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Carbon neutrality: Operations management research opportunities

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Abstract

Climate change, primarily driven by greenhouse gas emissions (GHGs), is a pressing environmental and societal concern. Carbon neutrality, or net zero, involves reducing carbon dioxide emissions, the most common GHG, and then balancing residual emissions through removing or offsetting. Particularly difficult challenges have emerged for firms seeking to reduce emissions from Scope 1 (internal operations) and Scope 3 (supply chain). Incremental changes are very unlikely to meet the objective of carbon neutrality. Synthesizing a framework that draws together both the means of achieving carbon neutrality and the scope of change helps to clarify opportunities for research by operations management scholars. Companies must assess and apply promising technologies, form new strategic relationships, and adopt novel practices while taking into account costs, risks, implications for stakeholders, and, most importantly, business sustainability. Research on carbon neutrality is encouraged to move beyond isolated discussions focused on specific tactics and embrace a more, though not fully, holistic examination. Research opportunities abound in both theoretical and empirical domains, such as exploring tradeoffs between different tactics, balancing portfolios, and investigating the strategic deployment of initiatives over time. As a research community, we are critically positioned to develop integrative insights at multiple levels, from individual processes to horizontal and vertical partnerships and ultimately to large-scale systemic realignment and change.

KEYWORDS

carbon neutrality, means of carbon reduction, operations management, scopes of carbon emission, supply chain sustainability

1 | INTRODUCTION

Climate change is widely viewed as one of society's most critical issues, evidenced by the increasing frequency of extreme weather events, disrupted agriculture, and substantial global costs of infrastructure damage, crop failures, and biodiversity loss. Greenhouse gas (GHG) emissions, with carbon dioxide being the most common, are a primary contributor. Many international environmental advocacy groups, including the United Nations Sustainable Development Goals, the Intergovernmental Panel on Climate Change (IPCC), and the Conference of the Parties (e.g., most recently, COP28), are actively working to reduce carbon emissions and the effects of climate change. The World Economic Forum (2024) also has emphasized the urgent need to reduce carbon dioxide emissions. To date, more than 120 countries, including major industrial countries such as China, the European Union, the United Kingdom, Japan, South Korea, and Canada, have pledged to achieve carbon neutrality by 2050–2060.

Carbon neutrality, also termed net zero, focuses specifically on reducing carbon dioxide emissions, combined with balancing any residual emissions with an equivalent amount removed or offset by others (Lenox & Duff, 2021; Xu et al., 2023). Given the worldwide urgency to achieve carbon neutrality, we face an immediate and critical need for research to explore the challenges, barriers, potential solutions, and pathways to achieve carbon neutrality. Industries such as the transportation, manufacturing, construction, and energy sectors are major contributors to carbon emissions (Ritchie et al., 2020), yet also critical to global economic growth. Increasing research efforts are investigating low-carbon supply chains and operations, emphasizing the need to enhance firms' energy efficiency (Sartal et al., 2020), undertake incremental or modular changes to existing products, services, and processes (Dooley et al., 2019), and shift away from fossil fuel-based energy sources to renewable energy in such sectors as transportation (Naumov et al., 2023).

Decarbonizing operations, supply chains, and business models requires significant innovation across multiple sectors. Unfortunately, incremental disconnected changes are unlikely to meet the aggressive goal that is embedded in the term 'carbon-neutral', namely, to limit global warming to 1.5°C above pre-industrial levels (UNCC, 2022). Thus, carbon capture technologies or offsetting with projects undertaken by others might offer important options to achieve carbon neutrality (Pereira et al., 2022). Companies must identify, assess, and apply promising technologies, form strategic partnerships, and adopt novel practices while considering costs, risks, implications for stakeholders, and most importantly, business sustainability. Thus, operations strategy must prioritize carbon neutrality and consider the transformational potential of doing so for both a firm's business model and supply chain.

In this editorial, we explore several key aspects of this complex, multifaceted challenge and examine emerging research opportunities. A primary objective is to catalyze research in operations and supply chain strategies that generate both environmental and societal benefits by achieving carbon neutrality.

2 | MOVING TOWARD CARBON NEUTRALITY

2.1 | Conceptualizing multiple dimensions

While carbon neutrality has emerged as a critical concern for operations and supply chain management, definitions vary in multiple important ways that point to at least three implicit dimensions. First, the *scope* or span of the supply chain encompassed varies. The GHG Protocol (https://ghgprotocol.org) is a widely acknowledged framework that categorizes a company's GHG emissions into three distinct Scopes (Lenox & Duff, 2021; UNECE, 2022). In essence, Scope 1 focuses on a firm's internal operations; Scope 2 captures purchased electricity and heat. Finally, Scope 3 encompasses all GHG emissions across a firm's supply chain (or value chain), including the use of its products and services, which collectively are often larger in magnitude than the other two Scopes. A comprehensive measurement of emissions across the three Scopes empowers management teams to make informed decisions, target reductions in their carbon footprint, and strategically position their firms in a competitive and sustainable landscape.

Managers face daunting challenges as they attempt to move toward carbon neutrality, particularly for Scope 3 (World Economic Forum, 2021). Unfortunately, data from first-tier suppliers can be spotty and unreliable, and transparency tends to decrease across multiple tiers in the supply chain and with smaller suppliers (Villena & Gioia, 2018). Moreover, because Scope 3 emissions are generated by others, the verification of data and power to influence change are either more limited or less direct. For example, the downstream consumption of products or use of services adds complexity and uncertainty as the energy mix used by customers varies significantly by location. Thus, research in operations management must inform both planning and prioritization that explicitly accounts for scope.

A second dimension is the *means of reduction*, or approach, used to achieve carbon neutrality. One means, termed process changes, broadly encompasses improved practices, new technologies, or new business models. Yet, these changes might be largely untested, very costly or beyond the firm's control, leaving some supply chains well short of carbon neutrality. Thus, carbon offsets or credits might be used to "neutralize" carbon emissions (Gao & Souza, 2022), for example, through investments in activities like reforestation, carbon capture, and renewable energy projects. Lastly, carbon capture and storage (CCS), which can include utilization (i.e., CCUS), might be employed in some operations (Işlegen & Reichelstein, 2011; Jiang et al., 2020). These latter two generate controversy among stakeholders (Fankhauser et al., 2022)[1] since consumers value these approaches to net zero differently (Roemer et al., 2023). Taken together, both the Scope and Means of Reduction combine to explicitly capture two dimensions that are central to an operational definition of carbon neutrality. Finally, "time horizon" is an implicit third dimension in the sense of "when" or "how quickly" carbon neutrality

TABLE 1 Evolution phases of climate change and carbon emission concerns.

Timing	Phase 1: Little attention on increasing carbon emission (prior to 2005)	Phase 2: Increasing attention prompting initial target setting (2005–2015)	Phase 3: Clear targets with incremental action (2015–2030)	Phase 4: Systemic transformation necessary (2030–2050)
The United Nations' initiatives	The Intergovernmental Panel on Climate Change (IPCC) assesses climate change, consequences, and potential strategies for mitigation and adaptation.	The Kyoto Protocol sets specific targets and timetables to reduce GHG emissions.	Paris Agreement aims to "hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels." (UNFCCC)	Key national milestone targets must be met by 2030, with net zero to follow by 2050.
GHG emissions	Expanding carbon intensive operations; widespread use of carbon-based fuels for energy; little attention to climate change.	Increasing debate and concern about the climate implications of carbon emissions.	Growing comprehension of the complexity of achieving net zero (Scopes 1, 2 and 3).	Roughly 50% reduction needed by 2030; net zero by 2050.
Technological focus.	Low-cost energy from carbon-based sources.	Initial investment in renewable energy and continued focus on energy efficiency.	Focus on Scopes 1 and 2. Significant cost reductions in renewable energy; growing electrification of transportation and other energy intensive processes; expanded adoption of offsets; early development of CCUS.	Primary focus expected to be reduction, with emphasis on reducing Scope 3. CCUS and offsets necessary for residual emissions.

is to be achieved, and 2050 is often pointed to as the target year.

Consistent with these three dimensions, the Science Based Targets initiative (SBTi, 2024) has recently emerged as one reputable standard for firms, where target setting, measurement, progress, reporting, and verification are integral for establishing credibility. In general, a firm must commit and have an approved plan to reduce its carbon footprint for Scopes 1 and 2 by 50% by 2030. Subsequently, by 2050, SBTi mandates achieving carbon neutrality (i.e., net zero) across Scopes 1, 2, and 3. Such commitments represent extremely challenging objectives for many firms; yet over 4300 companies globally had approved targets by the end of 2023.

2.2 | United Nations' initiatives support broadscale change

Considerable change has occurred in recent years regarding both the recognition of the problem and the breadth and depth of change required to address climate change. Understanding these changes at a macro level can inform how scholars in operations and supply chain management might expand and shift their research agendas. Governments and policymakers are increasingly considering regulations and incentives to encourage carbon neutrality (Fan et al., 2023; Wu et al., 2022), and ambitious targets and carbon pricing mechanisms are being introduced to stimulate emissions reduction and offsetting endeavors. As one of many organizations, the United Nations (UN) has played a pivotal role, first, in raising awareness of climate change as an urgent global issue and, more recently, through a series of initiatives and international agreements that shape or coordinate how nations, businesses, and other GHG-emitting organizations manage change. While multiple frameworks might be helpful, here we adapt and extend the work of Zhang et al. (2022) to characterize four phases of development (Table 1).

To begin, relatively little attention was focused on rising GHG emissions (Phase 1) until the UN established

the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC provided scientific assessments on climate change, its consequences, and potential mitigation and adaptation strategies. Subsequently, the Kyoto Protocol was established in 1997 at the Conference of Parties (COP3) of the United Nations Framework Convention on Climate Change (UNFCCC, n.d.). While some scholars acknowledged the potential impact of climate change on society, economic constraints and implications were only starting to be understood. Initiated by the Kyoto Agreement coming into force in 2005, Phase 2 saw 37 industrialized nations, economies in transition, and the European Union setting national targets that collectively committed to an average 5% reduction in GHG emissions compared to 1990 levels. This highly visible agreement fostered increasing attention and academic research. For example, efforts were made to enhance energy efficiency and reduce carbon emissions in carbon-intensive industries such as cement, steel, chemicals, and energy (Zhang et al., 2022).

Subsequently, with the adoption of the Paris Agreement (2015), Phase 3 has been characterized by a goal of limiting global warming to well below 2°C above pre-industrial levels, with a target of 1.5°C. In addition, UN Sustainable Development Goals (SDGs) specifically emphasized climate action (SDG 13). In recent years, many countries worldwide have proposed carbon neutrality targets and roadmaps to reduce GHG emissions by 50% by 2030. In parallel, scholars are increasingly shifting their focus from low- to zero-carbon, and research on carbon removal technologies has also gained prominence (Zhang et al., 2022). Finally, looking beyond 2030, Phase 4 foresees systematic transformation that key national milestone targets must be met by 2030, with the ultimate goal of achieving carbon neutrality by 2050. Firms must restructure operations, supply chains, and business models (Girotra & Netessine, 2013), first, to reduce and minimize carbon emissions and, second, to capture and offset residual emissions. This multi-pronged approach is crucial for achieving the broad-scale change that characterizes systemic transformation.

The UN Secretary-General (2020) emphatically stressed that *multiple* stakeholders must give greater priority to carbon neutrality and reshape economic and fiscal decision-making processes. For example, financial institutions and asset managers must align their lending and investment practices with net-zero objectives. In a very pragmatic way, as noted in the previous section, organizations also are setting their own carbon neutrality objectives, necessitating comprehensive strategies that encompass accurate measurement of progress, process changes, carbon offsetting, and CCUS (Desai et al., 2023; Wu et al., 2022; York et al., 2018). Such objectives have encouraged the expansion of regulatory-constructed carbon markets and the emergence of a wide variety of carbon offset projects to potentially lower the net cost of achieving carbon neutrality.

3 | EXPANDING CARBON-RELATED RESEARCH IN OPERATIONS MANAGEMENT

A large and diverse body of research has considered multiple dimensions of sustainability in supply chain management (Ahi & Searcy, 2013; Seuring & Müller, 2008), including an early special issue in the *Journal of Operations Management* (Linton et al., 2007). As noted by Wu and Pagell (2011), decision-making processes in sustainable supply chain management must adopt a holistic approach to manage sustainability issues, and climate change and carbon neutrality are particularly important areas. If we return to the first two dimensions of carbon neutrality noted in Section 2, namely Means of Reduction and Scope (Klassen & Lynch, 2023), much of the operations management literature has largely focused on only a subset of these. Atasu et al. (2020) characterize prior research in three streams. The first focuses on the adoption of energy-efficient technologies (Muthulingam et al., 2013), and a second, on renewable energy strategies (Kaps et al., 2023). Both approaches affect the direct carbon emissions of operations and energy consumed by manufacturing and service processes (see Figure 1), which is consistent with the 2030 milestones required by SBTi. Extending these streams to the supply chain, sustainable procurement can also yield important reductions in a buying firm's Scope 3 carbon footprint (Saunders et al., 2020). Supplier selection, inventory planning,

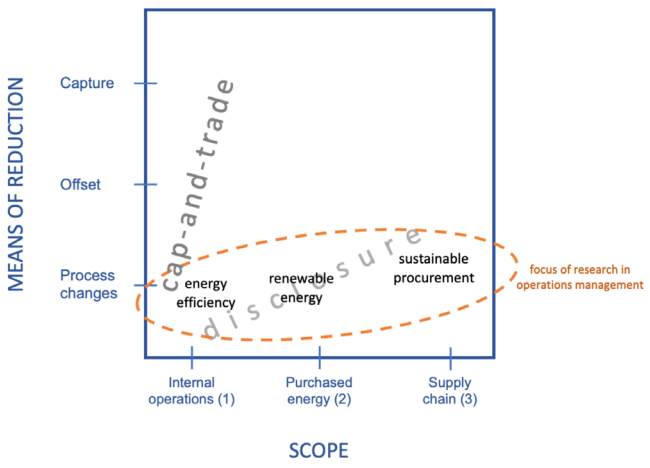

FIGURE 1 Mapping carbon neutrality for operations and supply chain management.

network design, and logistic decisions (Das & Jharkharia, 2018) affect processes, products, and services, although reduction efforts can be hampered by information gaps and limited supplier capabilities (Jira & Toffel, 2013).

Yet, a firm's supply chain is set within a much larger context and must strategize and operate based on regulatory and reporting regimes, noted as a third major stream related to the low-carbon economy in operations management (Atasu et al., 2020). This stream includes a range of contextual factors that shape operations, including carbon taxes, cap-and-trade systems, and carbon reporting. Research has varied from somewhat agnostic (e.g., Fan et al., 2023) to quite specific (e.g., Naumov et al., 2023) about both the means of reduction and the nature of disclosure and accountability (Blanco, 2021). The affected Scope captured in such research can be quite ambiguous and blurred. For example, research topics such as cap-and-trade might initially appear internally focused (e.g., the firm trades its permits based on its own process emissions), yet the broader competitive or regulatory setting implicitly determines the means pursued (Drake et al., 2016). Thus, cap-and-trade is illustrated as extending across Means and Scope in Figure 1; similar implications arise for carbon pricing and related policies (Zhao et al., 2023).

Information disclosure is similar. For example, societal factors often have a critical influence over the voluntary disclosure of carbon emissions (Villena & Dhanorkar, 2020). Liu et al. (2023) identified a negative association between carbon emissions and organizational performance, although surprisingly, firms with higher carbon emissions tended to provide a higher level of disclosure, possibly to manage perceptions. In a related sense, Ziegler et al. (2022) investigated how the assessment of GHG emissions might be simplified to support more frequent monitoring, which, in turn, aids decision-making to improve supply chains.

These regulatory policies encompass broadscale and complex business systems. Operations management scholars have only taken initial steps to explore inter-organizational connections that extend well beyond a firm's own operations and supply chain to other stakeholders, such as nongovernmental organizations and multi-industry consortia. These connections prompt questions about customer preferences, technological choices, and system design (e.g., Dooley et al., 2019). In doing so, scholars in operations management are being challenged to contribute to our understanding of how carbon neutrality might affect complex interactions among all three dimensions of environmental, social, and economic performance.

By drawing on prior research insights and contributions, organizations can make informed decisions to mitigate their carbon footprint and contribute to a more sustainable future. However, many studies have primarily emphasized *incrementally reducing* carbon emissions with a focus on a single means and scope, with very little attention to the explicit goal of (mostly) *eliminating* emissions, that is, carbon neutrality. In essence, our field has considered individual steppingstones without considering whether their collection provides a viable pathway to be constructed that reaches our key destination by 2050. Of course, reductions can be additive, but the likelihood of diminishing returns suggests that much difficult work remains.

As noted earlier, carbon neutrality requires multiple means to reduce emissions across a firm's business model, portfolio of products and services, and supply chain. Against this backdrop, research is exploring a wide variety of carbon removal technologies, sustainable land-use practices, and innovative strategies for emission reduction (Gibbs et al., 2022; UNECE, 2022). Other scholars are examining critical operational elements such as energy structure optimization, industrial sector adjustments, carbon market development, negative emission technologies, and the value of circular economy principles (Zhang et al., 2022). The feasibility and effectiveness of various offsetting approaches are also being examined (Xu et al., 2023). These multifaceted research endeavors collectively contribute to our understanding of carbon neutrality and propel us toward a more sustainable and carbon-neutral world.

4 | SPECIAL ISSUE

To stimulate research in operations and strategies for achieving carbon neutrality, our Call for Papers invited papers that emphasized theoretical and practical insights that might prompt and support managers as they strategize how to move their operations and supply chains toward carbon neutrality in a timely manner. In response, we received a total of 28 papers. First, we would like to thank the authors for considering our Special Issue as an outlet for their research. And just as important, we wholeheartedly thank the many reviewers for their efforts in assessing these papers. The submitted papers investigated carbon neutrality from a wide variety of perspectives, including consumer behavior, measurement development, disclosure, carbon permit trading, technological solutions, and supply chain management, among others; however, few studies examined carbon neutrality from both theoretical and practical perspectives. Each raised interesting points, yet as pointed out by

the reviewers, this Special Issue sought to publish insights into operations management for achieving *carbon neutrality*. As a result, we must infer that carbon neutrality in operations management is still in its infancy, with much opportunity for future research.

As discussed in earlier sections, commitments by and participation of suppliers to reduce carbon emissions are crucial to achieving carbon neutrality. The paper accepted by Lian et al. uses panel data to examine, first, how customer environmental disclosure affected GHG emissions of suppliers, and second, how innovation and competition across the customer base influenced this relationship. The study offers evidence of the value of environmental disclosure in a supply chain context, where disclosure serves as a signal to inform the customers' expectations of suppliers, cascading environmental efforts upstream to suppliers. The policy implications are important as regulators expand carbon-related reporting and supply chain members seek out innovative partners to move toward carbon neutrality.

5 | FUTURE RESEARCH DIRECTIONS

5.1 | Theoretical perspectives supporting carbon neutrality

Prior studies in operations management related to GHG emissions reduction, climate change, and environmental sustainability are underpinned by a wide range of theoretical frameworks, encompassing firm motivation, bundling of practices, and performance outcomes. At least three management theories have been exploited to explain the motivation for firms to declare and begin taking action toward carbon neutrality: stakeholder, legitimacy, and institutional theories. Stakeholder theory emphasizes the central role of stakeholder involvement in firms' commitments (UNECE, 2022; Zhang et al., 2022) and decisions toward carbon neutrality (McGahan & Pongeluppe, 2023; Odziemkowska & Henisz, 2021). Legitimacy theory explains how firms position themselves to be more acceptable and authentic to stakeholders, shedding light on the value of standards, reporting, and indices that document a firm's journey toward carbon neutrality (Ertimur et al., 2020; Velte et al., 2020). Institutional theory details how firms respond to external pressures, such as regulatory, normative, and mimetic pressures, shaping their sustainability practices (Ansari et al., 2013; Vedula et al., 2022; Villena & Dhanorkar, 2020). Extended to carbon neutrality, ideally, these pressures are expected to foster positive responses from firms to engage in carbon neutrality practices. Yet, such pressures might also prompt symbolic actions as a firm only signals commitment rather than takes genuine action (Crilly et al., 2016; Wright & Nyberg, 2017).

When considering business competitiveness and outcomes, difficult questions arise about the nature of investment required and how options that advance carbon neutrality might create value for multiple dimensions of performance (e.g., triple bottom line of environmental, social, and economic performance). The resource-based view of a firm identifies operational capabilities that are valuable, rare, inimitable, and difficult to substitute, both within the firm and across the supply chain structure, as potential sources of strategic value from carbon neutrality (He et al., 2024; Kök et al., 2016). Game theory, employed to consider strategic responses and interactions among stakeholders, explains differences in outcomes (Han et al., 2022; Subramanian et al., 2007). These theoretical perspectives collectively offer various lenses to examine and understand efforts by operations and supply chain managers to achieve carbon neutrality.

5.2 | General research opportunities

While previous studies have made significant contributions to understanding the role of operations management in achieving carbon neutrality, research shortcomings and gaps persist that present important opportunities for scholars. First, existing research, especially that which adopts a resource-based view of the firm, predominately explores incremental changes to internal processes and technologies. The emphasis is on Scope 1 emissions, occasionally considering Scope 2, while largely neglecting Scope 3's broadscale impact. This narrow scope driven by data availability and analytical tractability foreshadows a notable shortfall in emission reduction efforts given the interdependence of emission sources and differing capabilities across supply chains (Gopalakrishnan et al., 2021). Achieving carbon neutrality requires coordinated efforts and a deeper understanding of specific actions in the supply chain, involving resources beyond a firm's internal operations (Song et al., 2023; UNECE, 2022).

Second, existing studies focus on specific means or tactics for reducing carbon emissions, such as renewable energy and digital technologies, potentially responding to institutional pressures. Moreover, even nature-based solutions can raise concerns (Seddon, 2022). While these tactical examinations offer valuable insights, a firm's strategy for carbon neutrality requires a combination of means, including reduction, offset, and capture. Future research should provide a more holistic understanding of

tradeoffs and interactions between different means to achieve carbon neutrality, possibly through deeper connections to stakeholder theory.

Third, while prior work has started to explore the impact of policies and regulations on carbon reduction, they often overlook differences in national and international policies influencing Scope 3 emissions in international supply chains. Over 120 countries have committed to carbon neutrality, with a wide diversity of policies on pricing, trading, and taxing carbon emissions. In essence, these policy approaches vary significantly in terms of means and timing (recall Figure 1). Some evidence suggests that well-designed regulations can effectively reduce GHG emissions and enhance firm profitability compared to non-regulated markets (Anand & Giraud-Carrier, 2020; He et al., 2023). However, a significant gap remains in understanding how to regulate global supply chains for efficient, impactful outcomes.

5.3 | Promising research directions

5.3.1 | Stakeholder involvement and strategic value of commitment

Previous studies have explored drivers behind firms' commitments to carbon neutrality, such as stakeholder pressures, institutional influence, and legitimacy, but have overlooked how to involve stakeholders in these initiatives effectively. Commitments by firms are deemed crucial for stakeholder buy-in and the long-term success of carbon neutrality, particularly in the context of curbing Scope 3 emissions, which account for a substantial proportion of emissions. Yet, commitments don't necessarily change behavior (Wright & Nyberg, 2017). Research needs to explore further the strategic roles of different stakeholders and how firms can align their commitments with stakeholder values. While making carbon-neutral commitments and investments in practices might benefit firm performance, such an outcome is likely predicated on aligning the commitments and investment with the values of key stakeholders (e.g., the climate-oriented investor). Contextual conditions, such as business uncertainty and resource access, may also influence how firms respond to institutional pressures for adopting carbon-neutral practices.

Future studies reflect a more holistic approach, considering governance, market development, and regulation to identify opportunities that actively involve a wide variety of stakeholders (Gopalakrishnan et al., 2021; Jira & Toffel, 2013). In that vein, work is needed to explore how firms might leverage resources beyond their own operations, with governance structures playing a critical role in coordinating among stakeholders. Despite operating in different countries with varying carbon regulations, incentives, and taxes, diverse supply chain partners—including suppliers, customers, and logistics service providers—might cooperatively contribute to technology development, coordinate reduction accountability and responsibilities, and develop management practices for decarbonization.

5.3.2 | Measuring scope 3 across supply chains

The gradual expansion of research from firm-level commitments (Scopes 1 and 2) to supply chain-based solutions underscores the importance of a multidisciplinary approach. Accurate measurement and disclosure of indirect Scope 3 emissions are crucial for system-level change, with particular attention to climate-related risks, including physical, regulatory, reputational, and market risks (Blanco, 2021). A comprehensive carbon footprint analysis, coupled with identifying emission sources and formulating potential strategies, serves as a key starting point (Chen et al., 2022; Park et al., 2022). Engaging smaller suppliers in multi-tier supply chains, especially in emerging economies, poses challenges due to limited awareness, regulatory attention, uncertain capabilities, and investment constraints, necessitating collaborative efforts and partnerships (Odziemkowska, 2022).

Unfortunately, methods for measurement and frameworks disclosure remain in early stages, although developed economies are mandating greater precision and rigor. Voluntary disclosure has fallen short of expectations, instead yielding a proliferation of reports with varying terms and language, hindering legitimacy (Crilly et al., 2016). Standardizing accounting and reporting mechanisms across all emission scopes would enable firms to identify reduction opportunities and forecast the gap to achieve neutrality (Ertimur et al., 2020). Rigorous research would facilitate accurate cross-industry and cross-firm comparisons, providing clearer insights into operational changes and technology adoption.

5.3.3 | Integrating multiple means of reduction

Achieving carbon neutrality requires a comprehensive approach, considering technological advancements, scope of emissions, consumer preferences, and regulatory frameworks (Gao & Souza, 2022). This complex issue

requires forward-looking research, unlike much of the extant research on other topics in operations that retrospectively collect data on antecedents, practices, and outcomes or optimize existing strategies and practices. How can one assess the value and success of plans for carbon neutrality that extend 30 years into the future? Thus, identifying the 'best' strategy and combination of means is very challenging.

How might firms navigate tradeoffs between various carbon-neutrality options, striking a balance in their portfolio, given different consumer preferences and regulatory frameworks? For example, the viability of carbon offsets or capture projects depends on regulations like carbon pricing (Işlegen & Reichelstein, 2011; Zhao et al., 2023). Attractive pricing for offsets can also stimulate firms to reduce controllable emissions—assuming those can be monetized—challenging assumptions about hindering green technology innovation and adoption (Gao & Souza, 2022). Future research should explore integrated approaches and strategies that combine incentives, allocation of responsibility, supplier innovation, and directed development. Attention is needed to delve into complex decision-making processes, inherent tradeoffs, and scalability considerations amid budget constraints and conflicting priorities.

Looking forward, research must keep pace with climate science, technological developments, and evolving business models, with significant emphasis on the temporal aspects of strategies. Longitudinal studies of firms and supply chains implementing strategies for carbon neutrality, possibly viewed as strategic portfolios or real options, could provide insight into the effectiveness of multiple tactics and the interplay between specific strategies, scopes, and evolving organizational capabilities over time. Possibly, competency in one area creates synergies or conflicts with another, thereby informing the value of the sequential and cumulative impact of different strategies for carbon neutrality.

5.3.4 | Policies and regulations for scope 3

Understanding the impact of government policies on carbon neutrality strategies is evolving. Effective regulatory frameworks should consider industries and supply chain tiers contributing to carbon neutrality and competitiveness. Research should extend beyond Scopes 1 and 2 to evaluate the effectiveness of regulatory approaches to Scope 3 emissions, accounting for industry nature, product characteristics, and geographical considerations. By considering the interconnectedness among supply chain members, research can also identify and assess the implications of collaborative and coordinated regulatory strategies, particularly within larger trading regions, such as the European Union.

Furthermore, understanding the effects of regulations across multiple tiers in the supply chain is essential. Doing so might reveal how regulations ripple or cascade across tiers, thereby affecting the behavior and efforts of others to achieve carbon neutrality. Questions become more complex when considering the circular economy, such as the carbon footprint of transporting recycled products. For example, over what distance might recycled products be transported before the carbon footprint exceeds the 'value' of reduced raw material consumption? And to what degree is that a local (e.g., based on local transportation networks, options for recycling, emissions of industrial processes, etc.) versus global question (e.g., common regulations)? Both local conditions and dynamic supply chain relationships should be assessed to maximize the impact of regulatory interventions on reducing carbon emissions.

6 | CONCLUDING REMARKS

Addressing climate change and achieving carbon neutrality is a pressing issue requiring a holistic approach involving the coordinated strategies and efforts of governments, firms, and individuals, to name just a few stakeholders. Carbon neutrality presents numerous research opportunities within operations management, requiring a mix of theoretical perspectives and the inclusion of multiple tiers in the supply chain. Significant, timely investments are essential, and the potential for cost savings, efficiency improvements, and environmental sustainability prompts many unanswered research questions in operations and supply chain management.

Throughout this editorial, we have noted the realignment of operations management necessary to achieve carbon neutrality, drawing on various strategies and practices shaped by public policy. From comprehensive carbon footprint analysis to the adoption of sustainable business models and green technologies, the journey to carbon neutrality is multifaceted and differs among firms, even in the same industry. While cost barriers, complex regulations, and differing priorities, to name just a few impediments, create enormous challenges, we believe that vertical and horizontal collaboration and knowledge-sharing can pave the way for significant progress. Pursuing carbon neutrality is not just an environmental imperative but a strategic and operational necessity. In short, the journey must be taken, as there is no plan B!

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ENDNOTE

[1] A rough analogy is pollution prevention (i.e., reduce) versus control (i.e., capture or offset).

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