accessed on 9 August 2024).
9. MSCI ESG. ESG Ratings. Available online: https://www.msci.com/our-solutions/esg-investing/esg-ratings (accessed on 9 August 2024).
10. Ellen MacArthur Foundation. Towards the Circular Economy. 2013. Available online: https://www.ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an (accessed on 9 August 2024).
11. UNDP. Human Development Report 2023–24. 2024. Available online: https://hdr.undp.org/content/human-development-report-2023-24 (accessed on 9 August 2024).
12. Elkington, J. *Green Swans: The Coming Boom in Regenerative Capitalism*; Fast Company Press: New York, NY, USA, 2020.
13. Bolton, P.; Després, M.; de Silva, L.A.P.; Samama, F.; Svartzman, R. The Green Swan: Central banking and financial stability in the age of climate change. *Bank Int. Settl. (BIS)* **2020**, *229*, 1–15.
14. Global Footprint Network. Sustainable Development: HDI and Ecological Footprint. 2024. Available online: https://www.footprintnetwork.org/our-work/sustainable-development/ (accessed on 9 August 2024).
15. Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin, F.S., III; Lambin, E.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; et al. Planetary boundaries: Exploring the safe operating space for humanity. *Ecol. Soc.* **2009**, *14*, 1–33. [CrossRef]
16. Raworth, K. *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist*; Random House Business: London, UK, 2017.
17. Elkington, J. Cannibals with Forks: The Triple Bottom Line of 21st Century Business. *Altern. J.* **1997**, *25*, 42–43. Available online: https://www.sdg.services/uploads/9/9/2/1/9921626/cannibalswithforks.pdf (accessed on 9 August 2024). [CrossRef]
18. UN Global Compact. Who Cares Wins. 2004. Available online: https://www.unepfi.org/fileadmin/events/2004/stocks/who_cares_wins_global_compact_2004.pdf (accessed on 9 August 2024).
19. Stahel, W.R. *The Circular Economy: A User's Guide*, 1st ed.; Routledge: London, UK, 2019. [CrossRef]
20. Stahel, W.R. Product life factor. 1982. Available online: http://product-life.org/en/major-publications/the-product-life-factor (accessed on 9 August 2024).
21. Potting, J.; Hekkert, M.; Worrell, E.; Hanemaaijer, A. *Circular Economy: Measuring Innovation in the Product Chain*; PBL Netherlands Environmental Assessment Agency: Hague, The Netherlands, 2017.
22. Stahel, W.R. The Performance Economy. 1987. Available online: https://www.globe-eu.org/wp-content/uploads/THE_PERFORMANCE_ECONOMY1.pdf (accessed on 9 August 2024).
23. Fiksel, J.R. *Design for Environment: Creating Eco-Efficient Products and Processes*; McGraw-Hill: New York, NY, USA, 1996; ISBN 0070209723.
24. McDonough, W.; Braungart, M. *Cradle to Cradle: Remaking the Way We Make Things*; North Point Press: Berkeley, CA, USA, 2002; ISBN 0-86547-587-3.

25. United Nations Industrial Development Organization (UNIDO). National Circular Economy Roadmaps: A Global Stocktake for 2024. May 2024. Available online: https://www.unido.org/news/1st-study-national-circular-economy-roadmaps-unido-and-chatham-house (accessed on 9 August 2024).
26. Cohen-Shacham, E.; Janzen, C.; Walters, G.M.; Maginnis, S. *Nature-Based Solutions to Address Global Societal Challenges*; IUCN: Gland, Switzerland, 2016. Available online: https://portals.iucn.org/library/sites/library/files/documents/2016-036.pdf (accessed on 9 August 2024).
27. Hawken, P. *Regeneration: Ending the Climate Crisis in One Generation*; Penguin Random House: New York, NY, USA, 2021; ISBN 978-0143136972.
28. Mang, P.; Reed, B. Designing from Place: A Regenerative Framework and Methodology. *Build. Res. Inf.* **2012**, *40*, 23–38. [CrossRef]
29. E&Y. EY Global Integrity Report 2024. 2024. Available online: https://www.ey.com/en_gl/insights/forensic-integrity-services/global-integrity-report (accessed on 9 August 2024).
30. Chichilnisky, G. An Axiomatic Approach to Sustainable Development. 1995. Available online: http://mpra.ub.uni-muenchen.de/8609/ (accessed on 9 August 2024).