Redesigning the Value Chain: A Net-Zero Circular Economy Approach to Resource Retentio

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Abstract

The twin transition to a circular economy (CE) and net zero carbon is necessary yet complex, requiring a holistic set of practices that simultaneously retain resource value and eliminate carbon emissions. However, the literature lacks a unified framework that integrates CE practices aimed at developing resource value retention options (ROs) with net-zero carbon strategies along the value chain. The aim of this study is to propose a theoretical model, the net zero circular value chain model (NZCVCM), which explains how circular value chain practices (CVCPs), enriched with net-zero principles, help to redevelop ROs. The proposed model builds on the 10R classification of ROs (R0-R9) and extends a prior circular value chain framework by embedding renewable energy use, life-cycle emissions tracking, carbon-neutral design, carbon capture and offset, and other climate-focused practices into each stage. This research follows a systematic literature analysis approach to integrate 40 circular value chains and net zero practices identified across eight value chains, six support categories and three net zero categories. The extended model can be used to understand how CE and decarbonization can be codeveloped in the value chain, expanding current theoretical knowledge and helping stakeholders adopt integrated circular carbon strategies, plans, and actions. This study advances a dual objective framework that couples RO development with scope 3 emissions mitigation through energy and materials decarbonization, integrated carbon analytics, thereby extending circular-economy theory toward an integrated circular carbon paradigm. Key findings highlight that (i) every resource retention loop (R0-R9) offers opportunities to reduce or eliminate greenhouse gas emissions; (ii) primary circular practices must be powered by renewable energy and guided by carbon metrics to maximize climate benefits; and (iii) support practices for strategic, organizational, and technological enablers to implement zero-carbon circularity in integration with primary practices. This study provides practical guidance for businesses aiming to simultaneously achieve circular economy and net-zero goals. Policymakers and industry stakeholders can leverage these insights to align sustainability initiatives, drive strategic collaborations, and effectively accelerate the transition to a net-zero circular economy.

Keywords: Circular economy; net zero; net zero circular value chain model; circular net zero practices; resources retention; scope 3 emissions

1. Introduction

Climate change and resource depletion are two paramount challenges confronting global sustainability. To keep global warming below 1.5 °C as called for by the Paris Agreement, greenhouse gas emissions must be reduced by 45% by 2030 and reach net zero by 2050 (Anika et al., 2022). In response, many governments and industries have pledged carbon neutrality, spurring a wave of corporate net-zero strategies across supply chains. However, the world remains only 9%

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circular, meaning that out of 92.8 billion tons of material inputs consumed in 2015, only 8.4 billion tons were reused (Devi et al., 2023). This linear take-make-dispose model not only drives resource scarcity but also contributes heavily to emissions through the constant extraction and processing of raw materials. The extraction and processing of resources are associated with approximately 50% of global greenhouse gas emissions (Zheng et al., 2023). In this context, the circular economy (CE) has emerged as a critical approach to decelerate, narrow and close material and energy loops. Moreover, the value of products, components, and materials should be retained for as long as possible, thereby reducing both waste and emissions (Tomić and Schneider, 2018).

There is a growing recognition that circular solutions are crucial for addressing Scope 3 emissions, which are indirect value chain emissions that often dominate a company's carbon footprint. By decreasing dependence on virgin materials, extending product life cycles, and closing resource loops, CE strategies can significantly reduce the amount of carbon embedded in products and supply chains (Gaustad et al., 2018). Companies are beginning to acknowledge the role of the CE in achieving supply chain decarbonization. Moreover, offering product-as-a-service or sharing models can reduce the total number of products manufactured, thereby reducing upstream emissions, whereas recycling and recovery initiatives can avoid the need for energy-intensive primary production (Patil et al., 2024). However, circularity and carbon neutrality are not automatically aligned: if circular practices, e.g., recycling or remanufacturing, rely on fossil energy and product life extension comes at the cost of energy inefficiency, the net climate benefits erode (Zhuang et al., 2023). Thus, there is a critical need to integrate zero-carbon principles such as renewable energy adoption, low-carbon material sourcing, life-cycle emission tracking, and carbon offsetting into circular value chain practices. This integration ensures that resource value retention options (ROs) are developed in ways that also drive down greenhouse gas emissions across the value chain.

Recent research has systematized how firms can implement CE along their supply chains. Notably, Muller et al., (2022) identified 33 circular value chain practices (CVCPs) and categorized them into 8 primary and 6 support practice categories, illustrating how these practices contribute to developing resource value retention options (ROs) from R0 to R9. These ROs, which are based on the 10R framework of Reike et al. (2018), range from R0 (Refuse) and R1 (Reduce) through R3 (Reuse/Repair) and R5 (Remanufacture) to R9 (Remine), covering progressively longer loops of material recovery. Furthermore, Eisenreich et al. (2022) adapted Porter's value chain to CE, highlighting changes in procurement, production, and recovery. This model detailed stakeholder roles and circular design but do not systematize net-zero energy practices. This issue is urgent because resource-intensive value chains drive a large share of emissions. In fact, around 45% of global GHG emissions cannot be addressed by energy decarbonization alone and tackle through circular-economy strategies (Sturcken, 2023). Without a unified model, firms lack guidance on coordinating material reuse with emission reduction. The circular value chain models demonstrated how various circular practices, e.g., the use of recycled inputs, circular product

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design, reverse logistics, etc., can operationalize these ROs in business contexts. Moreover, it offers product-sharing services to help develop R1 (Reduce) by reducing production, or designing products for easy disassembly facilitates R7 (Recycle) and R8 (Recover energy).

However, a gap remains; the prior models did not explicitly incorporate carbon management practices. Companies looking to achieve both circularity and net-zero targets need guidance on how to simultaneously retain material value and eliminate emissions at each stage of the value chain. This study addresses that gap by proposing a novel theoretical model that fully integrates zero-carbon strategies into circular value chain practices. This study develops an integrated zero-carbon circular value chain model (NZCVCM[1]). To develop the NZCVCM, within this study, we identified forty circular value chains and net zero activities, further classified them into 8 value chains, 5 supporting and three net zero activities, and associated them with 10 ROs, which were examined through a climate mitigation lens. By integrating circular economy loops (R0-R9) with carbon management, NZCVCM fills a critical gap in the literature. In doing so, it provides a significant theoretical advancement by offering a unified framework that embeds net-zero principles into each resource loop. The objective of this study is to ensure that every RO from R0 (refuse) to R9 (remine) is developed in a manner that also contributes to the overarching goal of net zero. By integrating CE and net-zero principles, the model aims to expand theoretical knowledge at the CE climate nexus and provide practical guidance for managers, policy and decision makers, and supply chain partners to coordinate their circular economy initiatives with climate action.

The NZCVCM strengthens prior circular value-chain models in four ways: (i) energy decarbonization circular practices e.g., recycling, remanufacturing are explicitly powered by renewables and electrified equipment to avoid eroding climate benefits; (ii) materials decarbonization procurement and design choices privilege low-embodied-carbon and recycled inputs to narrow loops with minimal upstream emissions; (iii) carbon intelligence life-cycle analytics, real-time dashboards, and RO-mapping connect circular actions to quantified GHG outcomes; and (iv) residuals governance credible removal and offset instruments are reserved for hard-to-abate residues after maximum reduction. These additions transform the model into a dual objective framework of retaining value and reducing carbon and verifiably drives Scope 1-3 decarbonization.

CE recommendations emphasize material value retention, whereas net-zero roadmaps prioritize greenhouse-gas reduction, offering little direction for their joint operationalization at the level of concrete practices and ROs. The proposed NZCVCM addresses this by specifying how practices

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[1]Net-zero carbon is used to denote a state in which residual GHG emissions across Scopes 1-3 is reduced. Zero-carbon is used interchangeably when referring to processes with no direct emissions. Carbon neutrality is used only in contexts where residual emissions are balanced at the organizational or product level during a defined period.

should be structured, powered by low-carbon energy, instrumented with integrated carbon analytics, and governed through explicit decision rules so that verifiable emissions reductions are delivered in concert with value retention, thereby improving managerial decision quality and strengthening the work's theoretical and policy relevance. The NZCVCM organizes value-chain activities , support enablers, and net-zero activities so each practice explicitly develops one or more ROs (R0–R9) and reports its emissions effect through ICA. Figure 3 shows the flow logic across stages; Table 3 details practice-to-RO mappings with net-zero contributions.

The remainder of this paper is structured as follows: Section 2 outlines the research approach used to integrate net-zero principles into the circular value chain model. Section 3 presents the NZCVCM and discusses how primary, support circular and net-zero practices are adapted in a zero-carbon context. Section 4 concludes with key findings, academic and managerial implications, and suggestions for future research on implementing net-zero circular value chains.

2. Materials and methods

This study applied a systematic literature review (SLR) approach to integrate the concepts of the circular economy (CE), resource retention options (ROs), and net-zero practices in the recent literature. The methodology followed the structure of Muller et al. (2022) with refinements to expand the scope and rigor. The process was organized into clear stages: defining research questions, locating and selecting studies, analyzing and synthesizing the evidence, and reporting the results. Each stage is detailed in the subsections below.

2.1. Review protocol and research questions

This study formulates two main research questions (RQs) to guide the review's focus and objectives. These questions focus on CE practices and ROs and net-zero considerations:

RQ1: What circular economy practices are being implemented to retain resource value and simultaneously advance net-zero goals?

RQ2: How do these identified practices contribute to resource value retention and to achieving net-zero outcomes?

These questions establish the scope of the review. RQ1 seeks to identify and catalog the relevant CE practices, including strategies aligned with ROs that also feature in the context of net-zero-carbon or net-zero initiatives. RQ2 seeks to analyze and explain the ways in which those practices support resource retention, e.g., via the 10Rs framework of ROs, and contribute to net-zero objectives such as emissions reduction or carbon neutrality. The RQs ensure that the review is focused on the integration of circularity and decarbonization in corporate practice.

2.2. Database search and keyword strategy

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A comprehensive search strategy was developed to locate relevant studies. The search was conducted in early 2025 via two major academic databases, SCOPUS and Web of Science, which are known for broad coverage and are commonly used in CE, sustainability and net-zero SLRs (Nguyen & Kanbach, 2024; Nguyen & Kanbach, 2024; Mishra et al., 2023).

The search string was refined and extended to include terminology related to net-zero carbon. The search focused on the construct “practices toward a circular economy”, and iterative testing led to the dropping of certain terms, e.g., the abbreviations “CE” and “closed-loop system”, that caused irrelevant results. Our final query combined keywords for circular economy practices with terms capturing the context of climate neutrality. In particular, we included phrases such as “net zero”, “zero carbon”, “carbon neutral”, and related variants, alongside core CE terms such as “circular economy” and “circularity” and strategy descriptors such as “practice”* or *“strateg”**. We avoided generic synonyms that proved too broad; for example, we still excluded the standalone acronym “CE” to prevent the retrieval of irrelevant papers in chemistry/biology contexts. The refined search string thus ensured that the retrieved documents explicitly addressed circular economy practices and zero-carbon or net-zero initiatives in the same context.

Moreover, search queries were executed in both databases, filtering for peer-reviewed journal articles and review document types “Article” or “Review” published in English. As a result of this broad and inclusive search, a total of 1,605 documents were initially identified. This greater number reflects the broader scope, which includes burgeoning net-zero carbon literature alongside circular economy research. Language and document-type restrictions were applied to English-language journal articles to ensure the quality and relevance of the sources. All retrieved references were imported into reference management software, and duplicate records from the two databases were removed before screening.

2.3. Screening and study selection

The study selection followed a multistage filtering process with three screening rounds to progressively narrow the initial set of 1605 documents to the most relevant papers addressing our RQs. Each stage applied specific inclusion/exclusion criteria, as illustrated in Figure 1, which depicts a flow diagram of the SLR steps. To enhance rigor, two reviewers independently conducted each screening stage and then reconciled any differences through discussion, ensuring a reliable and unbiased selection process. The screening proceeded as follows: First, a filter that involves “Title and Abstract” screening was used. We reviewed the titles and abstracts of all identified documents to include studies that clearly had a circular economy or closely related concepts as a central theme and/or explicitly mentioned net-zero/zero-carbon initiatives in a sustainability context (Mishra et al., 2023). Furthermore, we accepted papers focusing on either the CE or net zero (or both), as long as they indicated content on practices or strategies. We excluded papers where these topics were only peripherally mentioned or not a main focus. In practice, this meant filtering out publications where the CE or net zero appeared only incidentally. A study primarily about a chemical process with a passing reference to “circular economy” would be excluded as off-scope. Likewise, papers on highly technical aspects, e.g., material science or biology research, that use “CE” as an abbreviation unrelated to the circular economy were removed. After this first filter, 650 documents remained, indicating that roughly one-third of the initial results were deemed centrally relevant, comparable to the base study’s retention rate. The second filter covers

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"Introduction and Conclusion" screening**,** which involves a closer examination of the remaining papers by reading their introductions and conclusions (Govindan, 2023). This step verified whether each study actually presented at least one practical action or strategy relevant to transitioning toward a circular economy and/or achieving net-zero carbon goals. We included papers that provided concrete practices, case studies, or implementation strategies, e.g., a study might propose reuse and recycling initiatives in a supply chain or adoption of renewable energy for carbon neutrality. We excluded papers that discussed the topics only in general or theoretical terms without identifying any specific practice, as well as those whose scope did not involve implementing CE or decarbonization measures. For example, purely bibliometric analyses of CE literature focusing on publication trends with no mention of practices were excluded at this stage. Similarly, a review about the "circular economy" that only theorizes concepts without highlighting actionable strategies would be dropped. After applying this filter, the set was reduced to approximately 310 documents. These papers all contained at least one explicit CE or net-zero practice or initiative, making them suitable for in-depth review. The third filter involved full-text screening**;** in the final screening stage, we conducted a thorough full-text reading of the 310 remaining articles. Here, we applied more stringent inclusion criteria centered on the context and applicability of the practices. We retained only studies that had a clear enterprise or supply chain perspective on implementing circular or net-zero practices (Okorie et al., 2023). In this context, the article highlights one or more practices that **c**ompanies or industrial value chain actors can adopt. We excluded studies that, even if they discussed CE/net-zero practices, did so purely from a governmental policy perspective or at a consumer behavior level without the involvement of company actions. After full-text evaluation, 257 articles met all the criteria and were approved for review. These constitute the final corpus for analysis, representing the key literature until December 2024 at the integration of the circular economy, resource retention strategies, and net-zero carbon practices. The sequence of identification and filtering steps is summarized in Figure 1, mirroring a PRISMA-style flow diagram of the included studies.

2.4. Data extraction and management

With the final set of 257 articles assembled, we proceeded to perform qualitative content analysis to extract and synthesize relevant data. This stage of the SLR focused on identifying the practices discussed in each paper, categorizing those practices into a coherent framework, and examining how each practice contributes to resource retention (ROs) and net-zero objectives. We used a combination of NVivo 12 software for coding qualitative data and MATLAB for aggregating and organizing coded data, following the approach of the base study. Adopting a mixed inductive deductive coding approach, we ensured that the coding was grounded in the literature data while also guided by an existing conceptual model of circular value chain practices (DeJonckheere et al., 2024).

First, we reviewed each of the 257 articles in depth to identify any described circular economy or net-zero practice a concrete action, initiative, method, or strategy that an organization implements to promote circular resource use or carbon reduction. Whenever an article mentioned a relevant practice, we coded that portion of text in NVivo. Each coded segment was given a descriptive label corresponding to the practice, e.g., "Product design for recyclability", "Use of renewable energy in production", "Industry symbiosis", etc. In doing so, we drew on a formal definition of "practice" to maintain consistency: we considered a practice to be "a professional or specific management

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activity that helps to carry out a process, through one or more techniques or tools (Abbasi and Jaafari, 2018). This definition ensured that we captured actionable activities rather than broad goals.

During coding, similar or synonymous practices from different sources were grouped under a unified code for consistency. If one paper referred to collaborative consumption models and another to product service systems (PSSs), these might be grouped into a broader practice code such as “Adopt sharing/collaborative business models” if they reflect the same concept. We allowed new codes (practices) to emerge from the data (inductive) but also recognized common practices identified in prior research (deductive). This led to a refined list of practice codes without duplication. By the end of this coding process, we identified 40 unique practices. Each practice code was tagged with references to all the articles that mentioned it, and we noted implementations or descriptions for use in the analysis.

Next, the list of coded practices was organized into a set of higher-level categories to structure the findings. We utilized a deductive-inductive categorization procedure. On the deductive side, we were informed by existing frameworks of value chain activities and circular economy models. In particular, we considered the classic Porter’s value chain segmentation (value chain vs. support activities) and recent literature on circular value chains (Kalmykova et al., 2018; Vinante et al., 2021). On the inductive side, we examined the characteristics of the practices themselves that emerged from our coding to see how they naturally cluster. We initially created provisional category labels on the basis of themes in the data through which several practices related to design and innovation were grouped into a potential “circular product design” category and practices related to energy and emissions into a “clean energy and manufacturing efficiency” category. We then refined these categories by aligning them with the two value-chain “views” (linear and circular) mentioned above and incorporating the net-zero dimension.

The resulting categorization scheme is an updated circular value chain model in Figure 2 that reflects both the CE and net-zero practice domains. It distinguishes value chain practice categories that are directly involved in the value chain’s operational processes of creating and retaining value support practices and net-zero categories that enable or enhance the primary processes. The value chain categories in our model include eco-source procurement (ESP), circular eco design (CED), clean manufacturing and efficiency (CPR), green logistics and reverse network (LOG), transparent eco-communication (TEC), circular sales strategies (CSS), life cycle extension services (LES), and waste-to-resource systems (WRS). These are akin to operational steps where circular and low-carbon practices are applied. The support categories include strategy and organizational net-zero vision (SONV), regenerative business models (RBMs), synergistic collaboration systems (SCSs), sustainability skills and engagement (SSE), and green innovation and technological development (GITD). The net-zero activities include renewable energy systems (RESs), integrated carbon analytics (ICAs), and carbon neutrality offsetting (CNO). The set of categories and their descriptions are presented in Table 2. We ensured that each of the coded practices from the literature could be mapped into one of these categories. In cases where a practice seemed to fit multiple areas, we discussed and assigned it to the category representing its core purpose. This structured approach allowed us to translate a wide range of individual practices into a coherent framework for analysis. Notably, by integrating a net-zero perspective into category development, our model extends prior circular value chain frameworks to explicitly include practices such as renewable energy adoption and carbon footprint management as part of support or primary

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activities, which is a novel approach compared with earlier models focused solely on material circularity.

2.5. Linking practices to ROs and net-zero outcomes

Finally, we analyzed how each identified practice contributes to resource value retention and to carbon emission reduction. For the resource retention aspect, we followed the established 10R classification scheme of ROs (from Refuse (R0) through Remanufacture, Repurpose, up to Recover (R9)), as proposed by (Reike et al., 2018). Each practice was examined to determine which of the 10 ROs it enables or supports. The details of ROs is presented in Table 1. This was done by looking at how the practice was described in the source articles. A practice such as the use of biodegradable materials (EPS0103) clearly aligns with R0 (Refuse), R1 (Reduce), R3 (Reuse/Resell), and R7 (Recycle) by avoiding harmful inputs and reducing waste. We also coded these relationships in NVivo, essentially tagging each practice with one or more R# labels on the basis of the content of the articles. However, in many cases, the articles themselves explicitly mention outcomes such as reuse, recycling, and emissions savings. On the net-zero carbon side, we noted any quantitative or qualitative information on emissions reduction associated with the practice, e.g., "solar panels reduced factory CO_2 emissions by X%" or, more generally, whether the practice was cited as part of a company's net-zero strategy. While there is no standardized classification scheme for net-zero contributions akin to the 10R for circularity, we qualitatively assessed how each practice aids in carbon reduction or climate goals. Many circular practices inherently contribute to emissions reduction. For example, energy efficiency directly reduces energy-related emissions, and material recycling often lowers the carbon footprint of production (Min et al., 2022; Vakili et al., 2022); therefore, we captured these links in our analysis grid.

Throughout the analysis, NVivo helped manage the evidence, allowing us to retrieve all excerpts for a given practice or category and see the context, whereas MATLAB was used to compile summary matrix practices vs. categories and practices vs. ROs and to quantify the frequency of certain practices or ROs across the literature. We adopted a deductive-inductive reasoning process in making sense of the data: starting with theoretical expectations, e.g., practices should cover all stages of the value chain and many ROs and then allowing the empirical findings to reveal new insights such as which ROs are most commonly targeted by net-zero related practices. This combined approach ensures a robust synthesis that is grounded in prior knowledge yet open to emergent patterns.

Table 1: Summary of Resources Retention Options (ROs)

RO	Description (Purpose)
Shortest Loops: They are close to the consumer	They are close to the consumer
R0-Refuse	Actively choose not to consume certain products or inputs, thereby preventing waste creation and environmental contamination.
R1-Reduce	Minimize the consumption of resources, products, or inputs to lower overall waste generation and environmental impact.

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R2-Resell/reuse	Directly reuse or resell products or their components for their original purpose without needing significant repairs.
R3-Repair	Perform maintenance or minor fixes to restore products or equipment to their original functionality.
Medium Loops Indirect Consumer Involvement	Typically managed by businesses, these loops have indirect connections to end consumers.
R4-Refurbish	Update products or equipment to improve performance, extending their useful lifespan beyond initial expectations.
R5-Remanufacture	Thoroughly reprocess products or components industrially to return them to their original condition and functionality.
R6-Repurpose	Adapt products or components by changing their original use to serve entirely new purposes or functions.
Long Loops: Traditional Waste Management	Traditional approaches employed in managing waste streams.
R7-Recycle	Process discarded consumer goods or waste products to produce recycled materials; this involves significant material alteration, including organic matter processing.
R8-Recovery (energy)	Extract energy from waste through specialized waste-to-energy technologies.
R9-Re-mine	Retrieve previously discarded resources or waste materials, typically from disposal sites such as landfills, for further usage or processing.

2.6. Reporting and using the results

The results of the SLR are reported in an organized manner to answer RQ1 and RQ2 directly and to facilitate further use of the findings. A visual summary of the review methodology is provided in Figure 1, which depicts the identification, screening, and inclusion steps of the SLR, as adapted for this study. The core findings on identified practices and their categorization are presented in a series of tables for clarity; Table 2 outlines the developed practice categories (value chain, support and net-zero) along with their definitions; Table 2 lists the specific practices identified under each category with illustrative examples from the literature; and Table 3 maps these practices to the ROs (0-9) and indicates any noted net-zero carbon contributions. These tables enable readers to see the breadth of practices and how they fit into the proposed framework and sustainability outcomes.

In addition to the tables, Figure 2 was created to illustrate the integrated circular value chain model emerging from this review. Figure 2 provides a conceptual diagram of how the primary and support practice categories collectively contribute to circular value retention and net-zero objectives along a company's value chain from inputs, design, production, distribution, and use to end-of-life. It visually highlights, for instance, which stages of the value chain are associated with which ROs and where carbon reduction measures interact with circular strategies. Figure 3 complements this

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by offering another analytical visualization of the results, a network or flow diagram linking each practice to the ROs it develops and to any net-zero targets.

All the results are described and discussed in Section 3 of this paper. We answer RQ1 by detailing the catalog of CE practices found, which are structured by the categories, and answer RQ2 by explaining how each practice contributes to resource circularity and carbon neutrality. This structured reporting is intended not only to address the research questions with evidence but also to provide practitioners and researchers with a useful reference. By clearly showing which practices map to which circular strategies and carbon goals, stakeholders can identify opportunities to implement these practices in pursuit of net-zero circular economy objectives. The use of the results is further discussed in Section 3, where we draw implications and suggest how the integrated approach to the CE and net-zero can inform future research and corporate strategy.

The SLR ensures transparency, reproducibility, and depth of analysis, laying a solid foundation for the results presented next. All data extraction and synthesis steps were carefully documented with coding records in NVivo and tabulations in MATLAB. This study aims to provide a rigorous and comprehensive review of the literature at the nexus of the circular economy, resource retention, and net zero until December 2024. Figure 2 differentiates primary, support, and net-zero activities by color hue, and draws thicker loop arrows to signal carbon benefit per cycle.

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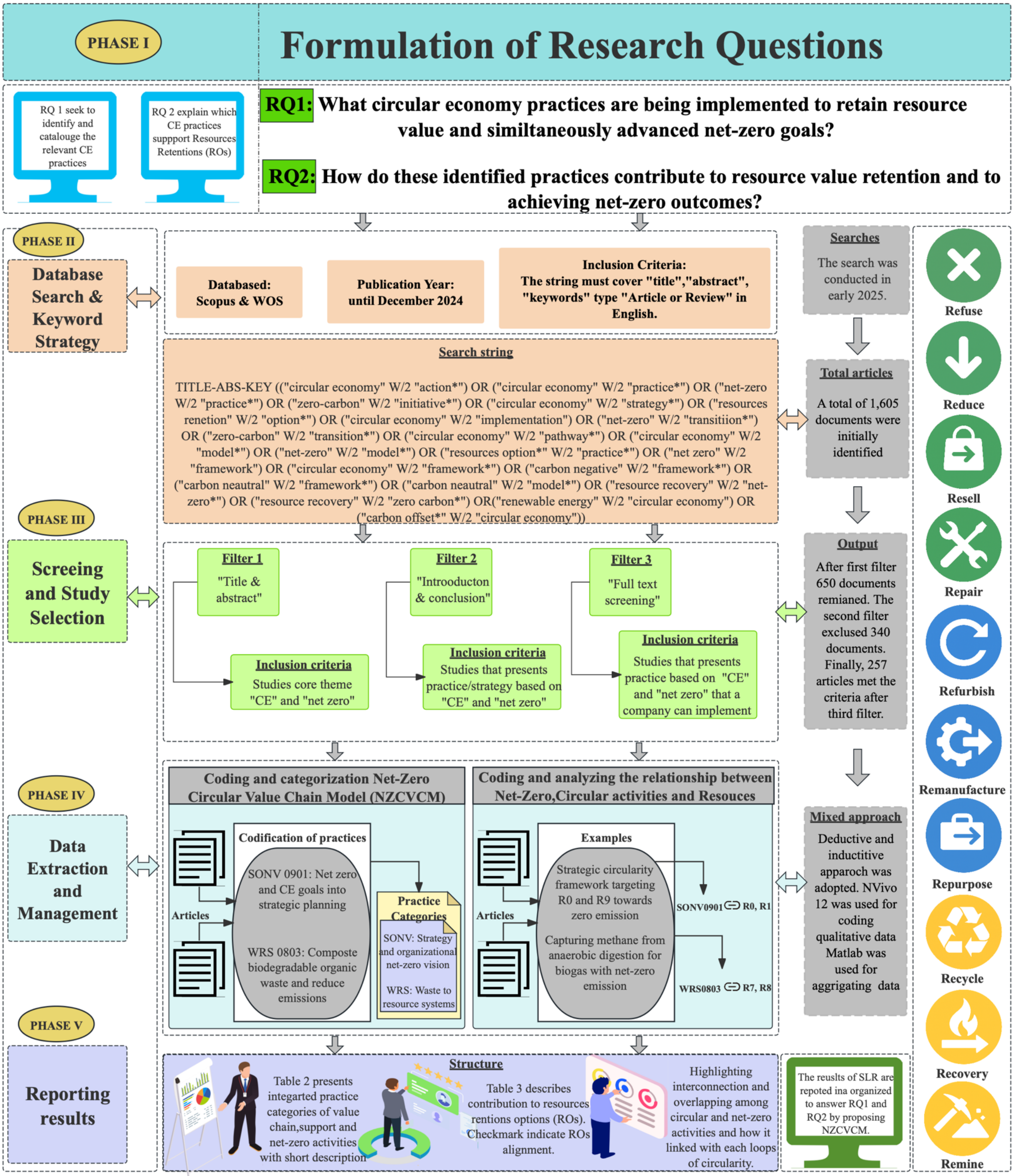

Figure 1: Systematic literaure review of net-zero circular value chain

3. Results and Discussion

NZCVCM systematically maps each circular practice to one or more R-loops (R0-R9) and simultaneously quantifies its carbon impact. In this way, every ROs is explicitly linked to a net-zero strategy, ensuring no loop is overlooked. This section explains the integration of net zero cirular value chain activities along with the ROs.

3.1. Net zero activities-A system catalyst

This study identified a total of 40 net zero circular value chain practices, which are presented in Table 2 and are distributed into eight primary activities, six support and three net zero categories. These practices range across the entire value chain, from product design to end-of-life management, and collectively, they develop all ten ROs. In the NZCVCM, each practice is now viewed through a dual lens: how it retains material value and how it reduces or eliminates carbon emissions. In the subsections below, we describe each primary practice category (Section 3.1.1) and support practice category (Section 3.1.2) and explain how its implementation can develop specific ROs (R0-R9) while also fulfilling zero-carbon principles. Table 2 provides a detailed description of these integrated practices.

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Table 2: Net zero circular value chain practice (NZCVCM) activities

Category (Code)	**Description (Circular Focus)**	**Zero-Carbon Adaptation**
Value chain Activities		
Eco-Source Procurement (ESP)	Sourcing and utilizing inputs that enable circularity (e.g. recycled or biobased materials). .	Prioritize low-carbon inputs: procure renewable energy (e.g. electricity from solar/wind) and materials with low embodied carbon. Refuse inputs that are nonrenewable or carbon-intensive (aligns with R0). Example: choosing organic or recycled raw materials to avoid GHG emissions from virgin production.
Circular Eco Design (CED)	Designing products and services for circular use cycles dematerialization, modularity, easy repair, upgrade, disassembly.	Embed carbon-neutral design principles: minimize material usage (lightweighting) to reduce emissions (R1), select sustainable materials (e.g. recycled polymers, biomaterials) to cut embodied carbon, and design for energy efficiency in the use phase. Ensure products can be powered by renewables where applicable (e.g. electric devices compatible with green energy).
Clean Manufacturing & Efficiency (CPR)	Implementing cleaner manufacturing processes with minimal waste/pollution, including efficient resource use and pollution control.	Transition to zero-carbon operations: use renewable energy or green fuels in production facilities (develops R0 by refusing fossil energy), improve energy efficiency to reduce GHG emissions (R1), and implement carbon capture technologies for any residual process emissions. For example, a plant might use solar power and capture CO_2 from flue gases for reuse, combining waste reduction with emissions elimination.
Green Logistics and Reverse Network (LOG)	Managing distribution and reverse logistics to enable return, reuse, or recycling of products and materials. .	Decarbonize logistics while closing loops: optimize transport routes and loads to cut fuel use (R1), switch to electric or biofuel-powered vehicles for forward and reverse logistics to reduce emissions, and design reverse logistics networks that backhaul used products efficiently (facilitating R3/R7 by returning items for reuse or recycling). Any necessary transportation emissions can be offset via credible carbon offsets (as a last resort) to achieve net-zero transport.
Transparent Eco-Communication (TEC)	Communicating circular offerings and principles to stakeholders;	Emphasize carbon transparency and education in marketing: disclose product carbon footprints and the emissions saved through circular features (e.g. "This remanufactured product saves X kg CO_2 vs new"),

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	raising awareness and acceptance of circular products.	run campaigns linking circular consumption with climate action. By informing and incentivizing consumers to choose low-carbon, circular options, MKC supports R0 (refusing unsustainable options) and R2 (reuse) by shaping demand for greener products.
Circular Sales Strategies (CSS)	Developing markets for circular products/services (e.g. engaging customers in take-back, leasing, sharing models). .	Integrate carbon-neutral value propositions: highlight cost savings from energy-efficient circular products, offer carbon-neutral product lines (through design and offsets), and use carbon labeling in sales. Marketing strategies should target environmentally conscious consumers and demonstrate how circular products meet needs with a lower carbon footprint. For instance, a sales program might offer trade-in for old products (facilitating R2/R5 reuse/remanufacture) and promote the fact that refurbishing an item emits significantly less CO_2 than making a new one.
Life Cycle Extension Services (LES)	Providing services that extend product life and performance (maintenance, repair, upgrades, warranties). .	Leverage after-sales for both longevity and efficiency: maintenance and repair services ensure products operate optimally, thereby reducing energy use and emissions during use (R1, R3). Upgrade programs can retrofit older equipment with more energy-efficient components (combining R4 refurbish with carbon reduction). By extending lifetimes (R3/R4) and maintaining energy efficiency, after-sales services prevent premature disposal and avoid the manufacturing of new replacements (saving the associated emissions).
Waste to Resources Systems (WRS)	Treating waste to recover materials or energy (recycling, composting, remanufacturing, energy recovery from waste). .	Implement low-carbon waste management: run recycling plants on renewable energy to minimize processing emissions and utilize waste-to-energy in a climate-positive way (e.g. capture methane from anaerobic digestion of organic waste for biogas, contributing to R8 Recover with net-zero emissions). For thermal treatments (incineration), employ carbon capture on exhaust to prevent CO_2 release, aligning even waste-to-energy with net-zero goals. This category supports R7 (recycle) and R8 (energy recovery) while ensuring those activities do not emit unchecked carbon. For instance, a cement producer coprocessing waste fuels would invest in CCS to neutralize associated CO_2.
Support Activities		

Strategy and Organizational Net-Zero Vision. (SONV)	High-level commitment, culture, and decision-making aligning the company with CE principles. .	Embed carbon-neutral vision into corporate strategy alongside circularity. Companies should set explicit net-zero targets and integrate them with circular economy goals in their mission and culture. For example, include both ROs and carbon KPIs in strategic planning. Use decision-support tools like Life Cycle Assessment (LCA) to evaluate both resource and carbon impacts of decisions. Digital sustainability systems (e.g. blockchain traceability of materials) can be adopted to monitor carbon and circular metrics across the value chain. In essence, SOV now entails an integrated (circular+carbon) strategic framework, ensuring that initiatives targeting R0-R9 also steer the firm toward zero emissions.
Regenerative Business Models (RBM)	Innovating business models to retain ownership of products, encourage reuse, sharing, and resource efficiency (e.g. Product-Service Systems, PSS). .	Develop business models for net-zero circularity: e.g. PSS models not only encourage maximal utilization of products (supporting R1 Reduce and R2 Reuse by reducing new production) but also allow companies to control the product's energy use and end-of-life. Firms can design PSS offerings (leasing, sharing) where they power operations with renewables and manage product take-back for remanufacture/recycling (R5, R7). Sharing platforms (car-sharing, tool libraries, etc.) directly cut the total number of products needed in society, translating to avoided manufacturing emissions. In CBM, incorporate internal carbon pricing into business cases to favor low-carbon circular options, and explore models like carbon credit generation from circular activities (e.g. selling scrap for reuse could earn credits for avoided emissions).
Synergistic Collaboration systems (SCS)	Collaboration across companies and industries to use each other's byproducts, share resources, or jointly develop circular solutions. .	Extend cooperation to carbon synergy: in industrial symbiosis networks, share not only materials but also energy and carbon streams. For instance, waste heat or biogas from one process is used by a nearby facility (reducing fossil fuel use for both, supporting R8), or captured CO_2 from one plant is supplied to another (e.g. for use in carbonation processes or as feedstock), effectively "recycling" carbon. Such collaborations can significantly cut net emissions while closing material loops. Additionally, companies can partner with renewable

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		energy providers or participate in collective renewable projects (like a solar farm consortium) to decarbonize their shared supply chains. CIS thus amplifies R2 (reuse), R7 (recycle), R8 (recover) by leveraging network-wide solutions that are optimized for minimal carbon footprint.
Sustainability Skills & Engagement (SSE)	Educating and motivating employees and stakeholders on CE practices; developing skills for circular initiatives. .	Broaden training to cover climate literacy and carbon management as integral to circular economy education. Employees should learn not only how to implement ROs (refusal, reuse, recycling, etc.) but also techniques for energy conservation, carbon accounting, and sustainable innovation. For example, training maintenance staff in energy-efficient operations (supporting R1), or educating procurement teams on evaluating suppliers' carbon footprints (contributing to R0 by refusing high-carbon inputs). By building a workforce committed to both circularity and decarbonization, companies ensure smoother adoption of NZCVCM practices. Incentive and reward programs (e.g. recognition for achieving waste and emissions reduction targets) foster a culture that values resource efficiency and climate action.
Green Innovation and Technological Development (GITD)	Developing new technologies and innovations to enable circular strategies (advanced recycling, remanufacturing tech, digital tools, etc.) .	Direct R&D toward low-carbon circular tech: research new processes that both save resources and cut emissions. For example, innovate recycling processes that use less energy or capture byproduct gases, develop biodegradable materials that sequester carbon, or create modular product designs that are easier to refurbish and use low-carbon components. Müller et al. noted that CE "demands innovations that avoid and/or reduce harmful emissions and the consumption of resources" in NZCVCM this dual aim is explicit. Specific emphasis is on technologies like green chemistry for safer materials, clean energy tech (e.g. improved energy storage enabling more renewable use), and carbon capture & utilization methods that turn CO_2 into valuable products (closing the carbon loop). For instance, R&D may focus on improving remanufacturing techniques for electric vehicle batteries (developing R5) with minimal energy use and exploring second-life applications that defer new production and associated emissions.
Net-Zero Activities		

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Renewable Energy Systems (RES)	Integrating renewable energy solutions across company operations, reducing dependence on fossil fuels, and enhancing energy self-sufficiency. Supports circular strategies by providing sustainable energy inputs essential for resource loops and minimizing environmental impacts.	Deploy on-site or off-site renewable energy projects (e.g., solar PV, wind, bioenergy) to replace fossil energy sources. Implement energy storage solutions to stabilize renewable supply, ensuring a continuous zero-carbon energy supply, crucial for maintaining circular economy operations with minimal emissions.
Integrated Carbon Analytics (ICA)	Comprehensive and systematic measurement, tracking, and analysis of carbon footprints throughout the product lifecycle. Aligns carbon assessment with circular economy strategies, enabling transparent management of resource efficiency and emissions reductions.	Comprehensive and systematic measurement, tracking, and analysis of carbon footprints throughout the product lifecycle. Aligns carbon assessment with circular economy strategies, enabling transparent management of resource efficiency and emissions reductions.
Carbon Neutrality Offsetting (CNO)	Utilizing carbon offset programs to compensate for unavoidable residual emissions after maximum implementation of circular and renewable strategies. Offsets should complement direct emissions reduction measures, ensuring holistic environmental management within circular economy frameworks.	Utilizing carbon offset programs to compensate for unavoidable residual emissions after maximum implementation of circular and renewable strategies. Offsets should complement direct emissions reduction measures, ensuring holistic environmental management within circular economy frameworks.

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3.2. Value Chain Activities- Circular practices with net-zero adaptations

The value chain activity categories constitute the core operational activities of a firm's value chain from the sourcing of inputs through production to customer delivery and end-of-life recovery. In the NZCVCM, the primary categories are leveraged to drive carbon reduction at each stage. Below, we discuss each value chain category Eco-Source Procurement through Waste to Resources Systems in detail, highlighting how its practices contribute to specific ROs and how zero-carbon principles are incorporated:

3.2.1. Eco-Source Procurement (ESP)

This category involves selecting and utilizing input materials and energy in a circular-friendly way, for instance, using recycled raw materials, biobased inputs, or sustainably sourced components. To integrate zero-carbon objectives, firms implementing ESP practices now emphatically refuse inputs with high carbon intensity aligned with the R0 Refuse and seek circular, low-carbon alternatives (Osei-Kyei et al., 2024). A key practice is sourcing renewable resources in which companies can purchase renewable electricity for their operations and favor materials produced with green energy (Petrovich & Kubli, 2023). Muller et al. (2024) recommended using sustainable energy sources and biodegradable materials to avoid non-renewables, which avoids not only unsustainable resource use but also the substantial CO_2 emissions tied to fossil-based inputs. By using materials of plant origin to replace fossil resources, firms can reduce pollutant emissions, waste generation and energy consumption in production (Sikiru et al., 2024). Thus, ESP practices develop R0 (Refuse) by eliminating harmful, carbon-heavy inputs (e.g., phasing out coal-based electricity, virgin plastic made from petroleum) and R1 (Reduce) by reducing overall input and energy needs. They also support R2 (Reuse) and R3 (Repair) indirectly by choosing durable, reusable inputs and spare parts and R7 (Recycle) by utilizing recycled content. Moreover, an electronics manufacturer may shift to aluminum and plastic, which is 100% recycled content (reducing mining and refining emissions), and power its facilities with solar energy; this practice yields a lower carbon footprint per product while contributing to circular material loops (R7) (Liu et al., 2023).

3.2.2. Circular Eco Design (CED)

The design phase is critical for embedding both circularity and carbon neutrality into a product's lifecycle. CED practices involve designing products for longevity, reparability, modular upgrading, dematerialization (providing utility with fewer materials), and end-of-life recoverability. These practices directly develop several ROs, e.g., designing for durability and easy fix (supports R3 Repair and R4 Refurbish), modularity for upgrades (R4/R5), design for disassembly and recyclability (R7), and even "virtualizing" products into services (which can support R0 Refuse by avoiding making a physical product at all). To integrate zero-carbon principles, designers must additionally prioritize low-carbon materials and energy efficiency. One key practice is

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dematerialization, which has already been highlighted as reducing material input (thus reducing R0/R1); this also reduces the embedded emissions of production proportionally. Another practice is designing for energy efficiency in use: since a product's use phase can contribute significantly to its carbon footprint (for example, appliances or vehicles), CED should include setting ambitious energy performance targets and ensuring compatibility with renewable energy (e.g., designing an appliance that can smartly schedule its operation when renewable electricity is available). Moreover, selecting materials with a lower embodied carbon, such as recycled metals, bioplastics, or components manufactured with green energy, means that even if the product eventually enters a reuse or recycle loop, its initial carbon investment is lower. Thus, the CED in the NZCVCM concurrently advances ROs such as R2 (Reuse), R6 (Repurpose), and R7 (Recycle) and ensures that each design decision contributes to a smaller carbon footprint over the product's life. Design standards can incorporate carbon criteria alongside circular criteria, for example, an internal guideline that any new product must not only be 100% recyclable and modular (circular criteria) but also achieve, for example, a 50% lower life-cycle CO_2 footprint than the item it replaces (carbon criteria). Through such integrated design requirements, CED practices have become a powerful driver of both circular economy outcomes and climate mitigation.

3.2.3. Clean Manufacturing & Efficiency (CPR)

Cleaner production refers to manufacturing processes that are resource efficient, nonpolluting, and generate minimal waste (B. F. Giannetti et al., 2020). In the circular context, CPR practices include adopting technologies and methods that reduce virgin resource consumption and avoid harmful emissions or effluents during production (Biagio F. Giannetti et al., 2023). These practices naturally support R0 and R1 by reducing input use and waste at the source and R7/R8 by implementing onsite recycling or energy recovery for any waste that is generated. Moreover, CPR might involve using closed-loop water systems, converting process waste into input for another process, or optimizing production to extend tool life and reduce scrap (Roy et al., 2019). When aligned with zero-carbon goals, cleaner production must also mean carbon-neutral production. This entails a few key strategies: (i) electrification and renewable energy: wherever possible, shift production machinery from fossil fuel use to electricity (for instance, electric heat pumps instead of gas boilers) and supply that electricity from renewable sources (solar panels onsite or renewable energy certificates). By doing so, the manufacturing process develops R0 (Refuse) in this case, which refuses fossil-based energy inputs, and R1 (Reduce), which reduces greenhouse emissions and energy waste. (ii) Energy efficiency and process optimization: Improving energy efficiency (through lean techniques, waste heat recovery, better insulation, etc.) not only reduces energy costs but also directly cuts emissions (R1). Many cleaner production initiatives overlap with energy efficiency; under NZCVCM, they gain added importance for meeting carbon targets. (iii) Pollution control and carbon capture: traditional cleaner production would install filters or treatment for pollutants; the extended model would also consider carbon capture and storage/utilization (CCS/CCU) for processes that inherently produce CO_2 (e.g., cement kilns, steel furnaces).

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Capturing CO_2 and either storing it or recycling it (as an input for chemicals or aggregates) aligns with R9 (remine) conceptually, it is recovering value from what would waste carbon emissions. As a result, CPR practices support ROs such as R0 (by avoiding unsustainable inputs such as coal energy), R1 (by cutting energy use and emissions), R2 (if process waste is reused internally), R7 (if scrap is recycled onsite), and R8 (if energy is recovered), all while moving the manufacturing stage toward climate neutrality.

3.2.4. Green Logistics and Reverse Network (LOG)

The logistics category encompasses forward logistics, distribution to customers and reverse logistics return flows for repair, reuse, and recycling. In circular value chains, logistics is crucial for enabling ROs beyond the point of sale, e.g., collection networks for used products facilitate R2 (Reuse), R5 (Remanufacture), and R7 (Recycle) (R. K. Singh, 2024). Integrating zero carbon into logistics operations decarbonizes and closes the loop. Transport is a major source of CO_2 emissions in most supply chains, so LOG practices must aim to minimize and offset those emissions. Key approaches include the following: (i) The optimization of transport, the use of route planning software, the maximization of truck load capacity, and the implementation of circular inventory strategies that position goods closer to users can reduce the total number of miles traveled (the development of R1 can be reduced by reducing unnecessary transport and fuel consumption). (ii) Green transport modes shifting from roads to rails or ships where feasible, using electric vehicles (EVs) or fuel cell trucks for deliveries, and incorporating bicycle couriers or other low-carbon last-mile methods in urban areas. For example, a company might use electric vans to collect e-waste from consumers for recycling, ensuring that the collection (which supports R7) does not itself generate emissions (Erdem, 2022). (iii) Backhauling and integration combine forward and reverse logistics so that delivery trucks carry returns on the way back improving efficiency and link with other companies to share transport resources (part of CIS cooperation but implemented in logistics). (iv) Carbon-neutral warehousing ensures that warehouses or distribution centers are powered by renewables and use energy-efficient systems (lighting, HVAC) since storage is part of logistics. In doing so, LOG practices contribute to ROs such as R2 (ensuring that products can be reused via efficient returns), R4/R5 (by retrieving items for refurbishing/remanufacturing), R7 (collecting recyclables), and R8 (transporting waste to energy recovery facilities), all of which are executed with an eye toward minimizing the carbon footprint of these logistics' activities.

3.2.5 Transparent Eco-communication (TEC)

This category involves outward communication, awareness-building, and education efforts to promote circular value chain practices among consumers, business partners, and society at large. Effective TEC can help overcome societal biases against secondary or used products (a known barrier in CE) and can stimulate demand for circular offerings (Opferkuch et al., 2023). Firms showcase success stories of product-life extension or recycling (to build trust in the R3 and R7 loops) or engage in educational campaigns about composting organic waste (related to R8). In the

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zero-carbon extension, TEC also carries the responsibility of communicating climate action as intertwined with circular action. Firms should transparently convey their carbon-neutral efforts and how those tie into their circular products/services (Chou et al., 2023). This involves eco-labels that indicate not only recyclability but also carbon neutrality, which is certified for products, or marketing content that highlights the emissions saved through a product's reuse. Moreover, an appliance retailer promoting refurbished appliances can inform customers that choosing a refurbished item over a new item avoids X kg of CO_2 emissions, in addition to saving materials. Disclosing climate impact has become increasingly important as consumers and investors seek accountability for emissions across the value chain (Zou & Zhong, 2022). TEC practices, therefore, develop ROs such as R0 and R1 by persuading customers to refuse overconsumption and reduce demand for linear products in favor of circular, low-carbon alternatives. They also support R2, R3, R5, and R7 by improving the acceptance of reused, repaired, remanufactured, and recycled products, and each of those ROs has carbon benefits.

3.2.5 Circular sales strategies (CSS)

While closely related to TEC, the CSS category is more oriented toward market analysis, customer engagement, and facilitating the actual transaction of circular products or services. CSS practices include analyzing consumer markets for circular offerings and implementing strategies that take-back incentives or subscription models to sell circular solutions (Bocken & Ritala, 2022). In the NZCVCM, the CSS integrates carbon considerations into the customer value proposition and sales process. One aspect is market segmentation and targeting: understanding which customer segments prioritize low-carbon products and tailoring circular offerings to them (Koide et al., 2022). Moreover, a segment of eco-conscious consumers might be especially receptive to a furniture company's leasing service for refurbished furniture if it is marketed as climate-positive furniture. Market research can reveal consumer willingness to pay for carbon-neutral certified goods, which can inform the pricing of circular options. Another aspect is developing sales programs that incentivize returns and low-carbon choices; offering discounts on new (or refurbished) items if the customer returns an old product for recycling (thus feeding R7), such a program can be framed around carbon savings, with the company offering an added carbon offset credit to the customer as part of the deal. CSS can also involve partnerships with retailers to set up dedicated green and circular sections or online filters that highlight products meeting certain circular and carbon criteria. By making circular, low-carbon products more visible and accessible, sales volume for those options can increase. For example, Patagonia's Worn Wear program not only sells used garments (circular) but also appeals to customers by emphasizing the environmental impact avoided; Patagonia's marketing frequently quantifies water, waste, and carbon saved (Michel et al., 2019). Moreover, CSS practices drive ROs by cultivating demand and facilitating transactions for circular products and drive carbon goals by positioning those products as solutions to climate concerns. The outcome is a growing market share for offerings that are both circular and

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carbon neutral, which financially reinforces the company's shift toward NZCVCM implementation.

3.2.6 Life cycle extension services (LESs)

After-sales services include maintenance, repair, spare parts management, product take-back, and warranty programs aimed at prolonging product life and ensuring customer satisfaction in the use of circular products. In the CE, strong after-sales service is a pillar of keeping products at their highest utility, which supports R3 Repair, R4 Refurbish, and indirectly R2 Reuse by enabling secondhand use with confidence. Offering maintenance services or extended warranties encourages customers to repair rather than discard products, and take-back services allow companies to recover products for refurbishment or recycling (Richter et al., 2023). By integrating zero-carbon principles, after-sales activities can also be designed to minimize emissions during the use and end-of-use phases of products (Tu et al., 2023). One key element is ensuring energy-efficient operation: service technicians can optimize appliances, vehicles, or machines so that they consume minimal energy, which reduces operational emissions (a contribution to R1 by reducing wasteful energy use). Another element is upgrading and retrofitting services rather than replacing an entire product; companies can offer to upgrade components to newer, more efficient versions, for instance, upgrading an older LED lighting system with next-generation LEDs that produce more lumens per watt. This aligns with R4 (Refurbish) or R6 (Repurpose) if the upgrade repurposes the product for new requirements, and it directly cuts carbon output by improving performance without a full reinvestment of manufacturing emissions. After-sales teams can also collect data on product usage to advise customers on how to use the product in the most sustainable (low-energy) manner, essentially acting as consultants for reducing scope 3 (customer-use) emissions (Li et al., 2023). When products do reach end-of-life or obsolescence, after-sales management of take-back ensures that they are routed into the proper circular loop (R5 remanufacturing, if possible, R7 recycling if not) under controlled conditions. From a carbon perspective, having the manufacturer handle end-of-life often results in higher material recovery and proper recycling, which can avoid emissions.

3.2.7 Waste-to-Resources Systems (WRS)

This final primary category addresses how any waste materials are processed to retain value through recycling (material recovery), composting or bioprocessing, and energy recovery, e.g., biogas and incineration with energy capture. In a fully circular system, waste is minimized when whatever is generated is seen as a resource for something else (Cobo et al., 2018). WRS practices develop R7 (Recycle) by turning waste into secondary raw materials, R8 (Recover) by extracting energy or nutrients from residual waste, and can even enable R9 (Remine) if they involve retrieving materials from older waste deposits (Tomić & Schneider, 2020). Zero-carbon integration in the WRS focuses on performing these recovery processes in a way that maximizes GHG mitigation. Several strategies have come into play: (i) Power recycling with renewables, recycling processes

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(sorting, shredding, remelting) and waste treatment plants can be heavy energy users. Powering them with renewable electricity or low-carbon energy sources ensures that the net benefit of recycling (versus producing new material) remains high in terms of carbon savings. For example, if an aluminum recycling plant uses 100% hydroelectric power, its product has an extremely low carbon footprint, far lower than that of primary aluminum smelter with fossil electricity. (ii) Capture emissions from waste decomposition or combustion; landfills emit methane (a potent GHG), and incineration emits CO_2. The WRS in the NZCVCM includes technologies to capture landfill gas (LFG) and use it for energy (which both generates renewable energy and prevents methane release) and to capture CO_2 from incinerators or cement kilns that use waste as fuel. By doing so, even the last-resort recovery processes align with net-zero ambitions. A municipal waste incinerator might install a carbon capture unit so that, as it produces energy from burning waste (R8), it does not emit CO_2 into the atmosphere (Pour et al., 2018). (iii) Prefer recycling and biobased recovery to incineration. From a carbon perspective, material recycling often avoids more emissions than energy recovery provides, especially if the energy is replacing natural gas or biomass rather than coal. Thus, the WRS strategy should prioritize recycling loops (R7) over incineration (R8) unless energy recovery has clear benefits and is cleaned with CCS. Furthermore, composting or anaerobic digestion of organic waste can be framed as a carbon-friendly WRS compost that sequesters some carbon in soil, and anaerobic digestion yields biogas (renewable energy) plus digestate (fertilizer), both of which are associated with circular carbon cycles (Cucina, 2023). (iv) one advanced concept is actively mining landfills or industrial waste piles for materials (RO-R9 Remine). Doing so can recover metals or plastics that were disposed of decades ago and remediate environmental risks.

3.3 Support practices- Organizational and Technological Enablers

Support practice categories provide the organizational, financial, and informational foundation that enables the primary practices to be implemented effectively. They are more strategic or crosscutting in nature and include company culture, business model innovation, partnerships, human resources, and R&D. Support CVCPs have an indirect yet crucial role in ensuring that the primary operational changes are feasible and sustained. Below, we outline each support category and how it is adapted to reinforce the integrated circular carbon model.

3.2.5 Strategy and Organizational Net-Zero Vision (SONV)

This support category entails the incorporation of circular economy principles into companies' high-level strategy, culture, and decision-making criteria. It includes leadership commitment, setting goals for circular performance, and aligning the company's vision and values with resource circularity. (Ananya Das & Ghosh, 2023) In ZNCVCM, the organizational vision explicitly expands to circular and carbon neutral. Firms formulate a unified sustainability vision that valorizes ROs and commits to science-based climate targets. A firm embeds in its mission statement the goal of maximizing resource circularity (R0--R9) while achieving net-zero emissions

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(Jenkins et al., 2021). In practice, when developing corporate strategies or new projects, circular metrics such as the recycling rate, % recycled content, product longevity and carbon metrics, e.g., CO_2 emissions per product and total carbon footprint reduction, are considered key performance indicators (KPIs) (V. Singh & Paposa, 2025). As part of the SONV, firms establish internal programs and policies, such as a green procurement policy that mandates a preference for circular and low-carbon suppliers affecting ESPs or a policy in which all new product development must comply with eco-design and carbon footprint standards (affecting CED). Cultural change initiatives are also critical: employees at all levels should understand and buy into the idea that circular economy efforts are part of the company's climate responsibility (Ozkan et al., 2023). Decision-support methods are another facet of the SONV. Tools such as life cycle assessment (LCA) and material flow analysis (MFA) are used to evaluate options on the basis of ROs; in the NZCVCM, these tools can also be calibrated to evaluate carbon impacts. For example, LCA can be used to assess how a change in material might reduce virgin material use and reduce carbon emissions, or MFA can be used to track not only material flows but also associated emission flows through the system (Na et al., 2024). Adopting such methods helps quantify the trade-offs and synergies between resource and carbon goals, thus guiding evidence-based strategic decisions.

3.3.2 Regenerative business models (RBM)

This category captures how companies innovate their business models to support circular economy principles moving from selling products to selling services such as PSS; implementing rental, leasing, or sharing models; and other models that incentivize resource retention over sales volume (Konietzko et al., 2023). These business model innovations are key to unlocking ROs such as R1 (reducing) PSS, which can reduce the need for customers to own seldom-used products; R2 (reusing) products, which are returned for reuse in service loops; and R4-R8, as companies maintain ownership, which they plan for maintenance, refurbishment, recycling and even energy recovery of their products. In the context of the NZCVCM, business model innovation should focus equally on monetizing low-carbon solutions and aligning profit incentives with emissions reduction. PSS, by its nature, often leads to emissions reduction: for instance, a car-sharing service results in fewer cars manufactured per capita and potentially fewer driven miles, cutting emissions from manufacturing and use. By adopting PSS models, companies have a direct financial motive to make products last longer and operate efficiently, which aligns with reducing carbon emissions from production and use (Xiang et al., 2023). Moreover, a performance contracting model a type of PSS, where a provider sells a function such as heating as a service rather than a boiler, motivates the provider to install the most energy-efficient, low-carbon system possible to deliver heat at the lowest cost, benefiting both circularity longer-lasting, upgradable equipment and carbon outcomes such as lower energy use, possibly integrating renewable heat sources. The RBV also includes collaborative consumption models, sharing, and peer-to-peer renting, which inherently reduce the total number of products needed (R1) and can be optimized for carbon (Ankita Das & Bocken, 2024). Thus, CBM practices support a wide range of ROs (from R1 through R8) and create a profit

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motive for circular and carbon reduction activities. The net effect is that the business model itself becomes a driver for achieving the NZCVCM goals: profit and purpose are aligned such that providing customer value inherently involves keeping resources in use and cutting emissions.

3.3.3 Synergistic Collaboration systems (SCSs)

Cooperation refers to partnerships and collaborations along or across supply chains, and industrial symbiosis specifically involves the exchange of materials, energy, water, or byproducts between different processes or companies so that waste from one becomes input for another (Aarikka-Stenroos et al., 2022). Such cooperative approaches are fundamental to a circular economy because no single company can close all loops alone; a manufacturer might need partners to take its production scraps for recycling, or multiple companies might join to set up a shared reverse logistics system. In the NZCVCM, cooperation is extended to encompass partnerships for carbon reduction and renewable energy. Many zero-carbon solutions, such as large renewable installations or carbon capture infrastructure, are complex and capital intensive and are often beyond the scope of a single firm. By cooperating, companies can achieve economies of scale and share risks in both circular and carbon initiatives. Moreover, a group of companies in an industrial park could collectively invest in a solar farm or wind turbines to power their operations, thereby all using renewable energy (R0: refusing fossil power) while possibly also exchanging materials. Industrial symbiosis in a zero-carbon context includes exchanges of energy streams; e.g., one plant's waste heat or steam is piped to a neighboring facility that needs heat, reducing the second facility's fuel consumption and emissions (Kandpal et al., 2024).

Furthermore, SCS practices under the NZCVCM foster an ecosystem approach: clusters of organizations collectively pursue circular and carbon-neutral objectives that would be hard to reach in isolation. These collaborations amplify the reach of ROs, enabling R2/R7 at scale through shared reuse/recycling programs, R8 through energy-sharing and recovery networks, and even R9 by collectively planning to mine old landfills or stockpiles. Similarly, it accelerates decarbonization by sharing resources such as renewable energy, carbon credits, or jointly lobbying for supportive policies, e.g., for greener grids or recycling infrastructure.

3.3.4 Sustainability skills and engagement (SSE)

Human resource development ensures that employees have the skills, knowledge, and motivation to implement circular practices and that a culture of sustainability thrives within the organization. SSE includes educating and training staff about ROs such as training in recycling methods and raising awareness of reuse and waste reduction (Sharma et al., 2022). Employees and managers who are well informed about circular strategies are more likely to identify and support circular opportunities in their work. For the NZCVCM, the training scope is broadened to cover climate change and carbon management topics alongside circular economy topics. This might be thought of as developing climate-circular competence in the workforce (Obeidat et al., 2023). Specifically,

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training programs teach employees about the company's net-zero commitments, basic carbon accounting, how different activities contribute to CO_2 emissions, and how these activities relate to the circular initiatives they are undertaking. Moreover, a factory floor worker trained under SSE would not only learn how to segregate and recycle materials (supporting R7) but also how to optimize machine settings to save energy and reduce emissions and why both actions are important to the company's goals. Managers responsible for product development receive training on eco-design and carbon footprint analysis, so they can simultaneously engineer for circularity and low emissions. Commitment is also a key part of this process and involves motivating employees to take ownership of sustainability goals through incentive systems or recognition. Many companies institute green champion programs, where certain employees lead sustainability initiatives in their teams (Lei & Yang, 2024).

Similarly, a lack of know-how in carbon accounting or clean energy can hinder decarbonization. The SSE in the NZCVCM ensures that the people implementing circular practices understand the carbon implications and are enthusiastic contributors to the company's dual goals. This human factor often determines whether strategies on paper become reality on the ground. By building a workforce that is literate in both a circular economy and climate action, companies create an internal engine for continuous improvement toward resource-efficient and carbon-free operations.

3.3.5 Green innovation and technological development (GITD)

GITD supports the transition by inventing and refining the technologies and processes that enable deeper circularity and decarbonization. The circular economy often requires green innovation, whether new materials that are easier to recycle, new processes such as chemical recycling, or digital platforms for sharing economy models (Perotti et al., 2024). Likewise, reaching net zero frequently depends on breakthroughs in improved batteries, carbon capture methods, alternative cements, etc. GITD is where the company actively seeks synergistic innovations that solve both resource and emission challenges. Innovations to avoid/reduce harmful emissions and resource use (R0/R1 oriented) and innovations to enable better recovery of products and materials (R2, R5, R7, R8) (Chang et al., 2023). This study carries forward those thrusts but emphasizes explicit carbon-related outcomes in each, (i) developing materials that are recyclable or biodegradable circular friendly. This includes green materials such as low-carbon concrete using industrial waste or CO_2 curing, bioplastics made from captured CO_2 or algae (thus tying carbon utilization into materials), or advanced alloys that are lightweight (reducing energy in use) and contain high recycled content. Some companies are already researching carbon-negative materials, such as bio composites that lock away CO_2 or building materials made from captured carbon; such innovations would be ideal for NZCVCM, as they create a building block for products that are both circular (often biodegradable or endlessly recyclable) and sequester carbon. (ii) Investing in technologies that drastically reduce energy use or switch to renewable energy in production and recycling (Qi et al., 2024). The development of a low-temperature process for the chemical recycling of plastics that can run on renewable electricity would support R7 while minimizing emissions and (iii) include

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piloting new service models or digital platforms overlapping with the RBM. The development of a next generation sharing platform or a blockchain for tracking product lifecycle emissions and materials are examples where innovation supports system transparency and optimization for both circularity and carbon.

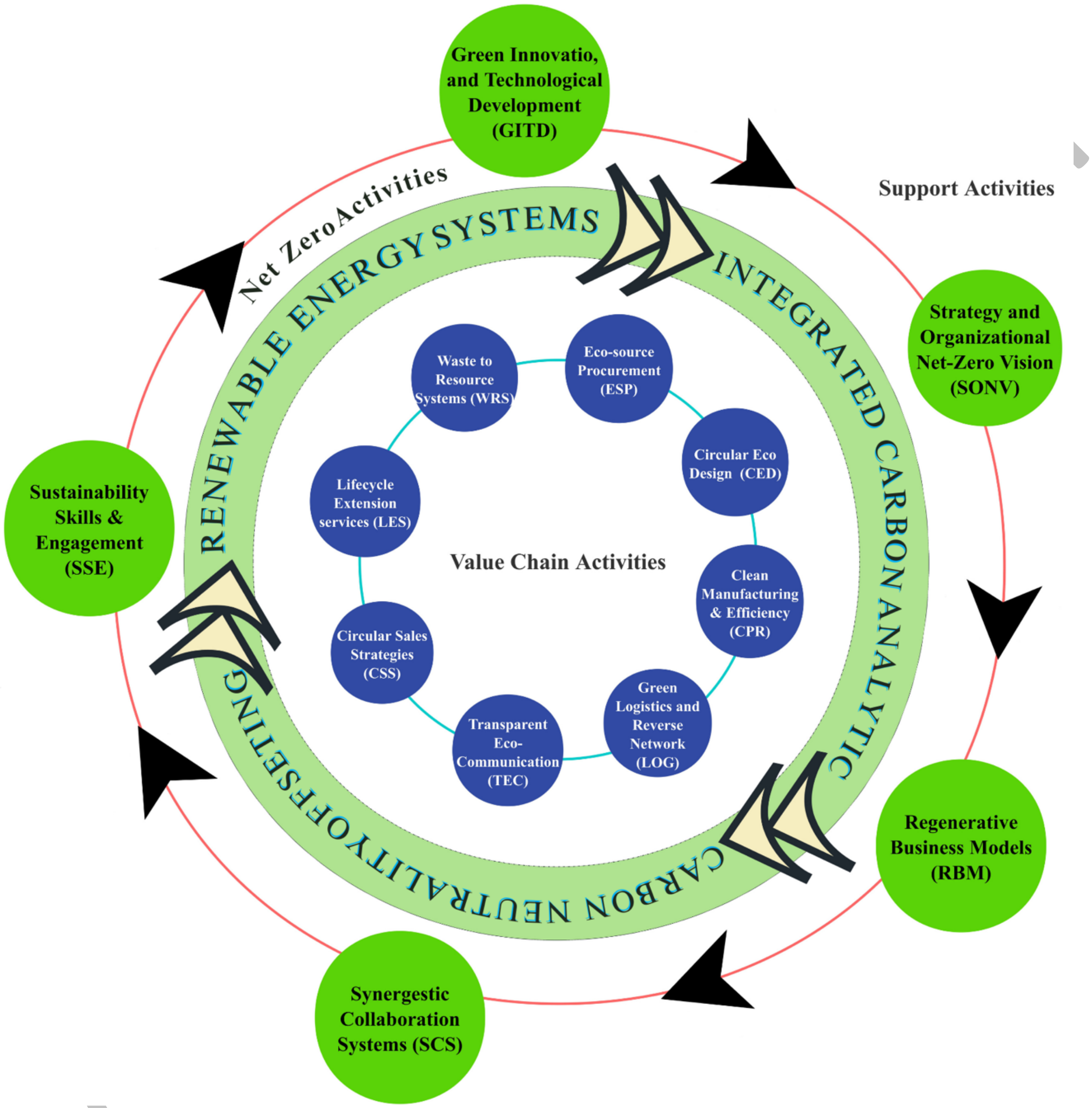

Figure 2: Net-zero circular value chain model (NZCVCM)

3.4 Net zero activities (NZCVCM)

3.4.1 Renewable Energy Systems (RESs)

Renewable energy systems (RESs) are fundamental to the transition toward net-zero operations, ensuring that the energy used across the circular value chain is sustainable and carbon neutral. RES involves integrating renewable energy technologies such as solar photovoltaic (PV) systems, wind turbines, biomass energy, hydroelectricity, and geothermal energy into operational processes to drastically reduce the dependence on fossil fuels (Khalid, 2024). A mid-sized appliance plant electrified process heat via high-temperature heat pumps and installed 2.8 MW rooftop PV with 3 MWh battery storage. The project covered ~85% of annual site electricity, cut Scope 2 emissions by ~82%, and reduced unit energy cost by 14% over three years. Co-scheduling recycling lines with PV generation reduced the carbon intensity of R7 operations and shortened payback through demand-charge savings demonstrating how RES directly amplifies circular gains (Biancardi et al., 2025). Key RES practices include the onsite installation of renewable energy generation facilities, the procurement of renewable energy from offsite installations through power purchase agreements (PPAs), and the utilization of advanced energy storage systems to balance energy supply and demand. By implementing RES, organizations achieve substantial direct emission reductions that support R0 Refuse and R1-Reduce and indirectly contribute to other ROs by supplying low-carbon energy to recycling, remanufacturing, and logistics operations. Firms such as Google and Apple have pioneered large-scale renewable energy investments, powering their data centers and operations with 100% renewable energy (Amendola et al., 2021). Similarly, IKEA has integrated rooftop solar systems into stores globally, directly reducing operational emissions and fostering sustainability across its supply chain (Shah et al., 2021). Thus, RES practices support the circular economy by ensuring that energy-intensive recycling and remanufacturing processes are powered sustainably, significantly reducing the overall carbon footprint.

3.4.2 Integrated Carbon Analytics (ICAs)

Integrated carbon analytics (ICA) involves systematically measuring, tracking, analyzing, and reporting carbon emissions across the entire circular value chain. ICA leverages sophisticated digital platforms, IoT-enabled sensors, blockchain technology, and real-time data analytics to provide transparent, comprehensive carbon emission data (Cong et al., 2024). This capability allows firms to identify critical emission hotspots, benchmark performance, and implement targeted emission reduction strategies effectively.

Practices within ICA include adopting robust lifecycle assessment (LCA) tools to quantify cradle-to-grave emissions, deploying real-time emissions tracking dashboards for operational transparency, and utilizing predictive analytics to model and optimize carbon reduction pathways. Companies such as SAP and Microsoft offer advanced analytics solutions that enable the precise monitoring and management of Scope 1, 2, and 3 emissions (Alzahmi et al., 2025). Similarly, Unilever has integrated carbon analytics into its procurement processes, enabling informed sourcing decisions on the basis of suppliers' emission profiles (Narikiyo et al., 2025). By effectively deploying ICA, companies not only advance their sustainability and transparency but

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also significantly support resource options such as reduce (R1), reuse (R2), and recycle (R7) by ensuring that these activities are optimally executed with minimal carbon emissions.

3.4.3 Carbon neutrality offset (CNO)

Carbon neutrality offset (CNO) practices focus on addressing residual carbon emissions that cannot be immediately eliminated through operational efficiency and renewable energy measures (Helppi et al., 2023). These practices involve investing in credible, verified carbon offset projects that remove or sequester carbon dioxide from the atmosphere, such as afforestation, reforestation, soil carbon sequestration, biochar production, direct air capture (DAC), and blue carbon projects.

Firms utilizing CNO not only compensate for their remaining emissions but also actively contribute to global climate mitigation efforts. High-quality offset projects are carefully selected to ensure authenticity, permanence, and additionality, typically adhering to internationally recognized standards such as the Gold Standard or Verified Carbon Standard (VCS). Companies have prominently incorporated carbon offsetting into their net-zero strategies, investing in global forestry projects and innovative carbon capture technologies. Furthermore, integrating offsetting strategies aligns with resource options such as Recover (R8) by investing in waste-to-energy projects that generate renewable energy and simultaneously reduce emissions (Abdallah & Elfeky, 2021). Ultimately, CNO practices serve as an essential transitional strategy for organizations striving to achieve comprehensive net-zero objectives alongside robust circular economy implementation.

With the detailed breakdown of the value chain, support and net-zero practices above, the NNZCVCM provides a comprehensive set of actions for firms to implement. Each practice category contributes to one or more ROs (as in the original model) and now also clearly contributes to the company's carbon-neutral objectives. Table 3 synthesizes specific practices within each category, indicating which ROs they develop and what their zero-carbon contributions are. This helps illustrate, in a more condensed form, the interlinkages between circular activities and carbon outcomes. Notably, many practices address multiple ROs simultaneously and attack multiple sources of emissions, underscoring the synergistic nature of integrating these goals.

Recent evidence reinforces patterns demonstrating our Table 3 mappings. The short loops CE practices such as refuse/reduce, reuse, and repair (R0-R3) deliver larger marginal climate gains than downstream options (Rückert et al., 2024). European indicators link lifetime extension to lower embodied emissions at scale, methodological work quantifies reuse GHG savings across platforms, and meta-analysis in the built environment finds reuse outperforms recycling on global-warming potential often by wide margins (European Environment Agency, 2024). Moreover, preserving those gains depends on clean power for circular operations; International Energy Agency (IEA) outlooks for 2024-2026 and to 2030 document rapid renewable additions and the

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centrality of electrification in industry, implying that remanufacturing, sorting, and recycling lines must be run on low-carbon electricity to avoid rebound of Scope 2 emissions (IEA, 2024).

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Table 3: Net zero circular value chain practices aligned with resource retention options

Code	Net Zero Circular Value Chain Practice	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9
ESP0101	Procure inputs from renewable materials such as bioplastics, plant-based or rapidly renewable resources to avoid fossil-fuel-based feedstocks.	✓	✓	✓					✓		
ESP0102	Source inputs from recycled or secondary raw materials, such as postconsumer plastics or metals, to reduce virgin resource extraction.		✓	✓	✓					✓	
ESP0103	Use biodegradable or compostable materials that can return to nature without harmful residues, enhancing biological circularity.	✓	✓	✓					✓		
CED0201	Design products to allow easy disassembly for repair, refurbishment, or parts replacement, facilitating future value recovery.		✓		✓	✓	✓		✓		
CED0202	Adopt modular product architecture with standardized, interchangeable parts to ease reconfiguration, repair, and component reuse.		✓		✓	✓	✓		✓		
CED0203	Focus product design on maximizing lifespan and reducing replacement cycles by incorporating durability, aesthetics, and customer acceptance.		✓	✓	✓	✓	✓		✓		
CME0301	Implement clean production technologies such as closed-loop water systems, solar-powered equipment, and low-carbon industrial processes.	✓	✓	✓							
CME0302	Optimize material and energy input per output unit to reduce environmental intensity and production waste.		✓	✓							
CME0303	Introduce water saving and reuse measures in production through rainwater harvesting, graywater systems, and high-efficiency equipment.		✓	✓							
GLOG0401	Electrify transport and logistics fleet using electric vehicles, hydrogen trucks, or rail to decarbonize delivery and collection activities.			✓		✓			✓		

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GLOG0402	Reduce emissions in transport and warehousing through route optimization, eco-driving training, and low-emission infrastructure upgrades.			✓		✓			✓		
GLOG0403	Develop logistics for product and component return, enabling reverse flows for reuse, remanufacture, and responsible end-of-life handling.				✓	✓	✓		✓	✓	
TEC0501	Label carbon footprints on products to inform consumer choices and increase transparency of embedded emissions.	✓	✓								
TEC0502	Launch awareness campaigns on zero-carbon and circular economy through digital media, workshops, and point-of-sale education.	✓	✓	✓							
CSS0601	Generate revenue from leasing, subscription, or reuse models that prioritize access over ownership and reduce resource throughput.				✓	✓	✓	✓	✓		
CSS0602	Offer product-as-a-service instead of ownership, integrating usage-based models to minimize overproduction and waste.			✓	✓		✓	✓			
LES0701	Provide after-sales repair and upgrade services to extend the useful life of products and maintain performance and customer satisfaction.					✓	✓	✓			
LES0702	Remanufacture products for reuse in original function by restoring used items to like-new quality through standardized processes.						✓	✓	✓		
LES0703	Extend functional life through maintenance plans, spare parts provisioning, and proactive product servicing agreements.				✓	✓	✓	✓			
WRS0801	Recycle material fractions via mechanical, chemical, or biological routes to return materials to manufacturing loops.								✓	✓	
WRS0802	Generate energy from nonrecyclable waste through anaerobic digestion, gasification, or incineration with energy recovery.									✓	✓
WRS0803	Compost biodegradable organic waste to generate soil nutrients, reduce methane emissions, and close biogenic loops.								✓	✓	
SONV0901	Incorporate net-zero and CE goals into strategic planning through policy documents, KPIs, and performance-linked governance.	✓	✓								
SONV0902	Publish net-zero and CE progress in annual reports or sustainability disclosures aligned with international standards.	✓	✓								

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RBM1001	Design regenerative models that replenish ecosystems and communities by integrating nature-based and socially inclusive solutions.				✓	✓	✓	✓			
RBM1002	Prioritize long-term social and environmental value over short-term gains by embedding stewardship and resilience into business logic.				✓	✓	✓	✓			
SCS1101	Establish industrial symbiosis for byproduct use by collaborating with other firms to valorize process waste or unused capacity.					✓			✓	✓	
SCS1102	Develop cross-sector platforms for resource exchange, joint innovation, and shared infrastructure aligned with circular carbon principles.					✓			✓	✓	✓
SSE1201	Train employees in net-zero and CE best practices using workshops, certifications, and hands-on simulations to build internal capacity.	✓	✓	✓							
SSE1202	Promote employee participation in sustainability initiatives through green teams, volunteer programs, and internal idea campaigns.	✓	✓	✓							
GITD1301	Invest in development of zero-carbon enabling technologies including circular materials, low-energy processes, and carbon capture solutions.		✓	✓	✓		✓		✓		
GITD1302	Generate patents in green process innovation that support material substitution, circularity, and emission reduction across the value chain.		✓	✓	✓		✓		✓		
RES1401	Use renewable energy for production and operations by sourcing electricity from solar, wind, hydro, or certified green providers.	✓	✓	✓							✓
RES1402	Install on-site solar, wind, or bioenergy systems to reduce grid reliance and enable self-sufficient clean energy generation.	✓	✓	✓							✓
ICA1501	Track emissions using real-time digital dashboards, integrating data across operations to inform timely decision-making.	✓	✓								✓
ICA1502	Apply life cycle assessments to all products and services to assess environmental impact from cradle to grave.	✓	✓	✓							✓

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ICA1503	Identify GHG reduction pathways using data analytics tools such as carbon modeling, benchmarking, and marginal abatement curves.	✓	✓	✓							✓
CNO1601	Offset remaining emissions with certified carbon credits such as Gold Standard, VCS, or government-backed programs.	✓									✓
CNO1602	Invest in afforestation, biochar, or DAC projects to remove carbon from the atmosphere and neutralize emissions beyond reduction efforts.	✓									✓
CNO1603	Balance operational emissions with neutralization measures as part of net-zero accounting protocols (Scopes 1–3).	✓									✓

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3.5 Integration of zero-carbon objectives into resource retention loops

This study proposes a net-zero circular value chain model by analyzing the relationships between practices and ROs. Several value chain practices have a broad range, influencing several ROs simultaneously. Importantly, those with the broadest RO impact, e.g., circular design, PSS business models also tend to offer the greatest carbon benefits since they address fundamental changes in how products are made and used. Decision makers should note that focusing on these high-impact practices can yield a double dividend: a wider improvement in circularity and a deeper reduction in emissions. A PSS model RBM1001 spurs repair, refurbishes, remanufactures, and repurposes, optimizes usage efficiency, and centralizes end-of-life handling, leading to significant emission cuts across product life stages. In contrast, a practice with a narrower RO scope might yield more modest immediate carbon savings, although it is still valuable. Understanding this range helps prioritize initiatives that drive systemic change.

3.5.1 RO loops and net-zero

The 10Rs are often grouped into short loops R0-R3, involving keeping products at their highest utility with minimal processing, medium loops R4-R6, reconditioning products, and long loops R7--R9, breaking down to materials or energy. Moreover, shorter loops correspond to lower carbon impacts because preserving a product or component intact avoids the energy of reprocessing. The model integration clearly shows this: the R0 (Refuse) and R1 (Reduce) strategies, such as dematerialization or efficiency, prevent emissions altogether by avoiding activity. R2-R3 (Reuse/Repair) keep products in service, entailing only minor emissions (perhaps transport or small fixes) compared with making new products. For R7 (recycling), there is an energy cost to reprocess materials, although it is usually much lower than primary production, and it is still a notable carbon expense. R8 (Energy recovery) can reclaim some energy but results in CO_2 (hence, we mitigate it via carbon capture to align with net zero). R9 (remine) addresses legacy waste beneficial but often energy intensively to dig up and reprocess old, landfilled materials, which in turn need to be powered by clean energy to be climate friendly. Therefore, the hierarchy of ROs from a carbon perspective generally aligns with the classic waste hierarchy: the higher the value is (refuse, reduce, reuse), the greater the degree of emission prevention. The NZCVCM highlights prioritizing these short-loop strategies, but it also ensures that when long loops are necessary, they are executed with renewable energy and the best-available clean technology to minimize emissions, thus closing the gap between loops in carbon terms. This insight reinforces earlier findings that decision-makers should highlight the range of CVCP, and the RO loops developed here add that they should highlight the carbon intensity of those loops as well. Strategies should aim to maximize the use of short loops and ensure that long loops are powered by zero-carbon energy.

3.5.2 Supply chain perspective and Scope 3 emissions

In the NZCVCM, this perspective is extended to Scope 3 emissions, such as upstream and downstream emissions, which often constitute the bulk of a product's carbon footprint. However, circular practices, particularly those beyond a company's direct operations influencing how customers use products or how suppliers produce inputs, directly address Scope 3 emissions

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(Wiedmann et al., 2021). Moreover, adopting circular inputs (PUIs) reduces upstream Scope 3 emissions from material production, and facilitating reuse among customers, the TEC and CSS reduce downstream scope 3 emissions by avoiding new product manufacturing. The integrated model reveals that a company cannot achieve net zero without engaging its value chain partners to adopt circular practices. Companies leading in sustainability already require suppliers to meet recycled content or renewable energy criteria by addressing upstream circular and carbon performance, whereas on the downstream side, they offer services for product returns and recycling to customers through downstream circularity and reducing customers' indirect emissions. The NZCVCM framework can be used to map out where in the value chain each practice occurs and whose emissions it affects, guiding firms to engage the right stakeholders for each initiative.

3.5.3 Support Practices Synergy

Support practices such as SONV, RBM, SCS, CSS, and GITD are enablers that operate in the background but determine success. In integrating zero-carbon, these support practices gained additional roles, e.g., SOV now involves a net-zero strategy, and R&D focuses on low-carbon technology. A critical insight is that support practices ensure coherence and avoid trade-offs. Without strategic alignment (SOV), one department might pursue a circular goal, whereas another pursues a carbon goal in conflict by using a material that is low carbon but hard to recycle. A unified strategy forces the selection of options that satisfy both. Without adequate R&D, some deep circular or carbon improvements, such as advanced recycling or CCS, remain inaccessible (Quan et al., 2024). This study noted that support practices play an important role and must be implemented with primary ones; our extension doubles down that, for example, achieving net-zero energy in recycling, a primary WTR activity is only possible if the firm's strategy (SOV) prioritized investing in renewables and perhaps if cooperation (CIS) provided a renewable energy partnership. Thus, companies should plan support initiatives in tandem with operational changes. A practical approach is to create cross-functional teams for each major initiative, including strategy, R&D, HR, etc., to ensure that all aspects (tech, people, partners, funding) are in place to yield both circular and carbon outcomes.

Moreover, integrating zero-carbon principles into the circular value chain amplifies the overall sustainability impact of each practice. Firms can use it to assess current practices; are there circular initiatives that could be powered by renewables? Are there decarbonization projects that could also enable more circular operations? The model encourages finding these win-wins. This study also highlights potential trade-offs to manage. One such trade-off might be recycling vs. reusing: recycling a material is good, but reusing a whole product is usually both more energy saving and more carbon saving. Thus, companies might invest more in reuse business models because of carbon dividends. Another trade-off: biodegradable vs. durable: a biodegradable product might reduce waste good for circularity if it replaces hard-to-recycle items, but if it is single-use, the production emissions might be higher than those of a durable reusable item. The model would push the company to prefer a durable, reusable solution paired with renewable energy over a single-use biodegradable solution with high production emissions.

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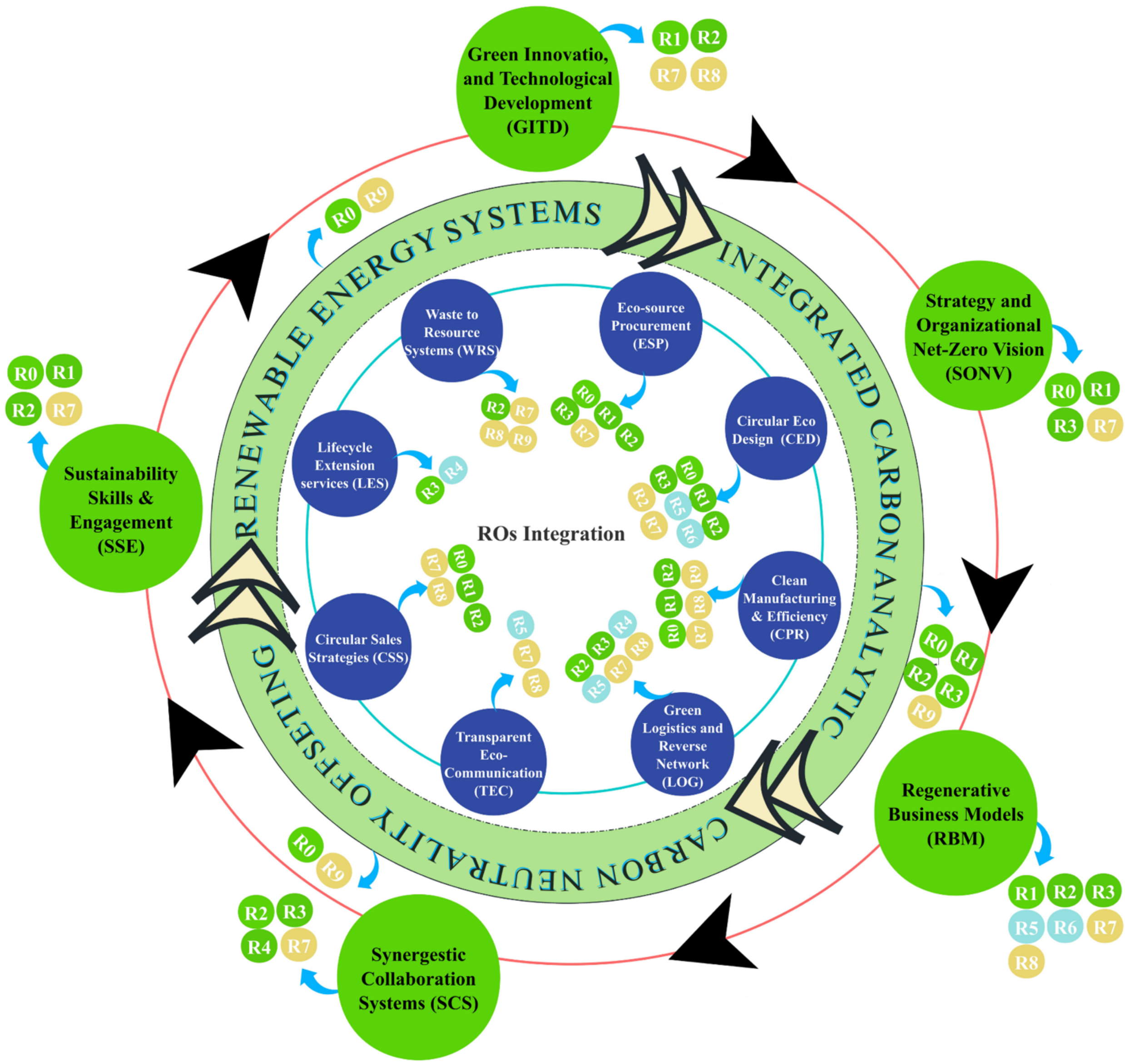

Figure 3: Net-zero circular value chain model (NZCVCM) align with resource retention options

The NZCVCM synthesizes transferable practices, yet adoption can be constrained by resource intensity, grid carbon intensity, capital access for renewables/electrification, supplier data quality, infrastructure gaps for reverse logistics, and regulatory heterogeneity across regions. Measurement uncertainty in Scope-3 inventories and variability in recycled-content availability may also delay benefits. We therefore frame NZCVCM as a directional guide whose outcomes depend on contextual enablers such as policy support, financing, data systems and staged capability building.

3.6 Implementation barriers and enabling conditions

Prior studies show a clear convergence between product-service systems and quantified decarbonization outcomes. It advances integrated PSS-LCA methods linking business model choices leasing, pay-per-use, take-back with system-level carbon effects over time so circular offers can be judged by both value-retention and greenhouse-gas performance (Alfarisi et al., 2024). The dynamic LCA approaches for PSS that combine system dynamics with environmental and economic indicators, and practice-oriented frameworks that connect PSS infrastructures to measurable emissions benefits across pilots and sectors (Werrel et al., 2024).

In parallel, the feasibility of renewable-powered manufacturing and industrial electrification has strengthened. Market analyses document unprecedented additions of renewable electricity to 2030, improving the emissions profile of electrified plants and reverse-logistics operations; policy and technical reviews outline concrete pathways for electrifying process heat and show where electrification delivers the biggest near-term CO_2 cuts (Rosenow et al., 2025). Sector outlooks for steel, aluminum, petrochemicals, and cement emphasize recycling, clean power procurement, and electrification as the dominant decarbonization levers, while industry trackers highlight infrastructure gaps that must be closed to scale these solutions.

Moreover, there is a rapid maturation of digital LCA/Integrated Carbon Analytics and regulatory Digital Product Passports (DPPs). The EU's eco-design for Sustainable Products Regulation (ESPR), in force since July 2024, establishes the legal framework for product-level data on circularity and carbon, with working plans and timelines pointing to staged DPP rollouts across priority categories later this decade (European Commission, 2024). Therefore, real-time carbon accounting, digital-twin-enabled product carbon footprints, and operational dashboards are moving assessment from retrospective reporting to continuous decision support at plant and supply-chain level (D'Adamo et al., 2024; Winter et al., 2025). These developments validate our use of ICA as a managerial control layer in the model and our emphasis on data standards to track RO-linked emissions outcomes.

4 Conclusion and research implications

This study presented a theoretical model explaining how integrated net zero circular value chain practices help companies retain resource value while achieving climate neutrality. The proposed net zero circular value chain model (NZCVCM) builds on 40 net zero circular value chain practices across 8 primary 6 support and 4 net zero categories to incorporate renewable energy use, carbon tracking, and emission reduction measures at each stage of the value chain. The main contribution of this work is the integration of two traditional separate-domain circular economies focused on R0-R9 resource loops and corporate carbon management into one integrated framework. We systematized how each CVCP can be adapted or reoriented to also drive down greenhouse gas emissions, identifying the relationships between these adapted practices and the ROs. By doing so, the model provides clarity on which circular practices yield the greatest climate benefits, and which carbon-focused actions reinforce circular goals. The NZCVCM thus expands current theoretical knowledge by demonstrating in concrete terms that the goals of resource circularity and carbon neutrality are not only compatible but mutually reinforcing when pursued holistically.

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4.1 Theoretical Implications

The NZCVCM advances CE theory by shifting from a materials-only orientation to a circular-carbon systems perspective in which value retention and emissions reduction are treated as joint performance criteria at the level of concrete practices and ROs (R0-R9). First, it extends RO theory by specifying two embedded design variables energy provenance, electrification and renewables, and materials carbon intensity that condition the climate efficacy of each loop; thus, loop selection becomes a multi-objective choice rather than a purely material one. Second, it introduces ICA as a formal control layer, positioning product- and process-level carbon data as part of the governance of circular practices; this links CE scholarship to measurement and management-control theory through operational, not merely periodic, performance feedback. Third, by mapping practice RO emissions outcome, the model provides a causal framework that supports comparative testing of loop hierarchies and clarifies when longer loops dominate. Fourth, it demonstrates boundary conditions notably grid intensity, supplier transparency, and reverse-logistics infrastructure that mediate the relationship between circular actions and carbon outcomes, thereby explaining mixed results in prior studies and guiding contextualized theorizing. Fifth, it reframes PSS and take-back models as emissions-control mechanisms, enriching business-model and value-capture theory with carbon performance as an explicit design goal. Sixth, it contributes to dynamic capabilities by identifying the capabilities bundle required to align circular and net-zero aims. Seventh, it offers norms for residuals governance by bounding the role of offsetting to hard-to-reduce remainders, addressing moral-hazard concerns in the CE-climate interface. Finally, the model opens a testable research agenda, including: (i) short loops (R0-R3) yield higher marginal carbon benefits conditional on low-carbon energy; (ii) ICA-enabled organizations achieve greater RO carbon alignment than peers; (iii) the carbon advantage of recycling vs. reuse is mediated by material class and grid factors; (iv) PSS intensity predicts higher closed-loop rates and lower lifecycle emissions; (v) offset reliance declines as ICA transparency and RES penetration rise. These implications reposition CE from a static taxonomy of loops to a governed, data-driven system where circularity and net-zero are co-optimized and theoretically integrated.

4.2 Practical Implications

From a practical standpoint, the results offer businesses a roadmap to address two pressing sustainability challenges simultaneously. Companies and supply chain stakeholders can use the NZCVCM to formulate integrated strategies, wherein initiatives are evaluated against circular performance, e.g., waste reduction, ROs achieved, and carbon performance through emissions reduced or avoided. A firm now has exemplars of how to green its procurement or how to reshape its business model to ensure that both materials and emissions are minimized. Practitioners can operationalize the NZCVCM by concentrating on short loops (R0-R3) and then extending to longer loops as capability and infrastructure mature. Early moves should electrify operations and switch to renewable power, so the climate dividend of circularity is not undermined. Day-to-day decisions should be steered by integrated carbon-analytics dashboards, making the carbon intensity of each

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RO option visible to managers. As noted in CE road mapping literature, having an integrated framework enhances the global coherence of circular initiatives (Abu-Bakar et al., 2024). NZCVCM can serve that role in practice by guiding firms and regulators on specific circular-carbon actions.

Commercial mechanisms such as take-back contracts and product-service-system offerings can secure stable reverse flows and unlock reuse/remanufacture revenues. Low-carbon procurement clauses for suppliers and internal carbon pricing further shift input choices toward lower-emission alternatives. Offsetting should be reserved only for hard-to-abate residuals. Together, this staged pathway links value-retention outcomes to verifiable Scope 1-3 emission reductions. The model also emphasizes three crucial aspects that practitioners should consider in their planning: (i) adopting a broad range of circular practices is necessary, but not enough firms should choose and prioritize practices that maximize both RO development and emission reduction. As observed, practices such as circular design, clean production, and PSS models stand out as having high leverage. (ii) Short loops (refuse, reduce, reuse, and repair) generally offer higher combined environmental gains and should be prioritized in strategy, but medium and long loops remain vital for capturing value and mitigating emissions from products that cannot be directly reused. Crucially, long-loop processes (recycling, energy recovery) must be powered by clean energy and advanced technology to align with net zero (iii) Implementing these practices often requires a value-chain or even cross-industry approach. Collaboration with suppliers, customers, industry peers, and even regulators will amplify success. A manufacturer alone can switch to renewable energy, but creating a circular supply loop for its product packaging might require working with suppliers to design recyclable packaging and with customers to return it. Such collaboration can be challenging, but our findings reiterate its importance. Moreover, engaging partners in circular initiatives can strengthen relationships and drive collective progress toward climate targets, as all parties share in the cost savings and reputational benefits of closed-loop, low-carbon operations.

4.3 Limitations

While the NZCVCM provides a robust framework, this study has several limitations. First, our model is conceptual and synthesized from the literature insights; it has not been empirically validated as an integrated whole. We drew from diverse examples and best practices, but not every relationship between a practice and an RO or carbon outcome may manifest uniformly in all contexts. A particular practice might not yield emissions reduction in a context where the energy mix is already clean, or a circular strategy might face diminishing returns in highly optimized systems. The absence of identified examples linking certain practices to certain ROs or carbon metrics in the literature does not mean that no link exists; it may simply be undocumented yet. Therefore, one should view the model as a guiding template that likely needs tailoring to specific industries or companies.

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Future research should focus on empirical testing and sector-specific adaptation of the NZCVCM. Case studies could be conducted in different industries, such as electronics, automotive, consumer goods, and construction, to assess which integrated practices yield the best results and to identify any sector-specific circular-carbon strategies not captured in the generic model. Interviews with industry practitioners could validate, refine, or expand the list of practices and reveal on-the-ground challenges or synergies beyond what literature alone provides. Additionally, quantitative modeling, such as system dynamics or life-cycle optimization models, could be used to simulate the implementation of the NZCVCM in a company's value chain and measure the potential impact on both material circularity indicators and the carbon footprint. This would help validate the claim that integrated approaches outperform separate efforts. Moreover, another promising area for future inquiry is the role of policy and regulation in enabling zero-carbon circular value chains.

Finally, we recommend that future studies delve into the economic implications of the NZCVCM. While we qualitatively argue that many integrated practices can be cost-saving or value-creating, a detailed economic analysis would be valuable. Understanding the return on investment (ROI) for combined circular-carbon initiatives versus separate initiatives could convince more businesses to adopt this integrated approach.

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