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Postponement strategies for supply chain environmental and economic sustainability: a systematic review, conceptual framework, and future research agenda

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ABSTRACT
Supply chains (SCs) are increasingly challenged to deliver greater value with fewer resources while minimising environmental impact. Postponement strategies have emerged as a potential solution to strike this balance, yet their impact on environmental sustainability beyond economic considerations remains under-examined. A systematic literature review provides a design-oriented approach combined with the Contexts, Interventions, Mechanisms, and Outcomes (CIMO) logic to deepen the understanding of the effects of postponement strategies on environmental and economic sustainability. The study reconceptualises postponement and traces its recent evolution, expanding it beyond delaying uncertainty-increasing value-adding activities to include their geographical location and the involvement of different supply chain partners. This further enabled the precise characterisation of contemporary postponement applications, leading to the development of propositions that suggest under which conditions postponement strategies may enhance or harm both the environmental and economic performances of SCs. Finally, a future research agenda is proposed to advance postponement and further support sustainable SCs.

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Postponement; environmental sustainability; economic sustainability; CIMO logic; conceptual framework; systematic review

1. Introduction

As climate change concerns intensify, scholars and practitioners are exploring supply chain (SC) strategies that enhance value while minimising environmental impacts through sustainable and efficient resource use (Cavallieri, Viles, and Montoya-Torres 2024). In this context, postponement strategies have been proposed to delay value-adding activities that increase uncertainty, such as deferring the specialisation of work-in-progress inventory into specific product variants or centralising distribution, thereby reducing inventory costs and associated resource consumption while maintaining customer service levels (Alderson 1950; Trentin and Salvador 2023; Zinn 1990). Recent research also highlights the importance of considering the geographical location in postponement implementation, particularly in navigating legal constraints, trade barriers, and environmental regulations in global SCs (Bednarski et al. 2023; Budiman and Rau 2019; Cohen and Lee 2020). Moreover, postponement can improve environmental sustainability by reducing inventory-related waste and transportation emissions (e.g. Simão, Gonçalves, and Taboada Rodriguez 2016; Varas et al. 2018; Varsei, Christ, and Burritt 2017). However, despite its potential, research that jointly examines the environmental and economic implications of postponement remains limited, with relevant gaps yet to be addressed.

Existing studies often overlook the tensions arising from postponement's potential negative impact on environmental and economic performance. While postponement can enhance SC efficiency by reducing uncertainty, it also introduces operational complexities (Forza, Salvador, and Trentin 2008; Trentin and Salvador 2023). These include smaller lot sizes in production and greater reliance on faster, often more energy-intensive, transportation modes (Yang, Burns, and Backhouse 2005a). Consequently, it may also lead to higher economic costs, such as processing costs and lost sales, potentially undermining economic performance (Forza, Salvador, and Trentin 2008; van Hoek 2001). While some scholars examined these trade-offs (Jabbarzadeh, Haughton, and Pourmehdi 2019; Simão, Gonçalves, and Taboada Rodriguez 2016), the absence of an integrative postponement framework that jointly considers both aspects weakens the practical applicability of postponement strategies and their relevance for firms striving to balance environmental and economic objectives. However, firms cannot address these aspects in isolation as they need to improve simultaneously (Wieland 2021). Additionally, as the postponement concept evolves (Zinn 2019), it is essential to contemplate its

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environmental and economic sustainability implications from a more comprehensive approach. This can include temporal aspects – when value-adding activities occur (Forza, Salvador, and Trentin 2008) – and spatial considerations – where these activities occur (Prataviera et al. 2020). Such an approach often entails a wider lens to postponement strategies, especially when business environments grow more interconnected and uncertain, emphasising the challenges of managing external networks in postponement implementation (Cohen and Lee 2020).

Given these limitations in the existing literature, this study adopts a systematic literature review (SLR) (Tranfield, Denyer, and Smart 2003) guided by a design-oriented approach using Context-Intervention-Mechanism-Outcome (CIMO) Logic (Denyer, Tranfield, and van Aken 2008) to address the following research question: '*How do postponement strategies affect supply chain environmental and economic sustainability?*'.

The SLR enables the synthesis of fragmented knowledge, advancing academic discourse while enhancing research relevance by providing practitioners with empirical insights to inform decision-making (Tranfield, Denyer, and Smart 2003). Its combination with the CIMO logic allows for structuring this synthesis following a realist approach that treats studies as cases, exploring how interventions operate across different contexts and identifying the mechanisms that drive specific outcomes. By systematically analysing and interpreting selected studies, this framework allowed for developing design propositions (Gauss et al. 2025; van Aken, Chandrasekaran, and Halman 2016) that clarify how postponement strategies influence specific sustainability outcomes under different conditions. This structured approach contributes to a deeper understanding of postponement's role in balancing environmental and economic objectives and highlights key areas for future research, ensuring a more comprehensive evaluation of its sustainability implications.

To the best of our knowledge, this is the first study that systematically analyses and synthesises the existing knowledge on applying postponement strategies within SCs while examining both environmental and economic sustainability implications. Accordingly, this study makes three main contributions. First, it offers a nuanced conceptualisation of postponement to capture its recent evolution, characterising contemporary postponement applications and considering environmental and economic sustainability in SCs. Second, it leverages a structured approach (CIMO logic) to propose an original conceptual model for postponement and its effect on environmental and economic sustainability performance, developing design propositions. These propositions consolidate the extant literature by clarifying how the same postponement strategies can produce either positive or negative outcomes. Also, they highlight that sustainability benefits vary in magnitude depending on contextual conditions. Third, the study formalises a future research agenda to encourage further advancements in postponement scholarship and contribute to more sustainable SCs.

The following section presents the research methodology. Next, we provide a brief descriptive analysis of the papers included, followed by a thematic analysis where we synthesise the contexts, interventions and mechanisms, and outcomes identified in the studies. Thereafter, building on these elements, we discuss the results of the studies in the form of design propositions and propose a research agenda for the future. We conclude with some closing remarks.

2. Research methodology

This study employed a research approach which combined the conduction of a Systematic Literature Review (SLR) with the adoption of a CIMO logic (Denyer, Tranfield, and van Aken 2008; Ghadge, Dani, and Kalawsky 2012; Tranfield, Denyer, and Smart 2003). This approach is widely recognised in operations and SC management for its ability to minimise bias, enhance the legitimacy and trustworthiness of data analysis (Durach, Kembro, and Wieland 2021), and provide prescriptive insights that increase research relevance (Gauss et al. 2025; van Aken, Chandrasekaran, and Halman 2016). A structured process was followed to ensure methodological rigour, outlining the identification of data sources, data extraction and synthesis, and data analysis and dissemination (Figure 1).

2.1. Identification of data sources

Given the scope and the nascent stage of postponement relating to sustainability, this study concentrates on mid- to downstream SC processes, particularly manufacturing and logistics activities. Focusing on manufacturing and logistics operations is crucial to improving firms' profitability and understanding how to reduce the environmental impacts of SCs (Jabbarzadeh, Haughton, and Pourmehdi 2019; Prataviera et al. 2020), as these operations are responsible for a substantial share of emissions (WEF 2025).

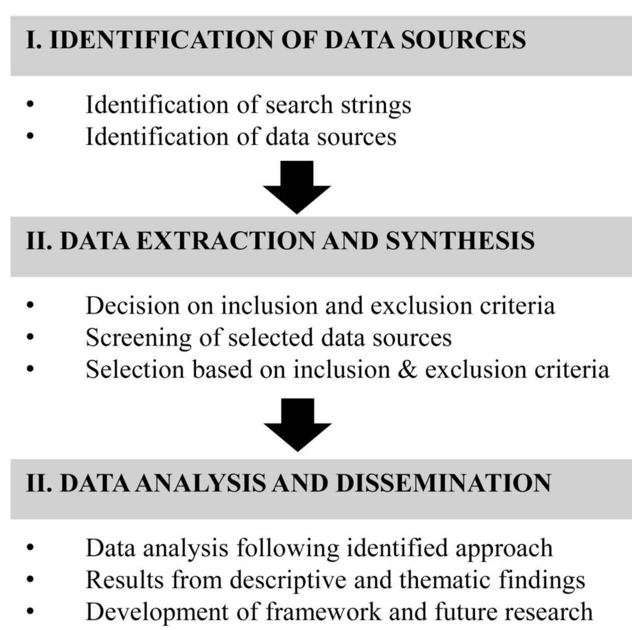

Figure 1. Systematic literature review process (adopted from Tranfield, Denyer, and Smart 2003; Ghadge, Dani, and Kalawsky 2012).

We then developed a search strategy across three reputable research databases: ABI Inform ProQuest, EBSCO Business Source Complete, and Scopus. These databases were selected because they are among the largest ones encompassing a comprehensive range of journals from major publishers. The key selection criterion was peer-reviewed published scientific articles and conference papers written in English that addressed postponement relating to both environmental and economic sustainability in SCs.

To locate relevant papers, we used the following search string using Boolean operators (AND, OR) to query the title, abstract, and keyword fields:

(postponement OR 'delayed configur*' OR modulari?ation OR 'mass customi?ation' OR 'location decision*' OR 'delayed product differentiation' OR 'late customi?ation')

AND ('supply chain*' OR 'value chain*' OR 'demand chain*' OR manufactur* OR logistic* OR distribut* OR 'supply network*' OR operation*)

AND ('economic sustainability' OR 'economic*' OR 'efficienc*' OR 'environmental sustainability' OR environment* OR sustainab* OR green* OR emissio* OR reverse OR reuse OR circular OR recycl* OR reduce)

The first part of the search string included 'postponement' along with commonly used terms in the postponement literature, such as 'delayed product differentiation' and 'late customisation' (see Lee and Tang 1997; Swaminathan and Lee 2003; Trentin and Salvador 2023), ensuring a comprehensive coverage of relevant studies. The second part encompassed variations related to SC management, particularly in manufacturing and logistics. The third part included terms related to environmental and economic sustainability, reflecting the review's specific objective to examine how postponement contributes to these outcomes. The inclusion of sustainability- and performance-related terms was a deliberate choice to ensure that the search retrieved studies explicitly linking postponement to sustainability outcomes. We included general terms such as 'economic' and 'environment' to capture a broad business environment despite the risk of retrieving a high volume of irrelevant papers.

2.2. Data extraction and synthesis

The preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram with three phases is adapted to present the literature selection process (Figure 2). Given the search string, the search was limited to peer-reviewed journals with no timeframe constraints. Then, we developed a review protocol to ensure all relevant papers were included and the selection and quality evaluation criteria were specified (Pittaway et al. 2004) (Appendix A and B). Importantly, given the limited exploration of postponement's effects on environmental sustainability, the selection criteria for this review required that studies address either environmental or economic sustainability, or both. This approach was intended to capture papers that, while not explicitly focusing on environmental outcomes, implicitly contribute to understanding the environmental implications of postponement. For example, Zinn (1990) investigated the economic benefits of postponement but also reported reductions in waste and resource consumption through improved inventory management, thereby suggesting environmental advantages. Similarly, environmental impacts can be linked to global distribution network design, typically driven by cost-effectiveness considerations (Prataviera et al. 2020). These studies illustrate how operational efficiency can enhance environmental and economic sustainability, thus warranting their inclusion in the analysis.

Following the protocols, the first round of screening titles and abstracts reduced the number of potential papers to 293. Next, a rigorous screening procedure was applied to the full text of the 293 articles through grading on a scale from zero to three for each quality element (Pittaway et al. 2004). For a paper to be accepted, a total score of at least six was required, with at least two points for theory and at least two points for methodology. Each paper was checked against the inclusion and exclusion criteria shown in Appendix A during full-text reading. Further, the reference list of all selected articles was examined to identify additional potentially relevant articles. Following calibration sessions and consensus discussions to ensure consistent interpretation and agreement across the research team (Pittaway et al. 2004), a total of 101 articles were selected for the final review.

Next, based on the scales reported in Appendix B, three researchers independently extracted data on postponement and its implementation, categorising it according to CIMO elements, achieving an inter-rater agreement rate of 91%. In cases of disagreement, the full version of the article was consulted by a fourth researcher to resolve discrepancies. This process was iteratively cross-checked against the existing literature (Forza, Salvador, and Trentin 2008; Norrman and Prataviera 2023; van Hoek 2001) to ensure consistency of the categorisation. Finally, the research team collectively discussed and agreed on the structure of the findings, further strengthening the validity of the results.

2.3. Data analysis and dissemination

The data analysis presents findings using descriptive and thematic analyses, following the approach proposed by Tranfield, Denyer, and Smart (2003). The descriptive analysis provides an overview of the research stream, while the thematic analysis is structured using CIMO elements, offering a well-documented, empirically tested generic design (Section 3.2.5) that ensures pragmatic validity (i.e. each study/research serves as a case) (van Aken, Chandrasekaran, and Halman 2016). This design is later supported by design propositions (Gauss et al. 2025; van Aken, Chandrasekaran, and Halman 2016), producing insight into where and how postponement strategies should be applied, following the pragmatic logic that if you want to achieve outcome Y in context Z, then use the intervention X (Denyer, Tranfield, and van Aken 2008), which in our study was formulated using CIMO logic.

In this regard, the CIMO-structured thematic analysis offers several benefits. First, it accommodates the complex interdependencies of SC phenomena, such as postponement, making it well-suited for analysing diverse SC management

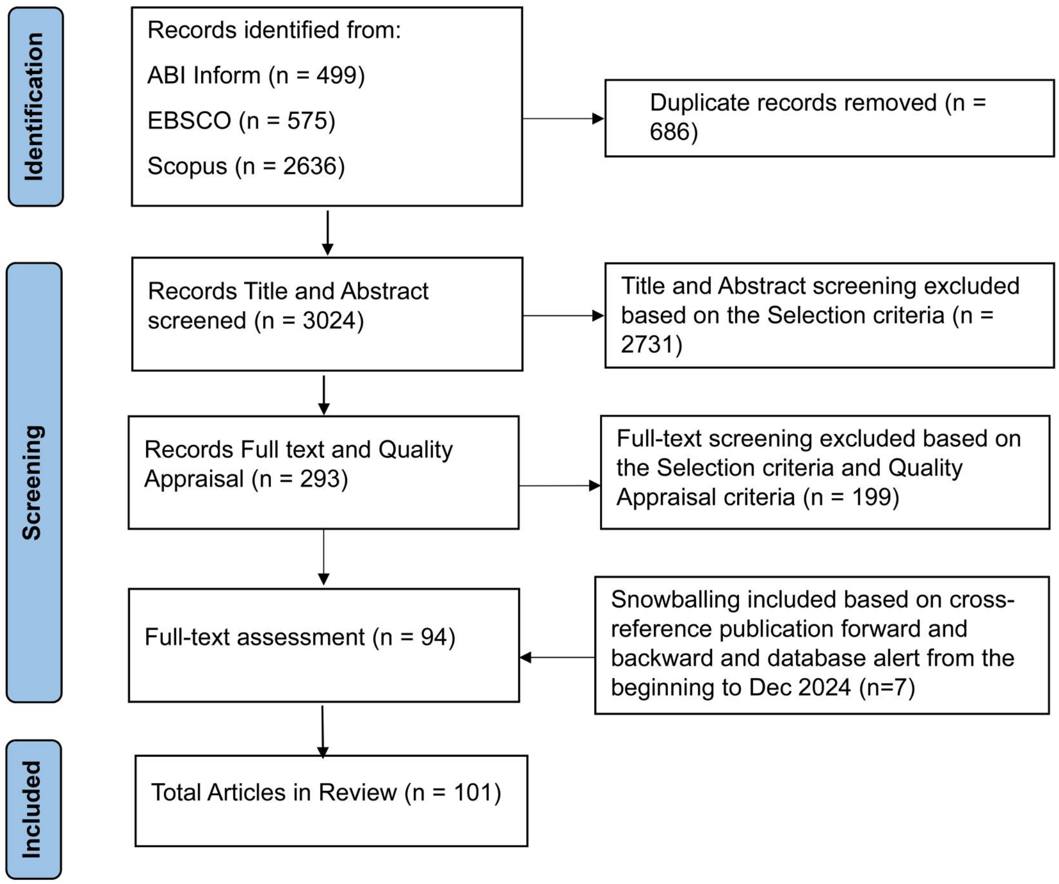

Figure 2. Paper search and selection process (PRISMA approach).

practices (e.g. Nurmala, de Leeuw, and Dullaert 2017; Pilbeam, Alvarez, and Wilson 2012; Rousseau, Manning, and Denyer 2008). Notably, it is adaptable to evolving contexts, particularly those related to environmental sustainability, which influences postponement implementation (Prataviera and Norrman 2024). Second, CIMO logic provides a structured framework for categorising elements, enabling the integration of solutions from different studies and supporting the development of a design that links postponement strategies to both environmental and economic performance. Third, it serves as both an analytical tool and a foundation for design propositions, formulating explanations regarding how postponement influences environmental and economic outcomes across varying contexts. Appendix C exemplifies the CIMO coding logic and illustrates gaps in the literature by highlighting the few papers that consider the impact of postponement on *both* environmental and economic sustainability, which are limited in their consideration of CIMO elements.

3. Findings

3.1. Descriptive analysis

The 101 articles identified are analysed in this section concerning the publication year and methodology. Based on Figure 3, it can be observed that a growing number of papers were published from 1990 to 2024, highlighting attention towards aligning postponement strategies with environmental and economic considerations in SC management. Specifically, in the year period from 1990 to 2010, 36 articles were released. This number sharply increased (65 articles) in the subsequent period.

In addition, various research methodologies have been utilised to investigate the effectiveness of postponement strategies and their impact on the environmental and economic sustainability of SCs. Notably, the rise in publications is largely driven by a number of mathematical modelling studies (48% of the reviewed papers), reflecting their strength in capturing key design elements of global production and distribution networks (Olhager, Pashaei, and Sternberg 2015). In contrast, case studies – despite their ability to explore complex, context-specific mechanisms and uncover new relationships – remain underrepresented, accounting for only 14% of the sample. This underscores the need for more empirical case-based research to better understand how postponement strategies influence sustainability outcomes in practice. Furthermore, the most recent literature review in this area dates back to 2018 (Sonego, Echeveste, and Galvan Debarba 2018), and it does not focus directly on postponement but rather on modularity as one of its enablers. The gap highlights the necessity for an up-to-date and

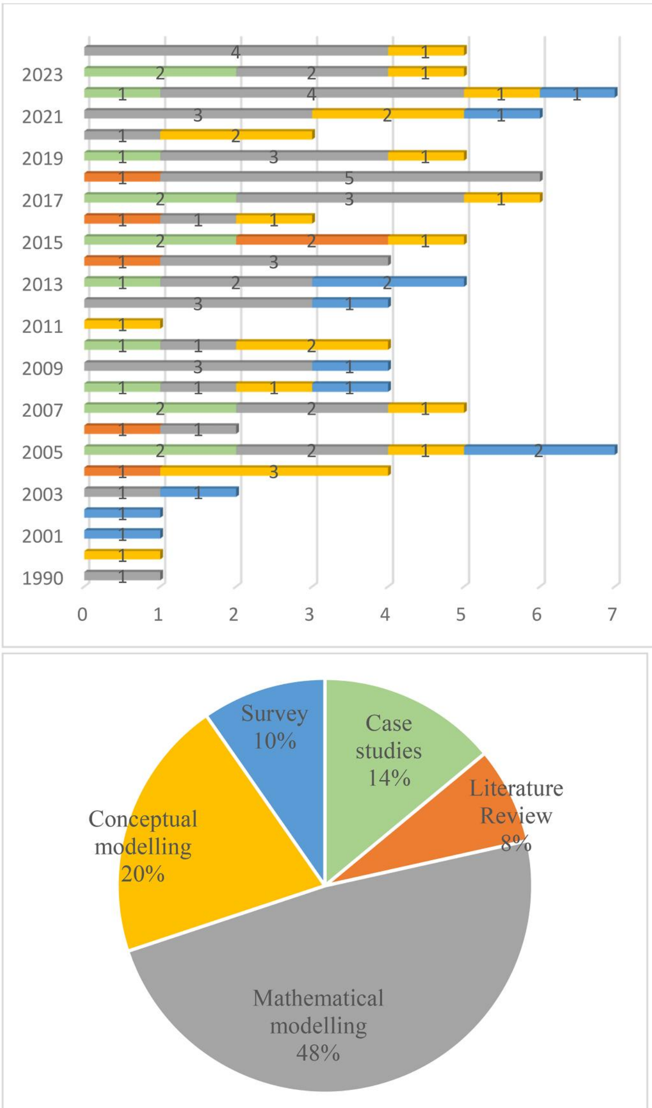

Figure 3. Year-wise and methodology-wise distribution of selected articles.

focused review of postponement strategies in relation to both environmental and economic sustainability – an aim that this study seeks to fulfil.

3.2. Thematic analysis

Developing a deeper understanding of causal mechanisms requires an iterative approach that builds predetermined themes based on existing theories and suggests new themes by examining empirical data (Durach, Kembro, and Wieland 2021). Following this approach, in this section, we first outlined potential themes based on contexts, interventions, mechanisms, and outcomes, as illustrated in Figure 4. These broad themes served as guidelines for subsequent categorisation for sub-category themes, such as product- and process-related contexts or environmental and economic performance, which were grouped based on similar underlying categorisations. An iterative process was followed to ensure that the analysis accurately represents the literature on postponement's effects on environmental and economic sustainability.

3.2.1. Contexts

Context is '*the surrounding (external and internal environment) factors and the nature of the human actors that influence behavioural change*' (Denyer, Tranfield, and van Aken 2008, 397). This study's context refers to systems and organisations where postponement implementation is studied. A discussion of the context involves describing the situation, environment, challenges, and the connections between such contextual factors. We identified twelve contextual factors through the in-depth qualitative content analysis of the selected papers, which were classified into four categories—product-related, process-related, market-related, and country-related—based on both prior classifications in the postponement and SC literature (e.g. Ketokivi et al. 2017; Norrman and Prataviera 2023; van Hoek 2001) and inductive refinement from the synthesis process. This framework enables a systematic connection between contextual factors and postponement mechanisms, as well as sustainability outcomes.

First, the product-related category encompasses product characteristics such as variety, obsolescence, bulkiness, and value density, consistent with the extant literature (e.g. Chiou, Wu, and Hsu 2002; Zinn 1990; Zinn and Bowersox 1988). Specifically, in modern SC management, the interplay of these characteristics with postponement strategies is crucial for environmental sustainability. High product variety fits well with postponement strategies due to shorter product life cycles and increased perishability, as seen in industries like food and electronics (e.g. Bandaly and Hassan 2020; Norrman and Prataviera 2023). Similarly, rapid product obsolescence in fast-paced sectors underscores the need for manufacturing postponement to enhance resource use efficiency and reduce waste (Harrison and Skipworth 2008; Yang, Burns, and Backhouse 2004a). This need is further amplified in the context of bulky products, where additional material consumption for packaging and labelling demands more efficient resource use and waste reduction, especially in transportation (Varas et al. 2018; Varsei, Christ, and Burritt 2017). Moreover, products with high-value density, tying up significant working capital due to premature manufacturing (Chiou, Wu, and Hsu 2002), benefit from manufacturing postponement strategies in terms of improved resource use efficiency and reduced waste, addressing economic and environmental concerns.

Second, the category of process-related factors concerns flexible manufacturing systems (Gualandris and Kalchschmidt 2013). In particular, high mix and volume flexibility are desirable for the postponed process, responsively providing a broad product range and offering short, reliable lead times (Harrison and Skipworth 2008; Salvador et al. 2007). In addition, required knowledge for differentiation or customisation – an appropriate level of know-how, as well as experience conducive to managing capacity and resources flexibly, is needed to adopt postponement strategies, including the capacity to support customers in identifying their own solutions or information-processing capacity during the manufacturing process (Pagh and Cooper 1998; Trentin, Forza, and Perin 2015, 2017; Trentin and Forza 2010).

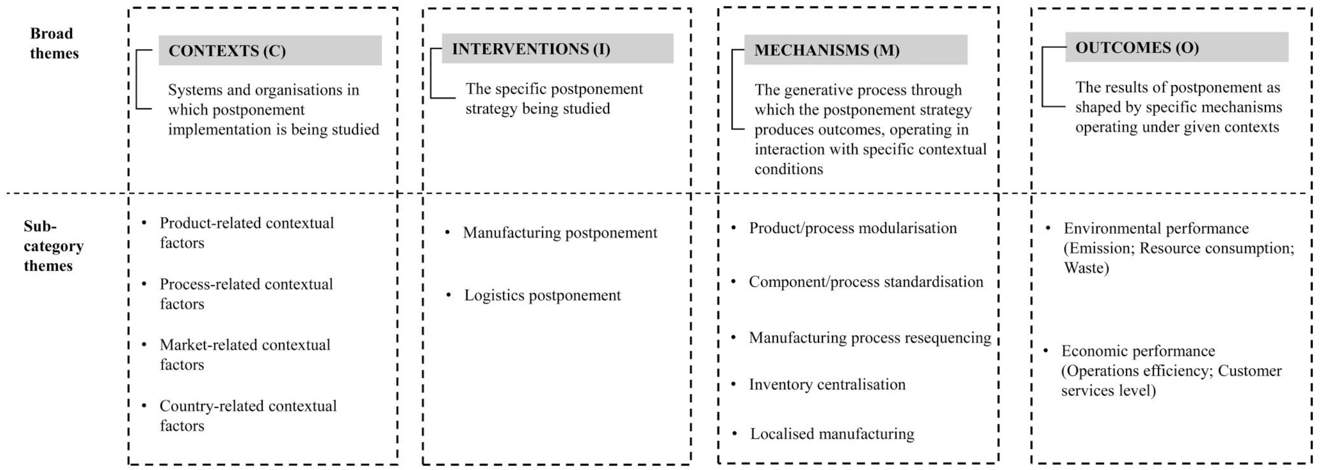

Figure 4. Themes used for the thematic analysis.

Third, the market-related category encompasses factors such as demand uncertainty and the degree of demand for customisation to meet market adaptations that introduce production and inventory complexities (Norrman and Prataviera 2023; Weskamp et al. 2019). These complexities increase the chances that firms will adopt postponement by keeping products in a generic form, which has been shown to improve SC performance. Additionally, industry-level SC collaboration intensity can positively impact postponement (Phares and Richey 2021). Collaborative relationships tend to support postponement, whereas power asymmetries in the SC can hinder it, especially when opportunistic behaviours overshadow the pursuit of optimal outcomes (García-Dastugue and Lambert 2007).

Fourth, the country-related category includes the role of trade and/or environmental policies, which are increasingly shaping the operations of global SC networks (Budiman and Rau 2019; Moradlou, Backhouse, and Ranganathan 2017; Prataviera et al. 2020). Previous scholars discussed the execution of value-adding operations as driven by factors about manufacturing costs specific to each country (Guericke et al. 2012; Ketokivi et al. 2017; Olhager, Pashaei, and Sternberg 2015). Coupled with the challenges of increased cross-country institutional heterogeneity, these factors highlight the importance of considering the spatial dimension in which postponed operations occur within the global SC framework (Table 1).

3.2.2. Interventions

Intervention refers to the event or phenomenon under investigation that managers have at their disposal to influence the behaviour of their organisations, such as through planning systems or training (Denyer, Tranfield, and van Aken 2008). This study examines two specific interventions – manufacturing and logistics postponement – aligning with our research scope. Given growing environmental concerns and global challenges, some scholars argue that postponement should be considered an evolving SC concept (Boone, Craighead, and Hanna 2007; Cohen and Lee 2020; Zinn 2019). More specifically, postponement traditionally involves delaying specific manufacturing or logistics activities – product form or inventory location – in response to demand uncertainty (Zinn and Bowersox 1988), allowing firms to determine 'when' and 'where' value is added (Forza, Salvador, and Trentin 2008; Pagh and Cooper 1998). Expanding on this perspective, Prataviera and Norrman (2024) examined postponement from an interorganisational perspective in global SCs, formalising four key dimensions: what, when, where, and who.

Building on this foundation, our review further refines the understanding of manufacturing and logistics postponement by characterising these dimensions, thereby developing a new taxonomy for postponement interventions, particularly concerning environmental and economic sustainability (Table 2). Specifically, this approach provides a geographical perspective on postponement implementation (Cohen and Lee 2020; Norrman and Prataviera 2023). Additionally, it incorporates interorganisational perspectives, which are critical since environmental performance is no longer confined to individual firm boundaries (Wieland 2021). By approaching postponement through more nuanced and structured dimensions, this study complements existing research on contemporary postponement applications and advances the understanding of how postponement influences both environmental and economic sustainability.

3.2.2.1. When dimension. Since postponement is inherently tied to the timing of operations relative to demand and customer orders to manage uncertainty (Forza, Salvador, and Trentin 2008; Yang, Burns, and Backhouse 2004a), the 'when' dimension seeks to answer the question: 'When do postponed activities happen?' The literature suggests that postponement can be applied not only to forecast-driven activities but also to order-driven activities that are deferred closer to product delivery or even after product delivery (e.g. Forza, Salvador, and Trentin 2008; Trentin and Salvador 2023). The timing of postponed activities influences operational performance, affecting economic and environmental outcomes. Specifically, if a manufacturing activity is delayed until the customer orders receipt, the supplier's uncertainty about market demand is eliminated (Forza, Salvador, and Trentin 2008; Zinn and Bowersox 1988). Conversely, if the

Table 1. Contextual factors affecting postponement implementation according to the selected literature.

Category	Contextual factors	Definition	Relevant references
Product-related	Product Variety	The number of different product versions a firm offers at a single point in time.	(Alptekinoglu et al. 2023; Alptekinoğlu and Örsdemir 2022; Appelqvist and Gubi 2005; Forza, Salvador, and Trentin 2008; Harrison and Skipworth 2008; Wong, Potter, and Naim 2011; Zinn 1990)
	Obsolescence	Products or components that are at risk of becoming outdated or no longer in demand due to perishability or changing market conditions.	(Chiou, Wu, and Hsu 2002; de Keizer et al. 2017; Leung et al. 2007a; Leung and Ng 2007b; Norrman and Prataviera 2023; Wong, Potter, and Naim 2011; Yang, Burns, and Backhouse 2004a)
	Product bulkiness	The product's size (or volume) in relation to its weight can be increased by packaging.	(Chiou, Wu, and Hsu 2002; Varas et al. 2018; Varsei, Christ, and Burritt 2017; Veiga 2013; Yang, Burns, and Backhouse 2004a, 2005a)
	Value density	The ratio between the value of a product and its weight and/or volume.	(Appelqvist and Gubi 2005; Chiou, Wu, and Hsu 2002; Yang, Burns, and Backhouse 2004b)
Process-related	Required knowledge for differentiation or customisation	Level of know-how and experience in manufacturing and/or logistics processes to be able to differentiate or customise the product to customers' requirements	(Harrison and Skipworth 2008; Norrman and Prataviera 2023; Suzic and Forza 2023; Trentin, Forza, and Perin 2012, 2015, Trentin et al. 2019; Trentin and Forza 2010)
	Manufacturing system flexibility (mix and volume flexibility)	Mix flexibility: The ability to change the range of products the manufacturing system makes within a given period. Volume flexibility: The ability to change the level of aggregated output within a given period.	(Gualandris and Kalchschmidt 2013; Harrison and Skipworth 2008; Huang and Li 2008; Krajewski, Wei, and Tang 2005; Liao, Deng, and Marsillac 2013; Salvador et al. 2007; Trentin, Forza, and Perin 2015; Wong, Wikner, and Naim 2010; Yang, Burns, and Backhouse 2004a)
Market-related	Demand uncertainty	The changes in demand for a given time bucket as it moves in time and approaches the delivery due date	(Budiman and Rau 2019, 2021; Huang and Li 2008; Jabbarzadeh, Haughton, and Pourmehdi 2019; Jin 2004; Manuj, Esper, and Stank 2014; Rau, Budiman, and Monteiro 2021; Weskamp et al. 2019; Yang, Burns, and Backhouse 2004a)
	Demand for customisation	The degree of components that are subject to market adaptation requirements (e.g. brand, peripherals, formulation)	(Chiou, Wu, and Hsu 2002; Jafari, Eslami, and Paulraj 2022; Norrman and Prataviera 2023; Tu, Vonderembse, and Ragu-Nathan 2001; Zinn and Bowersox 1988)
	Industry-level SC collaboration intensity	The relational structure of the market environment reflects the degree of cooperative interaction within and between firms to achieve mutual benefits (e.g. coordination, levels of trust, integration, joint decision-making)	(García-Dastugue and Lambert 2007; Harper 2022; Norrman and Prataviera 2023; Phares and Richey 2021; Yang, Burns, and Backhouse 2004b)
Country-related	Trade policies	A set of economic-driven government regulations and practices influencing trade activities such as import-export rules (e.g. tariff), regulatory compliance requirements, and market access (e.g. embargos or quotas).	(Harris et al. 2018; Ketokivi et al. 2017; Moradlou, Backhouse, and Ranganathan 2017; Norrman and Prataviera 2023; Olhager, Pashaei, and Sternberg 2015; Prataviera, Norrman, et al. 2022; Prataviera et al. 2020)
	Environmental policies	A set of measures and guidelines established by governments or other public and private organisations to achieve environmental sustainability and mitigate environmental impact (e.g. carbon taxes and carbon cap policies).	(Budiman and Rau 2019, 2021; Cai et al. 2022; Rau, Budiman, and Monteiro 2021; Varsei, Christ, and Burritt 2017; Veiga 2013)
	Country manufacturing costs	Differences related to production factors, materials, and part costs in different countries and jurisdictions worldwide can affect cross-border decision-making regarding what activities can be postponed and where.	(Guericke et al. 2012; Ketokivi et al. 2017; Norrman and Prataviera 2023; Olhager, Pashaei, and Sternberg 2015; Prataviera, Moretti, et al. 2022; Prataviera et al. 2020)
	Cross-country institutional heterogeneity	The configuration of SC operations across multiple countries and jurisdictions, shaped by national institutional conditions such as trade policies and regulatory frameworks, influences the spatial distribution of postponed manufacturing and logistics activities.	(Chen, Olhager, and Tang 2014; Choi, Narasimhan, and Kim 2012; Er and MacCarthy 2006; Guericke et al. 2012; Ketokivi et al. 2017; Prataviera et al. 2020; Ugarte, Golden, and Dooley 2016)

Table 2. Dimensions of postponement and their key concepts according to the selected papers.

Dimension	Key Questions	Highlights from reviewing literature	Relevant references
When	When do postponed activities happen?	- Linked to the state of demand: as late as possible, driven by forecast and order-driven activities.	(Forza, Salvador, and Trentin 2008; Harrison and Skipworth 2008; Huang and Li 2008; Iyer, Deshpande, and Wu 2003; Salvador et al. 2007; Weskamp et al. 2019; Wong, Potter, and Naim 2011; Yang, Burns, and Backhouse 2004a)
What	What activities are postponed?	- Value-adding activities that increase uncertainty, including manufacturing and logistics	(Alptekinoglu et al. 2023; Forza, Salvador, and Trentin 2008; Harrison and Skipworth 2008; Rau, Budiman, and Monteiro 2021; Suzic and Forza 2023; Varas et al. 2018; Wong, Wikner, and Naim 2010; Yang, Burns, and Backhouse 2004a)
Where	Where do postponed activities happen?	- Location across SC tiers - Geographical locations relating to global complexities such as customs tariffs, transport, and production costs.	(Moradlou and Backhouse 2016; Olhager, Pashaei, and Sternberg 2015; Prataviera, Norrman, et al. 2022; Prataviera et al. 2020; Svensson 2003; Varas et al. 2018; Varsei, Christ, and Burritt 2017)
Who	Who is involved with the postponed activities?	Emerging from the broader discourse to consider beyond the individual firm boundaries, emphasising inter-organisational dynamics.	(García-Dastugue and Lambert 2007; Norrman and Prataviera 2023; Prataviera and Norrman 2024)

postponed activity occurs before order entry but is closer to it, demand mix uncertainty is reduced but not eliminated. In both cases, less safety stock is required to maintain the same customer service level (Zinn 1990), which reduces inventory holding costs (Wong, Potter, and Naim 2011) and can be linked to resource use efficiencies and waste management, which benefit environmental performance (Simão, Gonçalves, and Taboada Rodriguez 2016; Yang, Burns, and Backhouse 2005a).

3.2.2.2. What dimension. The 'what' dimension addresses the question: 'What activities are postponed?' The literature typically associates postponement with delays in value-adding operations that increase uncertainty, such as assembly and final processing in manufacturing postponement (Alptekinoglu et al. 2023; Forza, Salvador, and Trentin 2008), and finished product distribution for logistics postponement (Pagh and Cooper 1998; Yang, Burns, and Backhouse 2004a). A key characteristic of manufacturing postponement is its reliance on identical components or modular designs across multiple final products, enhancing flexibility and efficiency (Gualandris and Kalchschmidt 2013; Harrison and Skipworth 2008). In contrast, logistics postponement focuses on inventory positioning – determining where inventory is held within the SC (Varas et al. 2018; Varsei, Christ, and Burritt 2017). This often involves delaying inventory movements downstream, such as centralising finished goods in a single warehouse. More recently, research has expanded the scope of postponement to include reverse operations, such as disassembly and remanufacturing, extending its application beyond a product's end-of-life and further contributing to sustainability goals (Rau, Budiman, and Monteiro 2021).

3.2.2.3. Where dimension. The 'where' dimension considers the question: 'Where do postponed activities happen?' and extends the discussion to examine inventory allocation (centralisation vs localisation) across the SC (Svensson 2003; Wong, Potter, and Naim 2011) and determine the optimal locations for specific market (home region, third countries, and destination) on a global scale (Chen, Olhager, and Tang 2014; Olhager, Pashaei, and Sternberg 2015; Prataviera et al. 2020).

Specifically, a geographical approach to postponement can influence economic and environmental sustainability in global supply networks. For instance, a centralised warehouse in a third-country region may be built to service one or more destination countries owing to the countries' competitive advantages (e.g. lower labour costs, customs duties) compared to those in the business's home region or destination region (Prataviera et al. 2020). In such cases, postponement decision-making is no longer solely based on responding quickly to customer demand but also considers profit optimisation. In addition, balancing trade-offs in carbon emissions may be required when considering environmental aspects. Postponement happening downstream can reduce emissions from international haulage by optimising space utilisation (Ugarte, Golden, and Dooley 2016). However, the final delivery stages often require faster transport modes or increased local deliveries, leading to higher emissions (Yang, Burns, and Backhouse 2005b). Moreover, in the context of stricter environmental regulations (Budiman and Rau 2019), firms need to (re)design their postponement approaches to achieve the appropriate level of product customisation to align with market-specific demand, further reinforcing the significance of this dimension.

3.2.2.4. Who dimension. Emerging from the broader discourse on SC relationships, the 'who' dimension shifts the focus from internal SC mechanisms to external parties, explicitly addressing 'Who's involved with the postponed activities?' (Prataviera and Norrman 2024). This dimension underscores the significance of SC relationships when implementing postponement strategies, which often involve actors beyond the conventional focal firm, including raw material suppliers, manufacturers, distributors, retailers, and consumers.

García-Dastugue and Lambert (2007) conducted an empirical study on inter-organisational time-based postponement. Their findings highlighted a sub-optimisation predicament when the needs of immediate or next-level customers precede those of the end consumers, which undermines the overall value of postponement and reduces total SC efficiency. Given the increasingly global and fragmented nature of SCs, postponement may also involve downstream actors, such as retailers or consumers, in logistics operations (Olhager, Pashaei, and Sternberg 2015; Prataviera et al. 2020). For example, retailers and consumers can participate in final processing activities and product customisation (Pagh and Cooper 1998; Zinn 2019). This also brings attention to the role of third-party logistics service providers in postponement strategies due to the increasing geographical dispersion of SCs (Trentin 2011; van Hoek 2000). However, their involvement has traditionally been driven by economic considerations, highlighting the need for further research into their role in supporting environmental sustainability within postponement strategies.

3.2.3. Mechanisms

Mechanisms consist of entities and activities that are *'contextually inferred causal processes running across an observed pattern of empirical conditions leading to an outcome or effect'* (Cornelissen and Werner 2026). Accordingly, mechanisms in the study can encompass what earlier studies labelled as enablers (e.g. Swaminathan and Lee 2003) and also emphasise their contingent and explanatory role in producing sustainability outcomes, remaining consistent with the design-oriented approach.

This study identifies five mechanisms from the extant literature (Forza, Salvador, and Trentin 2008; Gualandris and Kalchschmidt 2013; Prataviera et al. 2020; Simão, Gonçalves, and Taboada Rodriguez 2016; Trentin and Salvador 2023; Yang, Burns, and Backhouse 2005b) through which postponement can impact both environmental and economic sustainability: product/process modularisation, component/process standardisation, manufacturing process resequencing, inventory centralisation, and localised manufacturing (in terms of jurisdictions or SC tiers). It is noticed that mechanisms may interlink, depending on the specific interventions applied in the practices.

3.2.3.1. Product/process modularisation. Product/process modularisation is the basis for facilitating product variety and mass customisation. It can be defined as obtaining different products by leveraging flexibility, such as through mixing and matching different modules (Forza, Salvador, and Trentin 2008; Skipworth and Harrison 2004), allowing firms to offer customised products on a large scale while maintaining cost efficiency (Gualandris and Kalchschmidt 2013). Additionally, it can support localised manufacturing through enhanced outsourcing opportunities, decreasing international transportation emissions and associated waste (Yang, Burns, and Backhouse 2005a). Moreover, in reverse operations, modularisation also aids in disassembly processes, significantly reducing the costs related to repair and recycling, thereby improving the reverse flow operations in SCs (Rau, Budiman, and Monteiro 2021; Ülkü and Hsuan 2017).

3.2.3.2. Component/process standardisation. Component/process standardisation stems from optimising the number of identical constituent components across many (or ideally all) product variants within a product family (Forza, Salvador, and Trentin 2008; Yang, Burns, and Backhouse 2004a) to serve when applying manufacturing postponement strategies. In addition, this mechanism results in component rationalisation and increased component commonality. The higher the degree of component commonality, the lower the level of Stock Keeping Units as demand uncertainty is aggregated (Zinn 1990), helping firms achieve significant cost reductions through economies of scale and reduce associated waste and resource consumption (Trentin and Salvador 2023; Wong, Potter, and Naim 2011). However, the standardisation of modules or components does not come without costs, which are frequently accompanied by increased processing costs (Harrison and Skipworth 2008; Pagh and Cooper 1998; Zinn and Bowersox 1988).

3.2.3.3. Manufacturing process resequencing. Postponement by changing the sequence of activities of manufacturing processes is also mentioned in the literature (García-Dastugue and Lambert 2007; Guericke et al. 2012; Trentin and Forza 2010). The objective is to move the actual transformation of the product as close to the end customer as possible by moving the point of product differentiation closer to the market. This mechanism requires capital investment (Forza, Salvador, and Trentin 2008; García-Dastugue and Lambert 2007) and heavily relies on how modular the manufacturing process is (Trentin and Forza 2010). Yet, if done right, it can significantly improve the economic performance of SCs (e.g. refer to Benetton or HP DeskJet printer classic cases). This also implies increased efficiency in the utilisation of resources and a decrease in waste generation through the improved allocation of resource use (Yang, Burns, and Backhouse 2005a).

3.2.3.4. Inventory centralisation. Inventory centralisation results from products being shipped to customers only when demand is certain, if not actual order receipt, thus significantly improving time and place utility (Yang, Burns, and Backhouse 2004b). Traditionally associated with logistics postponement, where inventories are kept as finished goods, this method addresses the optimal location for storing finished stock within a distribution system. However, integrating logistics postponement with manufacturing postponement allows for a more flexible inventory that includes finished or semi-finished products or a combination of both (Guericke et al. 2012; Weskamp et al. 2019). This flexibility, dependent on the specific manufacturing postponement strategy (e.g. assembly or labelling), helps to reduce stock levels at various stages while ensuring high customer responsiveness (Forza, Salvador, and Trentin 2008). Despite these advantages, such a system may lead to more frequent and longer-distance shipments, potentially impacting the environment (Yang, Burns, and Backhouse 2005a).

3.2.3.5. Localised manufacturing (in terms of jurisdictions or supply chain tiers). The incorporation of spatial views in SCs has become imperative in response to the growing phenomenon of globalisation and the necessity for effective management of SCs, including suppliers, manufacturers, distributors, and retail markets across various geographical regions (Chen, Olhager, and Tang 2014; Olhager, Pashaei, and Sternberg 2015; Zinn and Bowersox 1988). In this context, postponement strategies enable firms to delay and localise some light or final processing operations (e.g. packaging, labelling) near the market, aiming for global efficiency and local responsiveness (Prataviera et al. 2020; Zinn and Bowersox 1988). This localised manufacturing may potentially benefit the environment. For instance, by moving packaging activities downstream (i.e. localised packaging), firms may reduce the number of transit movements between factories and local distribution centres (Varas et al. 2018; Varsei, Christ, and Burritt 2017; Yang, Burns, and Backhouse 2005a), thus providing some environmental relief. This also facilitates reverse SCs by using these facilities to consolidate products or do reverse operations (Rau, Budiman, and Monteiro 2021), thereby increasing resource-used efficiency.

3.2.4. Outcomes

Outcomes refer to the effects or results of an intervention driven by a specific mechanism under given contexts, which can be manifested as performance improvement (Denyer, Tranfield, and van Aken 2008). Accordingly, we consider supply chains' economic and environmental performance, aiming to have an integrated perspective that quantifies the impact of postponement strategies on the overall supply chain performance (Table 3). The discussion examines specific taxonomies as indicators of performance outcomes and their intended and unintended effects in the selected literature.

3.2.4.1. Economic performance. Numerous studies have looked solely at the effects of postponement on economic performance, which mostly show a positive impact on overall operations efficiency and overall costs, such as reduced inventory holding costs (García-Dastugue and Lambert 2007; Wong, Potter, and Naim 2011) while increasing or maintaining service levels, including increased delivery reliability and reduced delivery lead time (Guericke et al. 2012; Nair 2005; Skipworth and Harrison 2004). However, it is noted that postponement's mixed, or even adverse, effects on performance dimensions have long been mentioned in the postponement literature. For instance, manufacturing postponement applied before customer order entry can reduce inventory holding costs through risk-pooling effects (Forza, Salvador, and Trentin 2008; Zinn 1990). However, it may decrease transportation efficiency by increasing the number of shipments and their average size, leading to higher transportation costs and traffic congestion (Yang, Burns, and Backhouse 2005a). Conversely, postponement applied after customer orders entry and combined with manufacturing speculation (e.g. moved final processing operations downstream) (Pagh and Cooper 1998; Weskamp et al. 2019) would result in increasing processing costs due to duplication of fixed assets at the postponed activity but reduce transportation costs by eliminating haulages between factories and distributions (Forza, Salvador, and Trentin 2008).

3.2.4.2. Environmental performance. We identify three key environmental indicators: greenhouse gas (GHG) emissions, resource consumption, and waste generation. GHG emissions, which result from the absorption and emission of infra-red radiation, are a major contributor to global warming and climate change, making them a crucial measure of environmental impact (Simão, Gonçalves, and Taboada Rodriguez 2016; Yang, Burns, and Backhouse 2005a). Additionally, resource consumption and waste generation are critical for assessing eco-efficiency, as they influence both environmental sustainability and economic performance (Budiman and Rau 2019; Jabbarzadeh, Haughton, and Pourmehdi 2019).

Limited research from the selected articles has explicitly examined the issue of postponed operations considering environmental sustainability in relation to economic performance (e.g. Harris et al. 2018; Jabbarzadeh, Haughton, and Pourmehdi 2019; Simão, Gonçalves, and Taboada Rodriguez 2016; Ugarte, Golden, and Dooley 2016). Typically, the studies show positive effects on environmental aspects (i.e. environmental performance improves as postponement is adopted) and mixed effects on economic factors. Simão, Gonçalves, and Taboada Rodriguez (2016) found downstream postponement strategies, such as delayed packaging, reduced total inventory, shortened order lead times, and lowering CO_2 emissions. Conversely, manufacturing and assembly postponement might slightly increase transport traffic and potentially exacerbate environmental impacts. Ugarte, Golden, and Dooley (2016) demonstrated that manufacturing postponement enhances system flexibility, enabling firms to manage uncertainty better while reducing transportation-related emissions, albeit with a slight increase in facility-related emissions. Harris et al. (2018) further explored the environmental implications of different transport modes, routes, and packaging formats, illustrating how postponement can reshape global SCs to optimise both economic and environmental outcomes. Similarly, Jabbarzadeh, Haughton, and Pourmehdi (2019) examined the trade-offs between economic and environmental objectives in postponement strategies, concluding that postponement consistently generates cost savings across the SC, with benefits increasing as demand variability rises.

3.2.5. A CIMO-based conceptual framework of postponement strategies for SC environmental and economic sustainability

The existing literature provides a mixed picture, suggesting that the environmental outcomes of postponement are context-dependent (i.e. product-, process-, market-, and country-related contextual factors) and not always positive. We

Table 3. Postponement environmental and economic performance according to the selected literature.

Outcomes	Measurements	Effects of postponement and relevant references
Environmental performance	Reduction in emissions (e.g. airborne, affluent, land)	(+) (Budiman and Rau 2019; Jabbarzadeh, Haughton, and Pourmehdi 2019; Simão, Gonçalves, and Taboada Rodriguez 2016; Varas et al. 2018; Varsei, Christ, and Burritt 2017) (–) (Ugarte, Golden, and Dooley 2016; Yang, Burns, and Backhouse 2005a)
	Reduction in resource/energy consumption (e.g. water, electricity)	(+) (Jabbarzadeh, Haughton, and Pourmehdi 2019; Simão, Gonçalves, and Taboada Rodriguez 2016; Varas et al. 2018; Varsei, Christ, and Burritt 2017) (–) (Budiman and Rau 2019, 2021; Simão, Gonçalves, and Taboada Rodriguez 2016; Yang, Burns, and Backhouse 2005a)
	Reduction in waste (e.g. packaging waste, obsolescence)	(+) (Simão, Gonçalves, and Taboada Rodriguez 2016; Varas et al. 2018; Varsei, Christ, and Burritt 2017; Wong, Potter, and Naim 2011; Yang, Burns, and Backhouse 2005a)
Economic performance	Operations efficiency	
	Reduction in processing/production costs	(–) (Forza, Salvador, and Trentin 2008; Guericke et al. 2012; Weskamp et al. 2019; Yang, Burns, and Backhouse 2005a)
	Reduction in inventory holding costs	(+) (Budiman and Rau 2019; García-Dastugue and Lambert 2007; Skipworth and Harrison 2004; Weskamp et al. 2019; Wong, Potter, and Naim 2011; Zinn 1990)
	Reduction in transportation costs	(+) (Jabbarzadeh, Haughton, and Pourmehdi 2019; Prataviera, Norrman, et al. 2022; Varas et al. 2018; Varsei, Christ, and Burritt 2017; Weskamp et al. 2019) (–) (Forza, Salvador, and Trentin 2008; Harris et al. 2018; Jabbarzadeh, Haughton, and Pourmehdi 2019; Yang, Burns, and Backhouse 2005a)
	Customer service levels	
	Reduction in delivery lead time	(+) (Nair 2005; Skipworth and Harrison 2004; Yang, Burns, and Backhouse 2004a, 2005a) (–) (Forza, Salvador, and Trentin 2008; García-Dastugue and Lambert 2007; Guericke et al. 2012)
	Increase in delivery reliability	(+) (Harrison and Skipworth 2008; Nair 2005; Simão, Gonçalves, and Taboada Rodriguez 2016; Skipworth and Harrison 2004; Yang, Burns, and Backhouse 2004b)

Note: The signs (+) and (–) indicate positive and negative effects, respectively.

thus developed a CIMO based conceptual framework of postponement strategies for SC environmental and economic sustainability, as shown in Figure 5. Depending on the important contextual factors previously identified, we suggest that two primary interventions are manufacturing and logistics postponement, which can be approached through the four dimensions (when, what, where, and who), to capture postponement effects more accurately, enhancing understanding of the conflicting findings on environmental and economic implications. Also, this study identifies five mechanisms through which postponement strategies can influence performance outcomes. While economic benefits are frequently highlighted in the literature, the environmental implications are often less explicitly addressed. Specifically, manufacturing postponement can be implemented through product/process modularisation, component/process standardisation, and localised manufacturing – each of which has implications for both economic and environmental performance. For example, product and process modularisation increases inventory flexibility by maintaining stocks in a generic, semi-finished form (Forza, Salvador, and Trentin 2008; Salvador et al. 2007; Yang, Burns, and Backhouse 2004a). This allows firms to reduce safety stock levels (Wong, Potter, and Naim 2011; Zinn 1990) while offering a wide range of final products. Semi-finished and work-in-process items typically have longer lifecycles than fully finished goods, thus mitigating the risk of obsolescence and associated waste. In contrast, manufacturing process resequencing is primarily associated with economic performance, such as improving responsiveness and cost-efficiency (García-Dastugue and Lambert 2007), with limited evidence of direct environmental benefits. In addition, logistics postponement, which involves deferring decisions about inventory placement until later stages in the SC, is typically executed through centralised inventories (van Hoek 2001; Zinn and Bowersox 1988). This strategy enhances time and place utility by preserving flexibility in the final deployment of inventory. Centralising stock in fewer locations can also reduce the inventory required to maintain high service levels, decreasing waste due to obsolescence or product deterioration (de Keizer et al. 2017; Leung et al. 2007a; Leung and Ng 2007b).

4. Developing design propositions for postponement strategies towards environmental and economic sustainability

Drawing on a design-oriented approach grounded in CIMO logic (Denyer, Tranfield, and van Aken 2008; van Aken, Chandrasekaran, and Halman 2016), we present a structured understanding of how postponement influences environmental and economic sustainability, offering design propositions that show both when these strategies can enhance

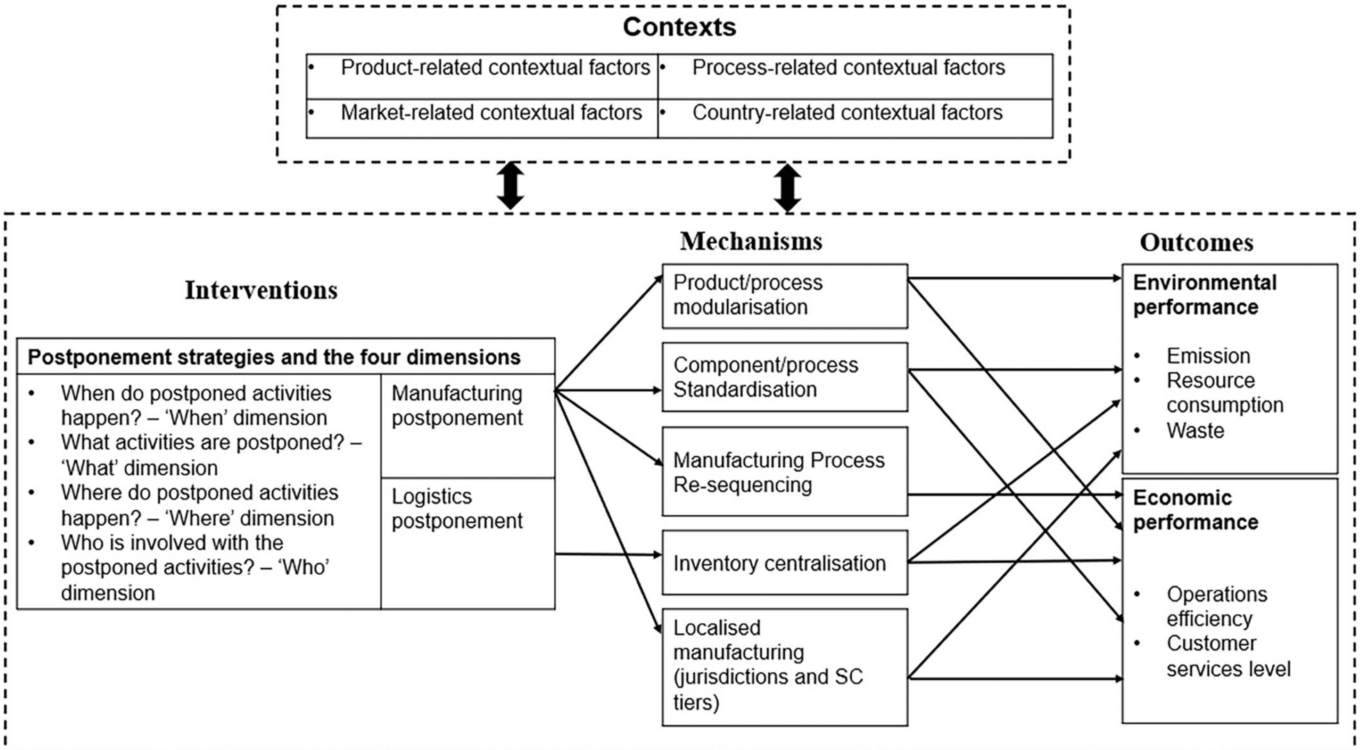

Figure 5. A CIMO-based conceptual framework of postponement strategies for SC environmental and economic sustainability.
Note: The double-ended arrows connecting contexts to interventions, mechanisms, and outcomes suggest the potential for bidirectional or reciprocal relationships. Although we recognise these relationships, this study emphasises the contexts that can influence the link between postponement strategies and SC environmental and economic sustainability outcomes.

sustainability outcomes and when they may lead to tensions or trade-offs. These propositions are not intended as precise instructions, but rather as theoretically grounded insights drawn from the SLR review pool.

4.1. Product-related contextual factors

First, product variety is crucial when discussing postponement strategies (van Hoek 2001; Zinn and Bowersox 1988). The increase in the number of products available, caused by the fierce competition of the modern market and globalisation, escalates inventory risks pertaining to demand uncertainty (Prataviera et al. 2020). Given the circumstances, firms tend to postpone their commitment to production choices and utilise modularisation and standardisation to handle complexity and uncertainties effectively (Budiman and Rau 2019). Implementing manufacturing postponement strategies reduces product/process complexity through modularisation and standardisation, leading to fewer components, processes, states, and variations, as well as reduced interaction among parts and operations (Forza, Salvador, and Trentin 2008; Gualandris and Kalchschmidt 2013; Harrison and Skipworth 2008). Specifically, when firms adopt modularisation and standardisation, they can effectively control the customer order decoupling point and the differentiating point in their production line, developing different types of manufacturing postponement. As a result, these strategic approaches not only enhance response to complexities and uncertainties by increasing flexibility in SCs but also profoundly impact environmental sustainability (Trentin, Forza, and Perin 2015). The efficient use of resources and minimisation of waste across production, inventory, and transportation stages can significantly reduce SC operations' environmental footprint (Simão, Gonçalves, and Taboada Rodriguez 2016). This discussion leads to the proposition:

Design proposition 1:	Manufacturing postponement, implemented through product/process modularisation and/or component/process standardisation, increases operational efficiency and reduces production and inventory waste, with greater benefits observed as product variety increases.

Second, the effectiveness of postponement strategies is influenced by obsolescence, which can be driven by a short life cycle and perishability of products (de Keizer et al., 2017; Norrman and Prataviera 2023). For example, modular product design enables the deferral of manufacturing in industries such as electronics and automobiles. Yet, in some process sectors, such as pharmaceuticals, there are instances where the duration of processing cycles exceeds the time it takes to fulfil customer orders. Moreover, expiration dates prevent firms from accumulating huge stocks of finished products that might expire before being sold to customers. In the context of manufacturing postponement, the risks associated with generic and semi-finished items are reduced because their aggregated demand is more consistent and predictable. Not only are predictions usually more precise, but they also have a lower expiration risk, leading to waste reduction (Yang, Burns, and Backhouse 2004a). This discussion leads to the proposition:

Design proposition 2:	Manufacturing postponement, implemented through product/process modularisation and/or component/process standardisation, increases operational efficiency and reduces inventory waste, with greater benefits observed as product obsolescence increases.

Another important context is product bulkiness (van Hoek 2001; Yang, Burns, and Backhouse 2005a; Zinn and Bowersox 1988). Specifically, when products are distributed after their assembly or packaging and often re-packaged rather than retained in bulk, the resulting increase in sizes and packaging can contribute to elevated freight and storage expenses, as well as heightened emissions, resource utilisation, and waste (Zinn and Bowersox 1988). Conversely, with modularised products, it might be possible to postpone manufacturing, moving unassembled products or components in bulk – i.e. localised manufacturing, generating huge savings attributable to inventory consolidation and decreased transportation costs (Budiman and Rau 2019, 2021; Varas et al. 2018; Varsei et al. 2017). Consequently, this may also incorporate positive environmental outcomes associated with the reduced intensity of transportation. This discussion leads to the proposition:

Design proposition 3:	Manufacturing postponement, implemented through product/process modularisation and localised manufacturing, increases operational efficiency and reduces transportation waste and emissions, with greater benefits observed as product bulkiness increases.

Fourth, the decision to implement postponement is profoundly influenced by product value density (Trentin and Salvador 2023; van Hoek 2001; Yang, Burns, and Backhouse 2004a). This factor is particularly critical for products where inventory costs outweigh transportation costs, especially for high-value-added items with numerous variations. For example, in the semiconductor industry, manufacturers typically refrain from producing specific chips before receiving orders due to the high price volatility for these valuable items (Chiou, Wu, and Hsu 2002). In such situations, a more viable approach involves maintaining an inventory of generic, standardised semiconductors, which can be subsequently reconfigured into various chip types. Consequently, by employing manufacturing postponement strategies such as modularisation and standardisation, firms can not only reduce pipeline expenses and inventory carrying costs but also implicitly minimise waste and resource consumption associated with overproduction and inventory obsolescence by better aligning demand and supply (Yang, Burns, and Backhouse 2004a). This discussion leads to the proposition:

Design proposition 4:	Manufacturing postponement, implemented through product/process modularisation and/or component/process standardisation, increases operational efficiency and reduces production and inventory waste, with greater benefits observed as product value density increases.

4.2. Process-related contextual factors

The concept of manufacturing postponement, which involves delaying product assembly or customisation so that even retailers can handle postponed operations (Pagh and Cooper 1998; Zinn 2019), often necessitates modularisation and standardisation of product/process (Budiman and Rau 2019; Rau, Budiman, and Monteiro 2021; Trentin and Forza 2010). However, the extent to which manufacturing postponement enhances operational efficiency and sustainability can be influenced by the flexibility of the manufacturing system – mainly mix and volume flexibility (Gualandris and Kalchschmidt 2013). Specifically, mix flexibility is crucial in the postponement process, allowing for a responsive production of a diverse range of products. This can be achieved through various methods, such as reducing setup times, minimising work-in-progress inventory, and shortening production cycles. Moreover, despite risk pooling effects that reduce stock levels, a certain degree of volume demand variability at a generic level is invariably present, which in many instances is substantial, thus underscoring the need for volume flexibility (Zinn and Bowersox 1988). As a result, when manufacturing systems already exhibit high flexibility, postponement strategies can be more effectively implemented through modularisation and standardisation, allowing firms to streamline planning and control, improve processing efficiency, and reduce resource consumption and waste (Harrison and Skipworth 2008). This discussion leads to the proposition:

Design proposition 5:	In manufacturing systems with high flexibility, the adoption of manufacturing postponement, achieved through product/process modularisation and/or component/process standardisation, leads to increased operational efficiency and reduced resource consumption and waste.

4.3. Market-related contextual factors

The effectiveness of postponement implemented among SC partners is impacted by collaboration (García-Dastugue and Lambert 2007), which underscores the criticality of the relational aspect in postponement strategies (i.e. the 'who' dimension). This is evidenced in logistics postponement, which is implemented through centralising inventories along the SC (García-Dastugue and Lambert 2007; Phares and Richey 2021) and reveals two primary dynamics. Particularly, in market environments characterised by high levels of SC collaboration among firms, there is an atmosphere of transparent information sharing, joint decision-making and mutual trust (Phares and Richey 2021). This environment fosters improved capacity planning and inventory management throughout the SC, leading to optimal resource utilisation and reduced waste (García-Dastugue and Lambert 2007; Mrabti et al. 2022). Conversely, challenges related to power imbalances or functionally isolated decision-making, where dominant parties take advantage and force others to centralise inventories to reduce their costs, can hinder the realisation of postponement benefits (García-Dastugue and Lambert 2007; Manuj, Esper, and Stank 2014). However, when collaboration is prioritised, these challenges can be mitigated, enabling a more efficient operation that positively influences overall SC performance and environmental sustainability. This discussion leads to the sixth proposition:

Design proposition 6:	Logistics postponement, implemented through inventory centralisation, leads to enhanced operational efficiency, reduced resource consumption, and decreased waste generation, with greater benefits observed in a high level of industry-level SC collaboration intensity.

4.4. Country-related contextual factors

Although postponement research is usually related to 'when' doing 'what' operations, it is crucial to consider the country-related contexts of cross-country institutional heterogeneity (i.e. 'where') (Ketokivi et al. 2017; Olhager, Pashaei, and Sternberg 2015; Prataviera et al. 2020). Regarding environmental impacts, adopting localised manufacturing under manufacturing postponement necessitates trade-off considerations. On the one hand, this might lead to environmental concerns about increased emissions from facilities because establishing or enlarging facilities in proximity to markets to support postponed operations incurs higher space, energy, and land costs (Guericke et al. 2012; Ugarte, Golden, and Dooley 2016). Nonetheless, the justification for these expenses arises with increasing geographical dispersion that captures the transnational configuration of operations across jurisdictions, as localised manufacturing can minimise international transportation movement and shorten the distance between collection and delivery points, thus reducing the logistics footprint (Varsei, Christ, and Burritt 2017; Yang, Burns, and Backhouse 2005a). In addition, the mechanism entails localising ancillary activities such as procurement and packaging (Zinn and Bowersox 1988) that often add an extra link to the SC. This, in turn, enhances operations efficiency by improving the consolidation of inbound flows for final product customisation or optimising freight consolidation and backhaul movements in reverse logistics, thereby potentially increasing the overall effectiveness of the SC. This discussion leads to the proposition:

Design proposition 7:	Manufacturing postponement, implemented through localised manufacturing, enhances operational efficiency and reduces transport-related emissions. However, these benefits can be offset by higher facility-related emissions and costs as cross-country institutional heterogeneity increases.

Finally, postponement implementation is influenced by heterogeneous trade and environmental policies across various countries and jurisdictions (Budiman and Rau 2019; Prataviera et al. 2020). Trade policies create tariff structures that influence where postponed activities can be most efficiently located (Prataviera et al. 2020). When tariffs are imposed on finished products, firms face increased costs if they export completed goods. Therefore, they might be incentivised to shift manufacturing or finalising operations closer to destination markets. Such near-market activities not only mitigate tariff-induced costs but can also reduce transport distance and associated emissions, as discussed in P7. However, when tariffs are imposed on bulky intermediate products, the economics of importing these items for local finalisation deteriorate, forcing firms to revert to centralised production and long-distance distribution. This configuration tends to increase both cost and environmental footprint, as illustrated in the wine industry, where tariff restrictions on bulk wine limit near-market bottling and lead to higher transport emissions (Harris et al. 2018). These contrasting patterns illustrate that different tariff structures generate divergent sustainability dynamics, including trade-offs between economic and environmental performance, particularly in the case of tariffs on finished goods. This discussion leads to the proposition:

Design proposition 8:	Tariff barriers shape the sustainability outcomes of manufacturing postponement by creating divergent incentive patterns: tariffs on finished products encourage near-market operations that reduce transport emissions but increase production costs, whereas tariffs on bulky intermediate products undermine both economic and environmental performance.

On the other hand, environmental policies influence firms' cost structures and market access (Ketokivi et al. 2017), thereby affecting the adoption of postponement strategies. Postponement strategies would be considered in conjunction with the equilibrium between environmental mandates and economic incentives or penalties these policies impose. However, when jurisdictions introduce increasingly stringent environmental policies, adopting manufacturing postponement strategies can offer significant environmental benefits while incurring a marginal increase in total cost attributed to implementing modularisation and standardisation (Budiman and Rau 2019, 2021). In this case, reduced inventory levels primarily drive this substantial effect due to the greater risk pooling effect and thereby increasing operational flexibility (Aviv and Federgruen 2001). This flexibility translates into lower costs and improved competitiveness while circumventing expenses linked to regulatory non-compliance (Simão, Gonçalves, and Taboada Rodriguez 2016). Moreover, modularisation is recognised as an effective eco-design practice throughout product life cycles (Sonego, Echeveste, and Galvan Debarba 2018), which becomes increasingly pertinent under rigorous environmental taxation regimes (Cai et al. 2022). By minimising waste from the outset, modularisation contributes to sustainable operations and improves environmental performance, demonstrating how strategic adjustments in response to environmental policies can facilitate more sustainable manufacturing and SC practices. This discussion leads to the proposition:

Design proposition 9:	Manufacturing postponement, implemented through product/process modularisation and/or component/process standardisation, enhances both environmental and economic performance by enabling waste reduction, resource efficiency, and cost savings. These benefits become more pronounced under stringent environmental policies that reward cleaner and more flexible operations.

5. Developing a research agenda

The nine propositions outlining the conditions under which postponement strategies influence both environmental and economic performance have been inductively developed based on a review of existing literature. In this case, they explain how postponement interventions lead to specific outcomes through mechanisms operating within defined contexts. This review focuses on the environmental and economic effects of postponement in manufacturing and logistics, highlighting that the mechanisms linking interventions to outcomes are complex and context-dependent. This consideration aligns with Forza, Salvador, and Trentin (2008) caution against overgeneralising effects that may apply only to particular manufacturing contexts while emphasising the risk of overlooking type-specific mechanisms. Denyer, Tranfield, and van Aken (2008) also argued that the research propositions are not intended as precise instructions to practitioners but require further testing to refine theoretical insights on contexts-intervention–mechanisms-outcomes relationships. To this end, we propose two forms of validation: conceptual testing and empirical testing, which also reveal directions for future research.

Specifically, Alvesson and Sandberg (2011) suggest that the robustness and utility of an explanation should be assessed by challenging its underlying assumptions – a process they describe as problematisation. Identifying these assumptions not only highlights the limitations of the propositions but also reveals directions for future research. For example, Proposition 8 contends that tariff barriers on bulk imports reduce the feasibility of localised manufacturing. However, such barriers do not necessarily eliminate economic viability across all contexts. Firms with favourable labour costs or strong resource complementarities with their SC partners may still find localised production economically advantageous (Ketokivi et al. 2017). Moreover, the proposition focuses primarily on the restrictive effects of tariffs, leaving out the possibility that some firms may strategically adapt or redesign their postponement configurations in response to such trade policies, hence turning regulatory constraints into opportunities for operational flexibility or regional responsiveness. Similarly, Proposition 9 assumes that efficiency gains depend on industry-specific factors such as capital intensity or regulatory frameworks. However, this assumption may not hold where, in capital-intensive industries for instance, modularisation often requires substantial upfront investments (van Hoek 2001). This consequently reduces short-term efficiency, even if long-term sustainability benefits eventually materialise (Budiman and Rau 2019). This suggests that the relationship between environmental policies, capital intensity, and efficiency gains is more complex than Proposition 9 implies and warrants further empirical examination.

Drawing on Pettigrew (2012), we suggest three essential analytical features of the technique that would permit postponement interventions to be unequivocally linked to outcomes. The first requirement is to conduct comparative studies of postponement interventions with variations in the outcomes. This would permit examining why and how variation in the mobilisation of different mechanisms creates variation in environmental and economic consequences. The second is identifying matched pairs of organisations in the same sector and political and economic context, but adopting different postponement mechanisms (e.g. modularisation versus localisation, or centralised versus decentralised logistics). Such comparisons would help isolate the effects of postponement interventions from background sectoral or contextual factors, thereby clarifying how differences in postponement interventions shape sustainability outcomes. The third is to ensure transparency and comparability in the definition of operational outcome variables across studies. While conceptual definitions of constructs such as economic efficiency may evolve over time (Wacker 2004), maintaining a baseline consistency is important for cross-study comparison.

Building on these requirements, Table 4 outlines three specific research avenues, each accompanied by future

Table 4. Future research questions, suggested methodological approaches and theoretical lenses.

Future research avenue	Illustrative Future Research Questions (FQs)	Suggested methodological approaches and theoretical lenses
Avenue 1: Empirically investigating 'when' conducting 'what' postponed operations to improve environmental and economic sustainability over time – *Temporal aspects*	FQ1: How can postponement impact emissions, operations efficiency, and customer service through such impacts as reductions in inventories and transport intensity, and how does this vary across different products and industries? FQ2: How do environmental and economic outcomes vary across the different postponement strategies adopted?	- Case studies - Natural resource-based view
Avenue 2: Examining the environmental and economic sustainability of 'where' postponement activities are carried out – *Geographical considerations*	FQ3: How do geographical locations, considering postponement strategies, affect SC environmental and economic sustainability?	- Mixed method with qualitative data (e.g. interviews) and quantitative data (e.g. survey) - Transaction cost economics
Avenue 3: Exploring how postponement influences collaboration across SC actors ('who') in the context of pursuing environmental and economic sustainability - *Interorganisational dynamics*	FQ4: How do postponement strategies impact supply chain relationships to improve environmental sustainability? FQ5: How do different postponement strategies impact different stakeholders and vice versa? FQ6: How can postponement be designed to enable improvement in environmental sustainability across SCs (i.e. involving multiple stakeholders)?	- Case studies - Stakeholder theory, the Relational view

research questions, suggested methodological approaches, and theoretical lenses for empirical investigation. Together with the proposed propositions, these aim to stimulate further research into the emerging opportunities and challenges of postponement strategies for sustainability, particularly in relation to (1) temporal aspects – empirical investigations are needed to test, validate, or extend understandings on how postponement affects environmental and economic sustainability over time; (2) geographical considerations – further examining the impact of the geographical location of postponement operations on environmental and economic sustainability; and (3) interorganisational dynamics – exploring in greater depth how interorganisational postponement and its implications for environmental and economic sustainability.

The systematic review of the available literature shows that while postponement's environmental implications have been researched, they remain fragmented and often secondary to economic considerations. Given this, future research can build on the empirically grounded insights of this review by conducting more in-depth field studies that capture real contexts of implementing postponement strategies, addressing not only the cost-responsiveness trade-off but also improving environmental sustainability. This can include empirical testing of the propositions developed above through case studies in relevant manufacturing and distribution settings. Furthermore, the use of general theoretical frameworks, such as the natural resource-based view framework, could be fruitful in terms of elucidating the rationale behind utilising postponement as a green practice, which can enable firms to generate prospects for differentiation and enhanced market influence, with the ultimate goal of attaining a competitive advantage (Trentin, Forza, and Perin 2015).

Moreover, geographical considerations in which operations occur are essential when implementing postponement for global SCs, especially in the context of frequent disruptions induced by trade tension and stricter environmental regulations in different countries. This might require researchers to engage with important work done in considering the environmental regulations (Budiman and Rau 2019), SC relationships (García-Dastugue and Lambert 2007), and cross-functional integration (Norrman and Prataviera 2023). Due to the extensive range of the subject matter, employing a mixed-methods approach can provide a better understanding of postponement applications and generate more thorough evidence by combining data sets that include quantitative methods and subjective opinions, which are best addressed through qualitative methods. In addition, transaction cost economics could provide robust theoretical support as various firms situated in different regions engage in postponement implementation, resulting in the expenditure of resources and the need to establish suitable modes of governance (Ketokivi et al. 2017; Norrman and Prataviera 2023).

Lastly, the acknowledgement of various SC partners' involvement in postponement strategies has prompted researchers to advocate for additional exploration of interorganisational dynamics (García-Dastugue and Lambert 2007; Norrman and Prataviera 2023), especially within the context of SC sustainability. For example, analysing power dynamics among various stakeholders within the SC holds the potential for strengthening SC governance in mitigating environmental consequences (Zinn 2019). Further investigation can start by discovering new relationships emerging when implementing postponement to facilitate its designation regarding environmental sustainability. Here, stakeholder theory or the Relational view can be proposed as a relevant (and timely) theoretical lens to approach environmental sustainability because it allows for capturing and analysing the broader context where multiple actors are not only involved but also accountable and directly affected by the problem in focus.

6. Closing remarks

6.1. Research implications

This study addresses a notable gap in the postponement literature by focusing on how postponement strategies affect environmental sustainability. While postponement has long been promoted to improve overall SC performance, its environmental implications have often been overlooked or treated as secondary to economic performance. In response, this study brings environmental considerations to the forefront by examining how postponement strategies affect SC environmental and economic sustainability simultaneously. Through a design-oriented approach, it also develops conditional design propositions that specify the contexts and mechanisms under which these effects occur.

In doing so, we first confirm that postponement outcomes are not uniform but context dependent. The analysis distinguishes between contingent benefits and disbenefits, which vary in strength across contexts where the same postponement intervention can deliver either positive or negative outcomes. This contribution sharpens the theoretical debate on postponement literature by clarifying when sustainability goals align and when they conflict, further advancing the broader discourse on the relationship between environmental and economic sustainability. Whereas existing postponement research often portrays these objectives as inherently conflicting (Carbonara and Pellegrino 2018; Harper 2022; Yang, Burns, and Backhouse 2005), some studies demonstrate that postponement can also generate win–win perspective by simultaneously improving cost efficiency and selected environmental indicators, particularly through modularisation and localised packaging operations (Budiman and Rau 2019; Varsei, Christ, and Burritt 2017). This body of work highlights that environmental improvements may co-occur with reduced lead times, better demand matching, and lower transport emissions, although such gains remain sensitive to SC design and geographical configuration. Our findings reconcile these positions by showing that postponement can yield synergies in some settings and trade-offs in others. This shifts the discussion from a simple dichotomy of 'trade-off versus synergy' to one of conditionality and design, highlighting how these goals can interact differently across SCs.

Finally, based on the novel approach to understanding postponement through its four dimensions (when, what, where, and who), the study sets out a forward-looking research agenda that calls for deeper empirical investigation into how firms can design and implement postponement strategies that explicitly integrate environmental sustainability. By positioning postponement as a tool for achieving dual sustainability objectives, we contribute to academic discourse and to the practical challenges firms face in pursuing SC sustainability. This perspective underscores the interdependencies across actors and locations, providing a more realistic and actionable understanding of how postponement can be deployed to balance environmental and economic performance.

6.2. Managerial implications

The CIMO framework for postponement strategies towards environmental sustainability provides a structured approach for adopting evidence-based practices within organisational settings. Hence, it offers practitioners valuable insights into the design and implementation of postponement strategies. Specifically, when manufacturing postponement is applied through product modularisation and standardisation approaches, it can yield beneficial environmental and economic outcomes where the product is high variety, product obsolescence risk is high, and the manufacturing system is highly flexible. Regulations aimed at mitigating environmental harm through stringent policies will further increase environmental sustainability performance.

Furthermore, when SCs are geographically dispersed, adopting localised manufacturing positively impacts environmental and economic sustainability performance. Despite the initial capital investment required for facility expansion or establishment, the long-term returns, manifested through enhanced operational efficiency, waste minimisation, and emission reductions, are compelling. This is particularly true when other functions, such as procurement and packaging, are also localised. However, the potential benefits of localised manufacturing must be weighed against the constraints imposed by trade barriers, which could negate these advantages by, for example, imposing high tariffs on semi-finished product exports. Additionally, the strategic consideration of centralised inventories in postponement strategies is salient, given the requirement for high levels of collaboration and coordination across the SC to optimise SC performance and enhance environmental sustainability holistically.

6.3. Limitations of the study

This study acknowledges several limitations. First, although the SLR process was conducted with rigour, the reliance on mechanical data extraction may have constrained the depth of interpretation. Second, while the selection of keywords and the screening process were applied systematically, they involved subjective judgement, which may introduce bias and affect the objectivity of the review. Notably, the search string was selected to identify studies relating specifically to environmental and economic sustainability rather than covering the broader postponement literature. This focus, while intentional, may have limited the breadth of the findings. Additionally, the study concentrated on postponement strategies in manufacturing and logistics, excluding other relevant areas such as product development and purchasing, which may also hold significant implications for environmental sustainability. Third, as postponement is a multidimensional concept embedded in complex, interdependent, and dynamic SC processes – particularly in global and fragmented contexts – the findings, while offering prescriptive insights, should be interpreted with caution. In line with earlier research (e.g. Forza, Salvador, and Trentin 2008), we advise against overgeneralising the effects of postponement on the environmental and economic performance of SCs.

Finally, consistent with the approach adopted by van Hoek (2001) and Boone, Craighead, and Hanna (2007), who refrained from using the term conclusion to reflect the evolving nature of the postponement concept, we conclude this study with closing remarks. It is our hope that this work will stimulate further research and contribute to the development of more sustainable SCs.

Author contributions

CRediT: **Trung-Hieu Le**: Conceptualization, Data curation, Investigation, Writing – original draft; **Lorenzo Prataviera**: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing; **Heather Skipworth**: Conceptualization, Formal analysis, Methodology, Supervision, Writing – review & editing; **Abhijeet Ghadge**: Project administration, Supervision, Writing – review & editing.

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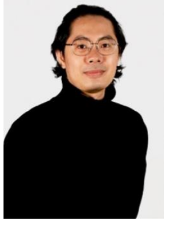

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Appendix A. Selection criteria

Criteria	Inclusion criteria	Exclusion criteria	Justification
Language	English	Any other language not formally translated	Limited resources for translation
Publication Type	Peer-reviewed academic journals and conference papers	Non-peer-reviewed or non-academic papers	Peer-reviewed journal articles are likely to be of higher quality than non-peer-reviewed publications.
Industry and Geography	All included		Contributions to the research area stem from around the world and various industries.
Research methods	All included		Different methodological approaches contribute to the research domain.
Topic	Papers on postponement in manufacturing or logistics that include its effect on either environmental sustainability or economic sustainability or both	'Location decision' only considers optimisation in general.	A large amount of literature has focused on cost minimisation and profit maximisation, which do not consider/interpret the postponement concept.

Appendix B. Quality appraisal criteria (adapted from Pittaway et al. 2004)

Element	0-Absence	1-Low	2-Moderate	3-High
Theory	The article does not provide enough information to assess this criterion.	Poor awareness of existing literature and debates about postponement concepts.	Basic understanding of the issues about postponement concepts.	Deep knowledge of relevant literature about postponement concepts. The theoretical background is clearly defined, and the research is positioned within the existing literature.
Methodology	The article does not provide enough information to assess this criterion.	Flawed research design. Unreliable methodology or unclear description of the methodology.	Research design may be improved. The methodology is transparently described, but there are minor discrepancies.	The research design is robust. Clearly defined methodology, logical and rigorous.
Findings	The article does not provide enough information to assess this criterion.	There is a weak linkage between postponement and environmental performance without an attempt to identify it.	There is an implicit linkage between postponement and environmental performance.	There is an explicit linkage between postponement and environmental performance with strong elaboration.
Contribution	The article does not provide enough information to assess this criterion.	The study adds little to the body of knowledge in linking postponement and environmental performance.	The study builds upon the existing theory and provides an adequate contribution to link postponement and environmental performance.	A significant addition to link postponement and environmental performance.

Appendix C. CIMO-based data analysis of studies examining both the environmental and economic effects of postponement

Related Studies	Methods	Contextual factors (product-, process-, market, country-related)	Postponement interventions: Type of postponement	What	When	Where	Who	Mechanisms	Outcomes: Economic- related	Environmental-related
(Yang, Burns, and Backhouse 2005)	Conceptual study		manufacturing and logistics	√	√	√	–	(1), (3), (4)	inventory and transportation cost	traffic congestion and pollution levels
(Simão, Gonçalves, and Taboada Rodriguez 2016)	Simulation modelling	product variety, demand for customisation	manufacturing and logistics	√	√	–	–	(3)	inventory and transportation costs, responsiveness	CO2 emissions in outbound transport
(Ugarte, Golden, and Dooley 2016)	Simulation modelling	manufacturing flexibility, industry-level SC collaboration intensity	manufacturing	√	–	√	–	(1), (3), (4)	cost, quality, and responsiveness	GHG emissions, facility-related emissions
(Varsei, Christ, and Burritt 2017)	Analytical modelling	cross-country institutional heterogeneity, product bulkiness	manufacturing and logistics	√	–	√	–	(3), (4)	operational costs, transportation cost	CO2 emissions, water availability and usage
(Harris et al. 2018)	Analytical modelling	cross-country institutional heterogeneity, product bulkiness	manufacturing and logistics	√	–	√	–	(2), (3), (4)	operational costs	GHG emissions
(Jabbarzadeh, Haughton, and Pourmehdi 2019)	Optimisation modelling	demand uncertainty, product variety	manufacturing and logistics	√	–	√	–	(2), (3)	operational costs	GHG emissions
(Budiman and Rau 2019)	Optimisation modelling	environmental policies, demand uncertainty, product variety	manufacturing and logistics	√	–	√	–	(1), (2), (4)	operational costs	GHG emissions, carbon tax and cap

Note: (1) Product/process modularisation; (2) Product/process standardisation; (3) Centralisation of inventories; (4) Localised manufacturing.