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The influences of Circular Economy practices on manufacturing firm's performance: A meta-analytic structural equation modeling study

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Abstract

Circular economy (CE) can arguably produce various performance benefits. Using meta-analysis and structural equation modeling (MASEM), this study synthesizes the findings from 66 empirical studies composed of 13,643 manufacturing firms. This study investigates the relationship between practices based on two CE principles (i.e., eliminating waste and pollution and circulating products and materials) and five performance outcomes grounded in the natural resource-based view of a firm. The results indicate that most CE practices significantly improve firm performance.

Specifically, *practices based on eliminating waste and pollution principle* positively affect environmental, cost-reduction, social, financial/market, and operational performances. *Practices based on circulating products and materials principle* improve environmental, financial/market, and operational performances, but not cost reduction and social performances. In addition, the *hybrid CE practices* (i.e., practices based on both CE principles) are positively linked to cost-reduction, social, financial/market, and operational performances, but they have a negative effect on environmental performance. The results suggest the possible synergy between the two CE principles. This study provides practitioners and policymakers with insights and recommendations for a better understanding of how CE practices (together) produce different performance outcomes.

Keywords: Circular economy, firm performance, Natural resource-based view, Meta-analysis, structural equation modeling, MASEM

1 Introduction

Circular economy (CE) is "an industrial economy that is restorative or regenerative through intention and design" (Ellen MacArthur Foundation, 2013). CE aims to minimize input, waste, and emission, and retain products and materials at their highest utility and value through durable design, maintenance, recycling, reuse, repair, remanufacturing, and refurbishment (Geissdoerfer et al., 2017). However, a great deal of innovation, coupled with regulatory, financial, cultural, and technology challenges may add costs and discourage firms from embracing CE (Cristoni & Tonelli, 2018). Very few companies consider CE as economically beneficial (Cristoni & Tonelli, 2018). The circularity of the global economy has decreased from 9.1% in 2018 to 7.2% in 2023, indicating a rise in material extraction rates (Circle Economy Foundation, 2023). A rigorous empirical research grounded in a solid theoretical foundation is necessary to determine whether CE can improve environmental and finance performance without adding cost burdens.

Through a meta-analysis, this study suspects the performance effects of two fundamental CE principles: i) eliminating waste and pollution, and ii) circulating products and materials (Ellen MacArthur Foundation, 2023d) may vary. We use the natural resource-based view (NRBV) of the firms by Hart (1995) to support our hypotheses. The first principle of CE emphasizes reducing waste and pollution (Ellen MacArthur Foundation, 2023c). Likewise, the NRBV argues using pollution prevention strategy and total environmental quality management to reduce waste and operational costs, and improve productivity (Hart, 1995). Currently, many packaging end up in inefficient open-loop systems. The second principle focuses on establishing closed-loop systems to improve the circularity of products and materials (Lai et al., 2013), which aligns with the product stewardship strategy that drives firms to take ownership of the impacts of the entire product lifecycle (Hart, 1995). However, closed-loop systems can be costly, and recycled or remanufactured materials or products are often lower in value, although such activities can create new business models (e.g., Loop, which is a Reuse platform) (Ellen MacArthur Foundation, 2023a). Thus, this principle may not reduce costs.

Previous studies have examined the performance effects of certain CE principles indirectly. Green supply chain management (GSCM) considers GSCM practices to consist of internal environmental management, green purchasing, investment recovery, and customer cooperation (Green et al., 2012; Zhu et al., 2011). Although GSCM literature often incorporates CE practices (Liu et al., 2018), many GSCM practices emphasize cooperation (Choi & Hwang, 2015) regardless of the CE principles. A meta-analysis finds that upstream, design, production, and downstream GSCM practices can improve market-, operational- and accounting-based performance (e.g., Golicic & Smith, 2013). Another meta-analysis ascertains that GSCM practices can improve environmental, economic, operational, and social performance (Geng et al., 2017). This study does not intend to replicate such GSCM meta-analyses that emphasize supply chain collaboration. However, since the specific GSCM practices reflect the two CE principles, this study considers GSCM practices, such as waste treatment (Agan et al., 2013), recycling and remanufacturing (Tang et al., 2022). This study also considers GSCM practices that reflect eco-design, as it emphasizes the design of products for waste reduction or for material reuse, recycling, and recovery (Younis et al., 2016).

This study is not the first meta-analysis for CE. This study differs from the recent meta-analysis by Yin et al. (2023), who mixed four types of CE practices (e.g., waste management, cleaner production, eco-design, and consumer responsibility) into a mega construct. While valuable, Yin et al. (2023) did not use a theory to differentiate the performance effects of different CE principles. To address the above research gap, this study classifies CE (and GSCM) practices into three categories: i) eliminating waste and pollution practices, ii) circulating products and materials practices, and iii) hybrid of i) and ii) CE practices. Following Hart (1995), we use the NRBV to explain the two CE principles as the basis to explain the relationships between the three types of CE practices and firms' environmental, cost-reduction, social, financial/market, and operational performances.

This study differs from previous meta-analyses in terms of method. We used the meta-analytical structural equation modeling (MASEM) approach to synthesize the evidence from previous empirical studies. Traditional meta-analysis synthesizes research findings from different primary studies into a single effect size that reflects the magnitude and direction of bivariate relationships. Instead, the MASEM helps synthesize correlation matrix and evaluate the overall fit of a hypothesized model on a set of variables, providing a more in-depth and powerful way of quantitatively integrating research findings and thus offering important insights that would advance knowledge in the field (Bergh et al., 2016).

The theoretical contribution of this study is three-fold. First, this study is the first study that integrates various CE and GSCM practices and examines them from the perspective of CE principles. Second, this study integrates the mixed findings on the performance outcomes of various CE practices into meaningful CE principles explained by the NRBV. We essentially test whether the NRBV can explain CE performance. This approach helps clarify whether different CE principles have different levels of feasibility, difficulty, and complexity, as we suspect eliminating waste and pollution is less challenging than creating a close-loop circular system. More so, few companies understand how to apply CE principles to achieve sustainable development goals (Mutezo & Mulopo, 2021). Thus, it is important to differentiate the performance outcomes of different CE principles. Third, this study extends the NRBV to better explain the mechanisms of CE principles and the complexities involved.

2 Theoretical background and hypothesis development

2.1 Theoretical framework

The theoretical foundation of this study is based on the Natural resource-based view of the firm. The NRBV plays a vital role in the changes in the relationship between the firm and the natural environment (Hart, 1995). The NRBV argues that the company's strategies and competitive advantages will be embedded in its abilities to facilitate the development of economic activities that are environmentally sustainable (Hart, 1995; Hart & Dowell, 2011). The capability of firms to overcome the constraints of the natural environment will become rare, inimitable, and valuable organizational abilities, which will consequently result in improved firm performance (Chan, 2005; Fang & Zhang, 2018). The NRBV consists of three key interrelated strategies, including pollution prevention, product stewardship, and sustainable development (Hart, 1995). Each strategy has different environmental driving forces, depends on different key resources, and possesses different sources of competitive advantages (Hart & Dowell, 2011). The three strategies are rooted in the resources and capabilities that other firms cannot easily replicate, which will not undermine the competitive advantages but instead, enhance and differentiate the firms' position in the marketplace compared to their competitors (Hart, 1995). While Golicic and Smith (2013) briefly referred to the three strategies in their meta-analysis on the relationship between GSCM and firm performance, this study argues that the NRBV may also serve as the theoretical foundation of CE practices for the following reasons.

First, the three strategies reflect CE principles. For example, pollution prevention reflects the CE principle of eliminating waste and pollution. Product stewardship means taking ownership of the impacts of the entire product lifecycle on the environment, which reflects the CE principle of circulating products and materials. Sustainable development requires the development of a shared vision, which is broader yet reflects the CE principle of regenerating nature. However, since the idea of regeneration is less understood, we do not expect to find extensive adoption of such practices.

2.2 Circular economy practices and the NRBV

CE is extensively promoted by the European Union (EU) and governments to businesses around the world (Korhonen et al., 2018). It is also considered to be a practical way for businesses to achieve sustainable development (Chowdhury et al., 2022). CE is a restorative or regenerative system that emphasizes using renewable energy and materials, eliminating the use of hazardous chemicals, and eliminating waste with careful design to retain the product's intrinsic value and highest utilization (Ellen MacArthur Foundation, 2013). CE principles include i) eliminating waste and pollution, ii) circulating products and materials, and iii) regenerating nature. CE aims to reduce the inputs of raw materials and energy resources, and the output of wastes and emissions in the production-consumption system (Rodríguez-González et al., 2022). CE is designed to decrease the costs associated with virgin materials and energy purchasing, waste disposal, and emissions control, and to create new product designs and expand market opportunities (Korhonen et al., 2018). CE is thought to promote social benefits and social equity (Kirchherr et al., 2017), human well-being, and the health and safety of employees.

As mentioned, GSCM practices are related or parallel (Liu et al., 2018) and overlap with most CE practices. The extant literature has investigated various CE practices, such as waste management (Lai et al., 2013), recycling and remanufacturing (Tang et al., 2022), and eco-design (Eltayeb et al., 2011). Various GSCM practices, such as eco-design, internal environmental management, customer cooperation, green purchasing, and investment recovery (Fang & Zhang, 2018; Fu et al., 2023; Zhu et al., 2011) may involve CE practices. However, CE or GSCM practices are conceptualized and operationalized in a variety of ways. For example, some scholars measure waste management as the sales of excess material or inventory, residual products and used materials, and replaced production equipment (Ljungkvist & Andersen, 2021), while some operationalize waste management as burning to ash landfilling (Lai et al., 2013). The former focuses on product and materials circulation, while the latter emphasizes waste elimination. Overall, CE and GSCM practices examined in the literature may reflect two CE principles: eliminating waste and pollution and circulating products and materials. We categorize CE practices into three categories (see Supplementary File A): i) eliminating waste and pollution practices (EWPs); ii) circulating products and materials practices (CPMs); iii) hybrid of i) and ii) CE practices (Hs).

Table 1 summarizes the definitions and measurement items for the three CE variables. The adoption of EWPs may be driven by regulations on pollution control or waste management. For example, the EU waste management law (Directive 2008/98/EC) requires that competent national authorities establish waste prevention programs and waste management plans (European Union, 2023). Its revised version or Directive (EU) 2018/851 further strengthens the rules on waste prevention and requires EU member states to take measures to prevent waste generation (European Union, 2023), thus giving them the power to exert coercive pressure on companies to reduce waste and pollution. Under these laws, companies may seek to reduce costs while meeting environmental legitimacy. Like the NRBV in Hart (1995), the principle of EWPs emphasizes minimizing waste and focuses on pollution prevention. Companies can replace end-of-pipe technologies (i.e., pollution control) with preventive technologies to avoid compliance costs. They can use renewable resources or reduce the use of polluting materials (i.e., pollution prevention) to gain cost efficiency and reduce compliance costs. According to Hart (1995), companies implement pollution prevention strategy through total quality environmental management (TQEM). Hart (1995: 993) described this strategy as “easy and inexpensive” and “low hanging fruit” since many companies already have TQEM, and a continuous improvement culture is required to reduce raw material input and energy consumption and prevent waste generation. EWPs without changes in product design and the management of product lifecycle cannot achieve sustainable development.

Hart (1995: 993) argued that “further reductions in emissions become progressively more difficult, often requiring significant changes in processes or even entirely new production technology”. Companies must broaden their responsibilities beyond their internal process and redesign the entire lifecycle process to minimize the lifecycle environmental cost of their product system. This gives rise to the idea of product stewardship (Hart, 1995). Through product stewardship, companies can redesign existing product systems or develop new ones with lower lifecycle costs (Hart, 1995). These ideas fit well with the circularity principle of CPMs. The adoption of CPMs may be driven by environmental policy tools such as extended producer responsibility (EPR). EPR shifts the financial responsibility of waste management from municipalities back to manufacturers, by requiring them to collect their end-of-life products and incorporate environmental considerations into their product design. Many countries have applied the EPR concept. For example, the EU Waste Management Law has introduced the EPR concept and the “polluter pays” principle. The law also mandates EU member states to encourage the design, manufacture and use of products that are reusable, repairable, durable, resource-efficient, upgradable, etc. By implementing CPMs, some manufacturers began to recycle or recover their products and materials for repair, remanufacturing, and refurbishment purposes. However, the collected materials or remanufactured/refurbished products are often lower in price and provide no or little profit. They often pay third-party logistics service providers to recycle, recover, refurbish, remanufacture, or repair end-of-life products and materials. Alternatively, some manufacturers may offer leasing services rather than selling products (e.g., Xerox) to generate new types of revenue. Other similar circular business models are driven by new regulations, such as the EU CE Action Plan and Right to Repair.

Many companies have integrated EWPs and CMPs (i.e., Hs) into their processes and business models. Hs is driven by i) laws or regulations that require countries and manufacturers to implement products and materials circulation, sustainable product design, and waste prevention, such as the EU waste management law and EU CE Action Plan; ii) EWPs and CPMs that are often used simultaneously in business operations to gain synergies. CE literature has investigated a mixture of CE practices (i.e., EWPs and CPMs) in a single construct. For example, Ljungkvist and Andersen (2021) operationalized green (new) product development as the design of products to reduce the consumption of materials/energy and the use of hazardous products and facilitate reuse, recycling, and recovery of materials and components.

Constructs	Definition	Measurement items (examples)
Eliminating waste and pollution practices (EWPs)	EWPs are related to controlling or preventing environmental pollution and waste generation in production-consumption systems.	• Reduction in the input of raw materials and energy resources (Agan et al., 2013) • Reduction in the use of hazardous materials (Ljungkvist & Andersen, 2021) • Reduction in carbon emission, waste, and pollution (Ali et al., 2021)
Circulating products and materials practices (CPMs)	CPMs are defined as practices that circulate products and materials to retain their inherent value and reuse them to minimize waste.	• Products or materials reuse, recycling, or recovery (Agan et al., 2013) • Products remanufacturing and refurbishment (Khor et al., 2016) • Design for investment recovery (Sahoo & Vijayvargy, 2021) • Use of recycled materials (Fraj-Andrés et al., 2009)

Hybrid CE practices (Hs)	Hs include CE practices that eliminate waste and pollution and circulate products and materials, with the aim to mitigate environmental damage at the product design stage.	• Design products to minimize the consumption of virgin materials and energy resources, avoid or reduce the use of hazardous materials, and facilitate the reuse, recycling, and recovery of materials and component parts (Khan & Dong, 2017; Ljungkvist & Andersen, 2021)

Table 1. Definition and measurement items of CE practices

2.3 Firm performance

Firm performance is a multidimensional construct (Wang et al., 2018). Following Geng et al. (2017) and the NRBV (Hart, 1995), we examine a broad range of firm performances that reflect sustainable development: environmental, cost-reduction, social, financial/market, and operational performances (see Table 2).

Environmental performance concerns environmental outcomes such as reduction in waste and material/energy consumption. Sustainable development emphasizes humanity. We thus examine the impact of social performance on the well-being, health, and safety of employees and wider stakeholders. We consider financial and market performances as a single construct (Green et al., 2012; Khan & Dong, 2017; Khan et al., 2021) because they are mutually interconnected. Specifically, financial performance is determined by the performance of firms in the marketplace, and market performance is driven by the financial stability and health of enterprises. Financial/market performance depends on market responses to the legitimacy of the adoption of various CE practices.

CE practices can improve cost efficiency. Cost-reduction performance depends on the effectiveness of CE practices in reducing costs. We separate cost reduction performance from financial/market performance since cost savings are the result of legitimization (i.e., reducing compliance costs) or resource efficiency (e.g., reducing material/energy consumption) from implementing CE practices. Moreover, we separate cost-reduction performance from operational performance. Adding practices to reduce waste or increase circularity could add complexity to operations, while few manufactures would be able to manage this challenge. Thus, we focus on the operational efficiency and effectiveness of firms. We measure how companies manage their resources to meet operational goals and deliver products/services, and the quality of their operational processes and activities.

Constructs	Definition	Measurement items (examples)
	ENP is associated with improving environmental quality and creating	• Reductions in air emissions, wastewater, solid waste generation, consumption of toxic materials, and

Environmental performance (ENP)	environmental sustainability through the adoption of CE practices	frequency of environmental accidents (Al-Sheyadi et, al., 2019; Sahoo & Vijayvargy, 2021) • Reduction in the consumption of virgin materials and energy (Gopal et al., 2015; Agrawal & Singh, 2019)
Cost-reduction performance (CRP)	CRP refers to the expected cost savings resultant of implementation of CE practices.	• Reduced costs in waste treatment/discharge, materials purchases, energy consumption, and fines for environmental accidents (Jain et al., 2020; Sahoo & Vijayvargy, 2021)
Financial/market performance (FMP)	FMP measures the expected financial returns, and market benefits of implementing CE practices.	• Return on assets (Novitasari & Agustia, 2021) • Asset turnover ratio (Tippayawong et al., 2016) • Return on investment, profitability, sales, and market share (Bag & Gupta, 2020; Cheng et al., 2014) • Competitiveness (Agan et al., 2013; Pinheiro et al., 2022)
Social performance (SP)	SP is defined as the overall welfare of stakeholders and corporate reputation and image after adopting CE practices.	• Employee turnover (Agrawal & Singh, 2019; Dey et al., 2020) • Occupational health and safety of employees (Cankaya & Sezen, 2019; Nara et al., 2021)

		• Consumer loyalty and satisfaction (Eltayeb et al., 2011; Fraj-Andrés et al., 2009) • Corporate reputation and image (Fraj-Andrés et al., 2009; Ghosh, 2019)
Operational performance (OP)	OP is related to the operational efficiency and operational service quality of a company with the implementation of CE practices	• Lead time (Lai et al., 2013; Younis et al., 2016) • Lower scrap rate and inventory level (Choi & Hwang, 2015; Sahoo & Vijayvargy, 2021) • On-time delivery and product quality improvement (Abdallah & Al-Ghwayeen, 2020; Eltayeb et al., 2011)

Table 2. Definition and measurement items of firm performance

2.4 Hypothesis development

The first principle of CE is to eliminate waste and pollution, which is designed and performed to control or prevent the release of emissions, wastewater, and solid/toxic wastes before their discharge or disposal into the environment. This CE principle is conceptually consistent with the pollution prevention strategy of the NRBV, with the aim to minimize emissions, effluents, and waste (Hart, 1995). Pollution prevention strategies can reduce environmental pollution and capital expenditures spent on pollution control, increase profitability, and operational efficiency, and enhance corporate reputation (Hart, 1995).

EWPs focus on waste and input reduction, which reduces pollution generated in the manufacturing process and input costs (Hart & Dowell, 2011). For example, less raw material and energy resources used can lower material and energy costs; reducing waste means the inputs can be utilized more effectively, saving the cost of raw materials and waste treatments (Hart, 1995; Young, 1991); reducing emission to a specified level can reduce the cost of regulatory compliance (Hart, 1995). The cost savings through implementing EWPs will in turn improve cash flow and increase companies' profits (Hart, 1995). Besides, reduced waste processing or resource consumption can help companies extract greater value from their assets (Palea et al., 2023), thus leading to enhanced financial performance. EWPs enable companies to improve operational performance as they can better utilize the inputs, which allows companies to lower the scrap rate and inventory levels, and thus enhance operational efficiency (Lee et al., 2013). In addition, companies can improve their product quality by purchasing goods that can be recycled and not using toxic materials (Ghosh, 2019).

A cleaner production environment also means better environment quality, health conditions, and wellbeing of stakeholders (e.g., employees). For example, a reduction in greenhouse gas emissions improves air quality, which in turn decreases the risks of heart and respiratory diseases. Reduction in the use of toxic substances (e.g., asbestos) means that the incidence of illnesses (e.g., cancer), and deaths will be lowered. In addition, implementing EWPs can enhance corporate reputation by disclosing firms' efforts in waste and pollution reduction through environmental reports (Hart, 1995), leading to a positive response from investors and consumers. Therefore, EWPs allow companies to improve their environmental, cost-reduction, social, financial/market, and operational performance. Considering that the NRBV supports the positive relationships between EWPs and firm performance as discussed above, we propose the following hypotheses:

H_1: Eliminating waste and pollution CE practices are positively associated with (a) environmental performance, (b) cost-reduction performance, (c) social performance, (d) financial/market performance, and (e) operational performance.

Uncertainties exist as to whether the first CE principle can achieve all of the above five performance outcomes for all companies. Some studies find that companies can improve environmental and cost-reduction performances by reducing waste and inputs of raw materials and energy (Al-Sheyadi et al., 2019). Purchasing products that have environmentally friendly attributes (e.g., reusable) not only helps companies improve their financial/market performance but also enhances their social and operational performances (Ghosh, 2019). However, some studies find that the adoption of zerowaste production processes is negatively associated with environmental and social performances. Energy and water resource conservation are not related to cost-reduction and operational performance (Amjad et al., 2022).). Sezen and Cankaya (2013) found that the effect of green manufacturing on financial/market performance is not significant. It is therefore important to examine all past evidence through a meta-analysis.

As the second principle of CE, circulating products and materials are designed for end-of-life product recycling, recovery, remanufacturing, repair, refurbishment, reconditioning, reuse, and resale, which helps retain the product's intrinsic value, and extend its lifecycle. Similarly, the product stewardship strategy of the NRBV requires companies to design products that can be easily recycled and reused (Hart, 1995) to maximize their product's lifespan and minimize product lifecycle costs. Thus, this CE principle conceptually aligns with the product stewardship strategy, and both serve the same purpose. Specifically, CPMs require companies to use renewable resources and products and materials with low environmental impacts. As a result, businesses abandon environmentally detrimental activities to avoid the costs of non-compliance penalties (Hart, 1995).

The implementation of CPMs (e.g., using effective reuse and recycling systems) helps companies improve the usage of energy and resource efficiency (Saha et al., 2021).

By implementing CPMs (e.g., remanufacturing), companies can establish circular business models, which not only demonstrate their commitment and ethical responsibilities toward sustainable production and consumption but also differentiate them from their competitors and align them with environmentally conscious stakeholders. For example, companies that implement recycling programs and communicate the programs with customers are perceived to be environmentally responsible, which encourages customers to spread positive feedback through word of mouth about the brand, thus improving brand reputation (Mazzucchelli et al., 2022) and enhancing customers' satisfaction and loyalty. Thus, implementing CPMs enhances the corporate reputation, product image, and consumer satisfaction and loyalty (Lu et al., 2018).

Moreover, by implementing CPMs (e.g., using recycled materials), companies can reduce the costs of product life cycle (Hart, 1995). Similarly, reducing, reusing, recycling, and recovery improve ROA, ROE, ROS, and sales (Kwarteng et al., 2022). By adopting product remanufacturing, companies can increase sales growth (Khor et al., 2016). By using circular product design, companies can improve profitability, market share, and open new markets (Pinheiro et al., 2022). Companies can also improve their operational efficiency by implementing CPMs. For example, Resortecs has developed dissolvable stitches that make the garment dismantling process five times faster and enable high-quality garment recycling at an industrial scale (Ellen MacArthur Foundation, 2023b), thereby reducing the scrap rate and improving operation efficiency. Similar positive findings on the effects of CPMs and operational performance have also been reported in previous studies. For example, Lai et al. (2013) found that the lead time and product quality can be improved by implementing reverse logistics design (i.e., adoption of modular design and use of standard materials). Implementing inventory investment, such as the sale of excess inventories or scrap materials, enables companies to reduce their scrap rate and inventory levels (Sahoo & Vijayvargy, 2021). Therefore, CPMs may positively affect firms' environmental, cost-reduction, social, financial/market, and operational performances. These findings support the tenets of the NRBV and thus we expect that CPMs will have positive effects on firm performance:

H_2: Circulating products and materials CE practices are positively associated with (a) environmental performance, (b) cost-reduction performance, (c) social performance, (d) financial/market performance, and (e) operational performance.

However, the effects of CMPs may not be universal. Studies have found negative or nonsignificant relationships between CMPs and firm performance. For example, product recovery is negatively associated with environmental performance, while its impacts on economic performance (e.g., cost reduction and profits) are not significant (Bhatia & Srivastava, 2019). Design for remanufacturing and reuse not only fails to reduce energy consumption, CO_2 emissions, and raw materials use, but also does not contribute to enhancing sales growth and profitability (Triguero et al., 2023). Similar insignificant relationships between reprocessing (e.g., refurbishment) and social, and operational performances are also reported in Lai et al. (2013). As Hart (1995) argued, it is easier to implement pollution prevention (EWPs) than product stewardship (CMPs). CMPs may require a significant redesign of products and business models. CMP requires extensive collaboration with non-traditional partners such as companies in open-loop systems, third parties, non-governmental organizations, etc. The symbolic sponsorship of a take-back scheme through third-party logistics service providers might not lead to any meaningful changes in product design and access to limited natural resources as stated in Hart (1995). Thus, the uncertainty of the H_2 will be higher than that of the H_1.

Hybrid CE practices incorporate both EWPs and CPMs. Some companies in practice combine EWPs and CPMs in their operations simultaneously. The NRBV indicates that pollution prevention and product stewardship strategies are interconnected (Hart, 1995), therefore EWPs and CPMs are interrelated. The interconnection incorporates two dimensions: first, CPMs may depend on their previous capabilities in EWPs. Specifically, companies need to make substantial advancements in EWPs to better understand materials and processes that can be made more environmentally responsible. Then they can use this knowledge to implement CPMs, such as product redesign or re-use materials from take-back schemes (Hart, 1995). When EWPs are poorly implemented, the media may perceive CPMs to lack credibility or even be hypocritical (Hart, 1995). CMPs enabled by EWPs can also contribute to waste reduction. Second, EWPs capabilities (e.g., TQEM) are embedded within CPMs and can facilitate and accelerate the capabilities development in CMPs (Hart, 1995). Companies can take advantage of the synergy effects of EWPs and CPMs to enhance firm performance. For example, environmental performance can be enhanced by accumulating EWPs and CPMs capabilities simultaneously (Hart, 1995). The above arguments provide the basis to extend the arguments of Hart (1995). Here we argue that it is likely some of the uncertainties and difficulties in H_1 and H_2 can be the outcome of the mutual complementarity between EWPs and CPMs. Hs reflects the combination and accumulation of EWPs and CPMs in a unique manner. Based on this extended view of the NRBV, we hypothesize that:

H_3: Hybrid CE practices are positively correlated with (a) environmental performance, (b) cost-reduction performance, (c) social performance, (d) financial/market performance, and (e) operational performance.

Previous studies find that Hs have positive effects on firm performance. For example, some studies have shown that implementing Hs, the combination of EWPs (e.g., designing products that reduce the use of material, energy, and toxic substances) with CPMs (e.g., designing products that facilitate reuse, recycling, recovery of materials), enables companies to improve environmental performance (Green et al., 2012; Iranmanesh et al., 2019), financial/market performance in terms of profitability, market share, sales growth rate, and earnings per share rate (Choi & Hwang, 2015) and operational performance in terms of scrap rate, inventory levels, product quality, and amount of goods delivered on time (Sahoo & Vijayvargy, 2021). Implementing EWPs through CPMs, companies can reduce costs associated with resource procurement and waste treatment (Rehman et al., 2022; Yu et al., 2022). Adopting both EWPs (e.g., eliminating the use of hazardous materials) and CMPs (e.g., designing products that promote repair, rework, and refurbishment) at the same time will improve the health and safety of stakeholders, thus leading to enhanced social performance (Abdul-Rashid et al., 2017). However, some studies reveal negative or insignificant effects of Hs. For example, some scholars find that Hs can increase firms' production costs (Green et al., 2012; Tang et al., 2022), while others find Hs is not related to environmental, social, and operational performances (Diab et al., 2015; Younis et al., 2016). This again justifies a meta-analysis.

Figure 1 shows a theoretical model that illustrates the relationships between CE practices and firm performance.

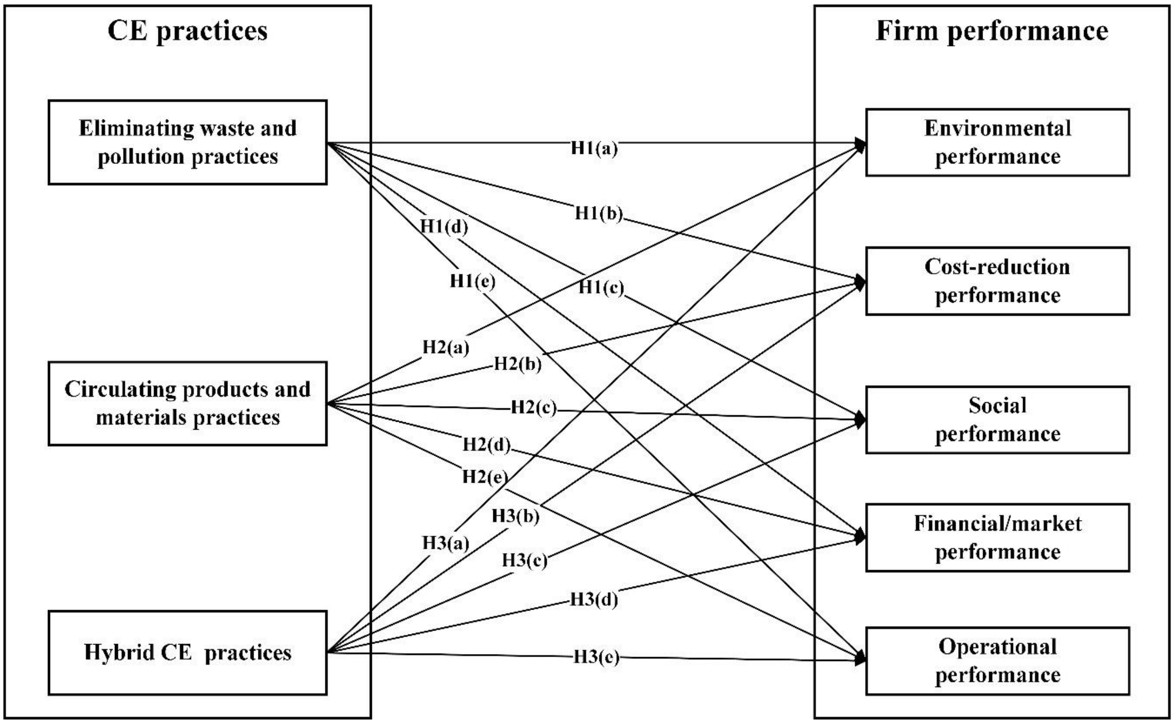

Figure 1. Theoretical model

3. Methodology

We adopted a four-step MASEM approach (Bergh et al., 2016) (see Figure 2). In Step 1, we: i) developed search strategies and conducted a literature search, ii) identified relevant studies and selected sample articles for the literature review, and iii) finalized the key variables, focal relationships, and theoretical foundation to construct the theoretical model. In Step 2, we conducted a meta-analysis to generate a pooled correlation matrix. This involved: i) data collection, ii) a sensitive analysis, which aims to identify the outlier studies; iii) model selection and heterogeneity test, which aim to determine whether the fixed or random effects model should be used in this study, and iv) a publication bias test, which determines whether the sample articles overestimate the true effect size and introduce bias. In Step 3, we performed a structural equation modeling analysis, and fit the structural equation model by using the pooled correlation matrix for the research results (Jak, 2015). Finally, we reported the MASEM results.

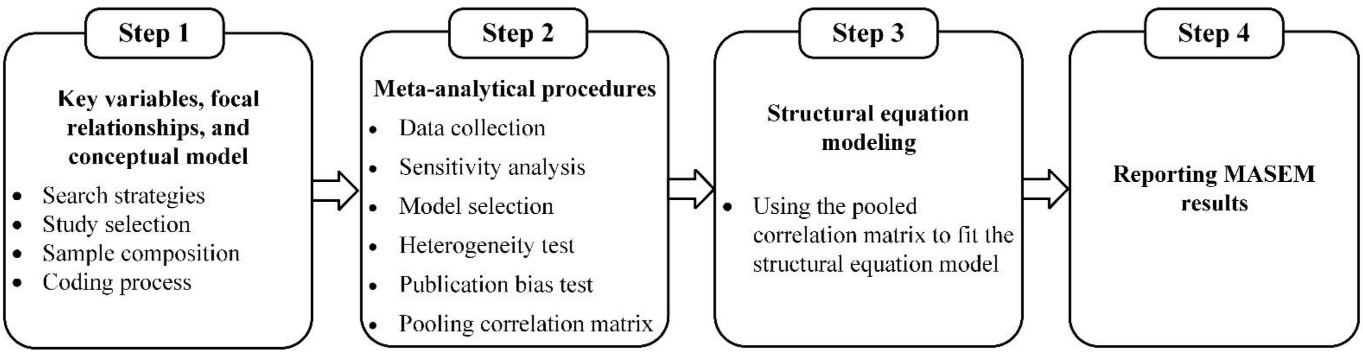

Figure 2. Specific procedures for conducting MASEM in this study.

3.1 Step 1: Key variables, focal relationships, and theoretic model

3.1.1 Search strategies

The systematic search process of publications was conducted by using two databases, including the Web of Science (WOS) and the ABI/INFORM Collection (See the justification of database use in Supplementary File B). To ensure the comprehensiveness of the literature search, we referred to the keywords and their synonyms in the literature on CE practices and firm performance. After that, we identified four sets of keywords and their relevant synonyms, including i) CE-related keywords[1]: circular economy, recycle, refurbish, remanufacture, repurpose, eco-design, and extended producer responsibility (Kirchherr et al., 2017); ii) practice-related keywords: practice, activity, environment, and manufacturing (Geng et al., 2017); iii) performance-related keywords: performance, outcome, consequence, benefit, effect, return, profit, turnover, revenue, firm value, growth, sales, competitive advantage, quality, market share, customer loyalty, and customer satisfaction (Grosse et al., 2015); and iv) empirical keywords: empirical, data, test, statistical, finding, result, evidence, survey, and investigation (Grosse et al., 2015). Next, we developed a search string based on these search terms (see Supplementary File C) and identified 14,956 articles published in English from January 1970 to December 2021. To avoid omission of the relevant papers, we manually collected 20 additional empirical studies from the databases of Science Direct, Emerald Insight, Taylor & Francis, Wiley Online Library, and Springer. In total, 14,976 studies were obtained.

[1] The keywords in CE-related keywords list, such as recycle, refurbish, remanufacture, repurpose, and eco-design, reflect CE principles and encompass sustainable practices on both CE and GSCM.

3.1.2 Study selection and sample composition

The selection process of publications consists of two phases. First, the titles and abstracts of the sample articles were reviewed for relevance. The exclusion criteria are review, modeling, and qualitative analysis studies, and studies that are irrelevant. After eliminating these studies, we obtained 12,618 studies. Then, we reviewed the full-text articles to assess their eligibility. The inclusion criteria are studies that: i) examined the relationship between CE practices at the firm-level and firm performance in the manufacturing industry; and ii) reported Pearson's product-moment correlation coefficients (r) (Geng et al., 2017; Hizarci-Payne et al., 2021) or other statistics such as standardized regression coefficients (β) that can be converted into correlation coefficients (Yadav et al., 2023; Zheng & Iatridis, 2022) on the relationship between CE practices and firm performance. However, studies that involved or were partially involved in the relationship between CE practices and firm performance in other industries (e.g., service industry) were excluded.

In addition, to ensure statistical independence between the included studies, the same dataset was adopted only once if studies used the same dataset. We identified studies that used the same databases by examining their data sources (i.e., name of the database, number of companies, country of origin, and industry sectors). If several targeted studies were found to use the same dataset, we selected the study that has the database with most companies. As a rule, a larger sample size indicates higher statistical power (Prajapati et al., 2010), which is especially important in interpreting findings from empirical studies (Fraley & Vazire, 2014). Studies with a high statistical power are more likely to provide accurate estimates of the effects and have a lower rate of false positive results than studies with a low statistical power (Fraley & Vazire, 2014). In the end, 66 empirical studies were considered eligible for synthesizing the results. Figure 3 shows the process of sample selection by using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram (Hansen et al, 2022).

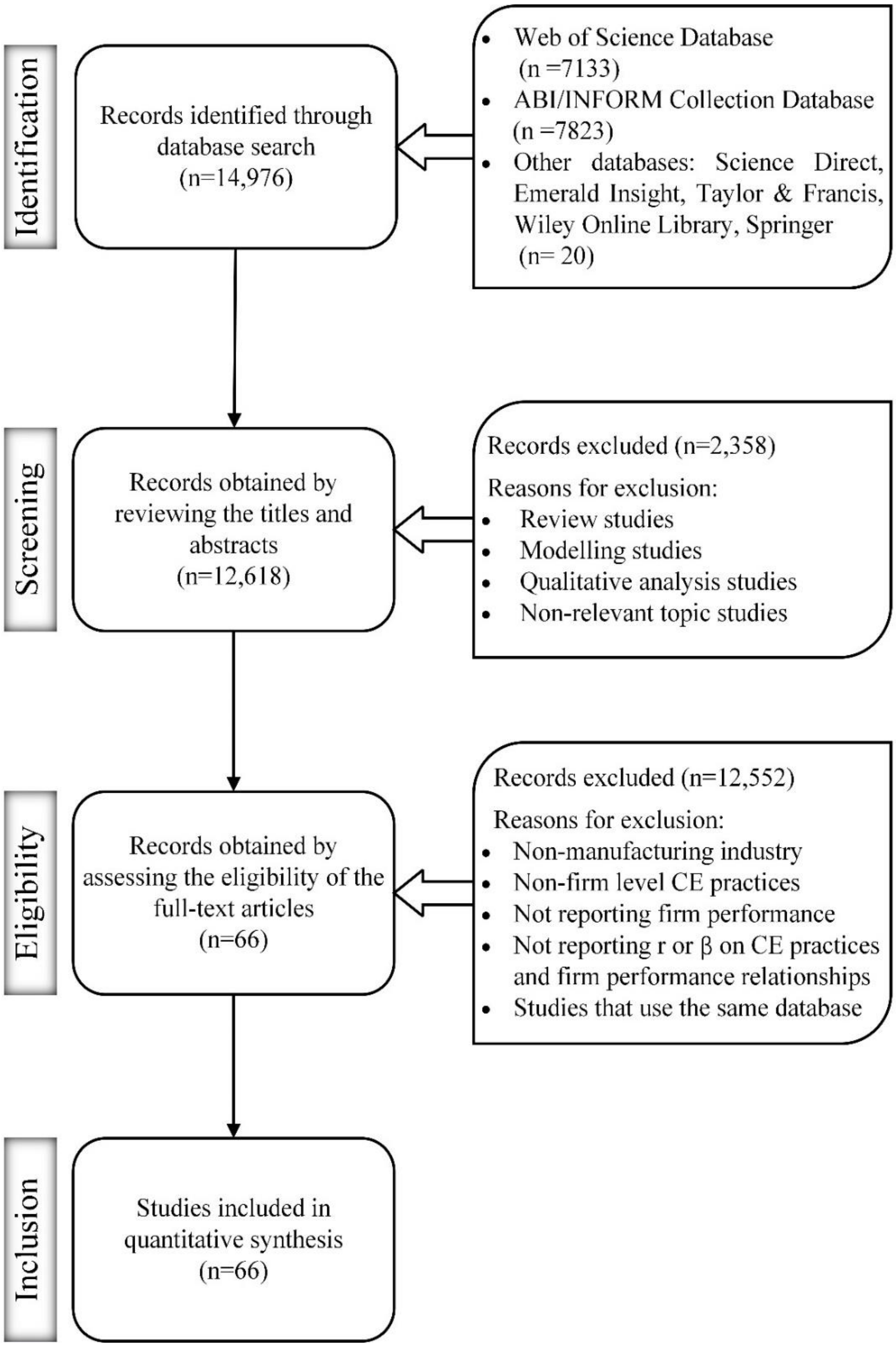

Figure 3. PRISMA process for selecting sample studies.

3.1.3 Coding process

The coding process comprised three steps. First, two authors reviewed the collected studies that examined the relationship between CE/GSCM practices and firm performance in the manufacturing industry. Second, the authors reached a consensus that the classification of CE/GSCM practices based on CE principles, the NRBV as the theoretical foundation, and the conceptual definitions of CE/GSCM practices (i.e., EWPs, CPMs, and Hs) and firm performance (i.e., environmental, cost-reduction, social, financial/market, and operational performances) (see Sections 2.2 and 2.3). In addition, the variables/constructs in each sample study were classified into the identified categories when more than 75% of the measures of each variable/construct closely matches the proposed conceptual definitions of CE practices and firm performance (Hunter & Schmidt, 2004). Finally, two authors coded the data independently to minimize coding errors, and the interrater reliability exceeding 90% (Tsai et al., 2020). Coding discrepancies were discussed until a unanimous 100% agreement was achieved (Bergh et al., 2016). Based on the NRBV, we established the relationships between CE practices (i.e., EWPs, CPMs, and Hs) and the firm's environmental, cost-reduction, social, financial/market, and operational performances, and developed a theoretical model (see *Section 2.4 and Figure 1*). The specific details of the coding process are shown in Supplementary File D.

3.2 Step 2: Meta-analytical procedures

Comprehensive Meta-Analysis (CMA) version 3.0 software was used to perform the meta-analysis.

3.2.1 Data collection

To examine the relationship between CE practices and firm performance, we used r as the effect size (Geng et al., 2017). If r was not reported in the articles, other statistics (i.e., β) were extracted from the articles for the meta-analysis (Chen et al., 2021). Among the 66 empirical studies, 15 studies did not directly report r but instead reported β on the relationships between CE practices and firm performance. As β cannot be directly used as the effect size in the meta-analysis, $r= \beta+0.05\lambda$[2] was used instead as per Peterson and Brown (2005) to convert β into the corresponding r. Besides, we developed a coding sheet to compile the data and information from the sample articles, including the: i) study characteristics: study name, industry type, region/country, and published journal; ii) theoretical foundations; iii) methodology: effect size (i.e., r or β), sample size, data type, and analytical method (see Supplementary File E).

3.2.2 Sensitivity analysis

A sensitivity analysis was performed by using the "one-study-removed" procedure in CMA 3.0. This method recalculates the meta-analysis after removing one study at a time to identify potential outlier studies that affect the results. We conducted the "one-

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[2] $\lambda=1$ when β is nonnegative and 0 when β is negative, $\beta\in(-0.5, 0.5)$ (Peterson and Brown, 2005).

study-removed" sensitivity analysis to determine whether the overall estimate of the relationship between CE practices and firm performance would be affected by any potential outlier studies (Salyers et al., 2017). The results showed that the point estimate of the average effect size did not change substantially when any single study was removed. Therefore, we continue to use the 66 articles for the analysis.

3.2.3 Model selection and heterogeneity test

In a meta-analysis, two types of models can be applied: i) a fixed-effects model and ii) a random-effects model (Borenstein et al., 2009). Under the fixed-effects model, all studies share a true and common effect size[3], and thus all differences in the observed effect size from one study to another are attributed to sampling errors (Borenstein et al., 2009). However, the random-effects model assumes that the true effect size might vary among studies. The dispersion of the observed effects[4] in the primary-level studies is due to the variances of the true effects and sampling error (Borenstein et al., 2009). In this study, the collected articles show heterogeneity in their characteristics, including the industry type, country of origin, respondent category, and measurements, which would impact their results in different ways, and thus these studies would not share a common effect size. The random-effects model is more appropriate when studies are

[3] The true effect size refers to the effect size that we would observe if the study had an infinite large sample size (Borenstein et al., 2009).

[4] The observed effect size refers to the effect size that is actually observed in the sample (Borenstein et al., 2009).

collected from the literature that have been published (Borenstein et al., 2009) and the studies involve different respondents and measurements (Nogueira et al., 2023). Therefore, the random-effects model is more appropriate for this study.

We also conducted a heterogeneity analysis to determine if we had chosen the right model (i.e., random-effects model) for further analysis. Table 3 shows the results of the heterogeneity analysis in terms of the Q statistic and its p-value, I^2, T^2, T, and prediction interval (PI)[5]. Specifically, the Q value of the entire sample is 939.28 with 65 degrees of freedom and p<0.001, which reflects the true heterogeneity across the sample. An I^2 statistic of 93.08% indicates the high degree of heterogeneity presented among studies, and 93.08% of the variance in the observed effects reflects the variance in the true effects rather than the sampling error. The PI is between -0.01 and 0.77, which means the true effect size in 95% of all comparable populations will fall in this range. The variance of the true effects T^2 is 0.065 and the standard deviation of the true effects T is 0.255. Therefore, we use the random-effects model for further analysis.

However, the results indicate that there is no heterogeneity between studies with

[5] Q statistic is to assess whether true heterogeneity is found in the meta-analysis (Huedo-Medina et al., 2006) and its p-value serves as a significant test (Borenstein et al., 2009). Using the Q statistic, the null hypothesis that all studies share a common effect size is tested (Borenstein et al., 2009). In the null hypothesis, the Q statistic will follow a chi-square distribution with degrees of freedom (n-1, where n is the number of studies) (Borenstein et al., 2009). In this case, a fixed-effect model is adopted since the estimated effect size differs only by sampling error (Huedo-Medina et al., 2006). In contrast, it is suggested that a random-effect model is adopted since this model considers both within and between studies variability if the null hypothesis is rejected (Huedo-Medina et al., 2006). I^2 refers to the ratio between the true heterogeneity and the total variance in the observed effects (Borenstein et al., 2009). Heterogeneity is considered as low, moderate, or high when I^2 equals 25%, 50%, or 75%, respectively (Borenstein et al., 2009). PI is used to address the distribution of true effect size, T^2 represents the between-study variance, and T refers to the standard deviation of the true effects (Borenstein et al., 2009).

Q=0.543, p=0.762, I^2=0%, and T^2=0.000 for the association of SP and OP. Thus, we report the mean effect size calculated in the fixed-effects model for this relationship. For the relationship between CRP and SP, the results of the Q=3.651 and p=0.161 indicate that there is no heterogeneity among the studies. However, the Q statistic and its p-value only test the significance (Borenstein, 2009). Thus, an insignificant p-value cannot be used as evidence to indicate that studies share a common effect size since studies with small sample sizes, high within-study variance, or significant between-studies dispersion will lead to an insignificant p-value (Borenstein, 2009). In this case, T^2 and I^2 should also be considered. I^2 and T^2 are directly related, the higher the T^2, the higher the I^2 (Huedo-Medina et al., 2006). The between-study variance T^2 is 0.004, and I^2 of 45.216% indicates moderate heterogeneity. In addition, the studies that examined the relationship between CRP and SP were conducted in different countries (i.e., Pakistan, China, and Thailand), in different manufacturing industries, and with different types of respondents from different cultural backgrounds. Thus, a random-effect model was adopted to calculate the average effect size for the relationship between CRP and SP.

3.2.4 Publication bias test

Publication bias threatens the validity of any research work (e.g., meta-analysis) that uses published studies. (Fragkos et al., 2014). The publication bias occurs because studies with statistically significant results are more likely to be published than those with statistically non-significant results. Such selective reporting of scientific results is called the "file drawer" problem, which extends the possibility that the published findings reflect Type I errors (Franco et al., 2014). Published studies are more likely to be included in the meta-analysis, which means any data from grey or unpublished literature are excluded (Borenstein, 2009). In a meta-analysis, the true effect size might be overestimated if the analysis is based on a biased sample (Borenstein, 2009). Specifically, missing studies with nonsignificant results are likely to be excluded from a meta-analysis, and these studies would nullify the observed effect if included (Borenstein, 2009). Therefore, there is a need to examine the potential risks of publication bias in this study (Rosenthal, 1979).

In this paper, publication bias is determined by aggregating each single correlation under a random-effects model (Scherer et al., 2019). First, we tested Rosenthal's fail-safe number (N_{fs}), which is used to calculate the number of missing studies that are required to be included in the meta-analysis before the p-value becomes insignificant (Rosenthal, 1979). The fail-safe *Ns* indicated that 42,675 missing studies should be included to nullify the CE practices and firm performance correlations (see Table 3), which is unlikely to happen. Besides, according to Rosenthal (1979), the publication bias is minimal if the $N_{fs} > 5k + 10$, where N_{fs} is the fail-safe number, and k is the number of studies. The results show that N_{fs} is minimal for every single correlation.

Next, we combined the "funnel plot[6]" and the "trim and fill[7]" method to identify the extent of each correlation that was influenced by publication bias (see Supplementary File F) (Scherer et al., 2019). Although the results indicate publication bias in some relationships (e.g., EWPs-CPMs), it is not a serious issue in this study for two reasons: i) none of the adjusted effect sizes changed in direction or significance (Herhausen et al., 2021); and ii) overlapping of the confidence intervals between the average effect size calculated from the meta-analysis and the adjusted average effect size by using the trim and fill method (Allan et al., 2019) (see Supplementary File G). For example, the average effect size of EWPs-CPMs from the meta-analysis is 0.393 with a confidence interval of 0.235 to 0.530. By using trim and fill techniques, the adjusted effect size is 0.370 with a confidence interval of 0.216 to 0.506. Thus, we used the adjusted effect sizes in the pooled correlation matrix. In sum, the results suggest that publication bias is not a concern in this study.

						Heterogeneity					
Relationship	k	N	r	95CI	N_{fs}	Q statistic	p-value	I^2	95PI	T^2	T

[6] The funnel plot is a visual assessment method, which is used to check for any publication bias (Borenstein et al., 2009).
[7] The "trim and fill" method employs an iterative procedure to remove most extreme small studies that cause the asymmetry of the funnel plot, and then recalculate the effect size at each iteration until the funnel plot becomes symmetric, which yields an unbiased estimate of the effect size (Duval & Tweedie, 2000).

CE-FP	66	13,930	0.468	[0.413, 0.519]	42,861	939.280	0.000	93.080	[-0.01, 0,77]	0.065	0.255
EWPs-CPMs	14	3,252	0.370	[0.216, 0.506]	1,595	323.195	0.000	95.978	[-0.70, 0.93]	0.106	0.326
EWPs-Hs	7	1,559	0.583	[0.408, 0.717]	1,276	128.235	0.000	95.321	[-0.81, 0.91]	0.094	0.307
CPMs-Hs	15	3,644	0.615	[0.541, 0.680]	6,574	160.903	0.000	91.299	[0.24, 0.83]	0.044	0.210
EWPs-ENP	23	4,201	0.588	[0.481, 0.678]	7,242	396.935	0.000	94.458	[0.01, 0.87]	0.096	0.311
EWPs-CRP	10	1,792	0.419	[0.276, 0.544]	1,018	106.684	0.000	91.564	[-0.16, 0.78]	0.063	0.250
EWPs-SP	10	1,646	0.417	[0.223, 0.579]	900	167.003	0.000	94.611	[-0.36, 0.85]	0.114	0.338
EWPs-FMP	16	3,034	0.448	[0.310, 0.567]	1,873	267.921	0.000	94.401	[-0.19, 0.82]	0.093	0.305
EWPs-OP	3	5,48	0.373	[0.226, 0.504]	43	6.240	0.044	67.950	[-0.88, 0.97]	0.012	0.110
CPMs-ENP	32	6,656	0.454	[0.359, 0.540]	10,016	666.871	0.000	95.351	[-0.17, 0.82]	0.101	0.318
CPMs-CRP	17	3,585	0.374	[0.263, 0.475]	2,496	218.714	0.000	92.685	[-0.15, 0.74]	0.062	0.248
CPMs-SP	10	2,149	0.280	[0.163, 0.388]	449	71.046	0.000	87.332	[-0.15, 0.62]	0.033	0.183
CPMs-FMP	14	3,702	0.428	[0.306, 0.536]	2,036	207.717	0.000	93.741	[-0.09, 0.76]	0.058	0.241
CPMs-OP	13	2,529	0.431	[0.257, 0.577]	1,579	304.434	0.000	96.058	[-0.34, 0.86]	0.129	0.360
Hs-ENP	27	5,782	0.486	[0.418, 0.549]	10,920	278.427	0.000	90.662	[0.08, 0.75]	0.046	0.215
Hs-CRP	16	3,974	0.490	[0.376, 0.589]	3,861	348.562	0.000	95.697	[-0.13, 0.83]	0.091	0.302
Hs-SP	7	1,292	0.394	[0.235, 0.532]	406	57.533	0.000	89.571	[-0.20, 0.78]	0.050	0.224
Hs-FMP	11	2,393	0.495	[0.366, 0.606]	1,621	160.489	0.000	93.769	[-0.09, 0.83]	0.071	0.267
Hs-OP	9	2,065	0.488	[0.268, 0.659]	1,318	271.842	0.000	97.057	[-0.41, 0.91]	0.151	0.389
ENP-CRP	18	3,755	0.538	[0.461, 0.606]	6,181	165.141	0.000	89.706	[0.15, 0.78]	0.043	0.207
ENP-SP	14	2,659	0.638	[0.579, 0.691]	4,966	72.815	0.000	82.146	[0.38, 0.81]	0.025	0.159
ENP-FMP	13	2,270	0.512	[0.410, 0.601]	1,915	111.992	0.000	89.285	[0.05, 0.79]	0.050	0.223
ENP-OP	8	1,470	0.655	[0.554, 0.737]	1,826	65.306	0.000	89.281	[0.21, 0.87]	0.047	0.217
CRP-SP	3	580	0.542	[0.459, 0.616]	161	3.651	0.161	45.216	[-0.44, 0.93]	0.004	0.066
CRP-FMP	4	942	0.643	[0.491, 0.757]	445	32.218	0.000	90.689	[-0.28, 0.95]	0.046	0.215

CRP-OP	6	1,268	0.624	[0.548, 0.690]	1,020	20.907	0.001	76.085	[0.33, 0.81]	0.016	0.125
SP-FMP	5	768	0.758	[0.556, 0.876]	610	70.109	0.000	94.295	[-0.28, 0.98]	0.126	0.354
SP-OP	3	625	0.415	[0.348, 0.478]	87	0.543	0.762	0.000	[-]	0.000	0.000
FMP-OP	5	1,277	0.404	[0.247, 0.542]	339	49.978	0.000	91.997	[-0.30, 0.82]	0.046	0.215

Note: CE=all CE practices examined in this study, FP=all types of firm performance examined in this study, EWPs=eliminating wastes and pollution practices, CPMs=circulating products and materials practices, Hs=hybrid CE practices, ENP=environmental performance, CRP=cost-reduction performance, SP=social performance, FMP=financial/market performance, OP=operational performance, k= number of studies, N=sample size, r=average effect size, *95CI*=95 percent confidence interval for r, N_{fs}= Rosenthal's fail-safe numbers, and *95PI*=95 percent prediction interval.

Table 3. Meta-analytical results of the entire sample

3.3 Step 3: Structural equation modeling

To test the hypotheses proposed in this study, we apply structural equation modeling by using the maximum likelihood algorithm of AMOS 26 with the correlation matrix as the input (see Table 4). Specifically, i) we synthesized the mean effect size of every single correlation that was obtained from the meta-analysis into one correlation matrix and calculated the harmonic mean of the total sample size as the sample size (Cao & Lumineau, 2015); ii) we set the value of the mean and standard deviation of each construct to 0 and 1, respectively. (Foerstl et al., 2016; Maseeh et al., 2021); iii) we considered the correlations extracted from the sample articles were sometimes based on observable variables, which caused measurement errors due to unreliability. To control the measurement error, we collected data of reliability coefficients (i.e., Cronbach's α or composite reliability) from the sample to correct the correlations

(Naragon-Gainey et al., 2017; Scherer et al., 2019). We calculated the average reliability of the relevant constructs from the entire sample. After that, we followed James et al. (1983) to set the factor loading as the square root of the mean reliability and the error terms equal to one minus the average reliability (Franke & Park, 2006; Zablah et al., 2012) for all of the constructs in the model.

	EWPs	CPMs	Hs	ENP	CRP	SP	FMP	OP
EWPs	*0.829*							
CPMs	0.370	*0.806*						
Hs	0.583	0.615	*0.845*					
ENP	0.588	0.454	0.486	*0.858*				
CRP	0.419	0.374	0.490	0.538	*0.848*			
SP	0.417	0.280	0.394	0.638	0.542	*0.866*		
FMP	0.448	0.428	0.495	0.512	0.643	0.758	*0.886*	
OP	0.373	0.431	0.488	0.655	0.624	0.415	0.404	*0.853*

Note: Italicized values on the main diagonal are reliability coefficients. The harmonic mean of N =1603.

Table 4. Meta-analytically pooled correlation matrix of the entire sample

4 Results and discussion

The results indicated an appropriate fit of the overall research model to the data with χ^2(df)=26.323 (1), p<0.001, GFI= 0.996, CFI= 0.996, NFI= 0.996, and RMR= 0.022. Interpretation of the model fit indices is based on the model fit criteria presented in the literature[8]. Table 5 shows the results of the effects of CE practices on firm performance.

4.1 Results of the effects of EWPs on firm performance

The results show that EWPs are positively related to environmental performance (β=0.634, p<0.001), thus providing support for H_1(a). The effect of implementing EWPs on environmental performance is the largest among all types of performance outcomes examined in this study. This result is not surprising since EWPs are primarily designed to control or prevent emissions, wastewater, and toxic wastes. EWPs have a positive effect on cost-reduction performance (β=0.199, p<0.001), which shows that companies reduce raw material and energy consumption, waste, and emission can decrease costs simultaneously. Thus, H_1(b) is supported. EWPs are positively associated with financial/market performance (β=0.267, p<0.001), which supports H_1(d). The improvement in cost-reduction performance by implementing EWPs, creating the basis for a positive financial/market performance, such as improved

[8] Following Bergh et al. (2016), this study reports the chi-square (χ^2) and its associated p-value, degree of freedom (df), goodness of fit index (GFI), comparative fit index (CFI), normed fit index (NFI), and root mean square residual (RMR). The model fit criteria of the SEM indicate the extent the specified model fits the data (Schermelleh-Engel et al., 2003). Specifically, the p-value associated with an χ^2 greater than 0.05 indicates that the model fits the data (Schermelleh-Engel et al., 2003). However, due to the drawback of the χ^2 test (e.g., model complexity, violation of assumptions, or dependence of sample size), other descriptive model fit indices have been developed for model evaluation (Schermelleh-Engel et al., 2003). A GFI and NFI greater than 0.90 are interpreted as an acceptable model fit, while 0.95 indicates a good model fit (Schermelleh-Engel et al., 2003; Schumacker & Lomax, 2004); A CFI larger than 0.95 is interpreted as an acceptable model fit, while 0.97 indicates a good model fit (Schermelleh-Engel et al., 2003). Finally, an RMR closer to 0 indicates a good model fit (Schermelleh-Engel et al., 2003).

profitability and cash flow. The positive relationship between EWPs and social performance (β=0.337, p<0.001) indicates that corporate reputation and stakeholders' welfare (e.g., health and safety) can be achieved by implementing EWPs. Thus, H_1(c) is supported. The positive impact of EWPs on operational performance (β=0.120, p=0.004) suggests that companies that implement EWPs (e.g., optimizing resource utilization and management) can improve their operational performance, which is reflected in outcomes such as lowering scrap rate and inventory levels. Thus, the result supports H_1(e).

4.2 Results of the effects of CPMs on firm performance

CPMs are positively related to environmental performance (β=0.370, p<0.001), which indicates the effectiveness of CPMs (e.g., remanufacturing) in reducing waste and pollution, and resource consumption, lending robust support to H_2(a). The positive relationship between CPMs and financial/market performance (β=0.224, p<0.001) demonstrates that CPMs, such as selling refurbished products or providing leasing services, contribute to opening new market opportunities and boosting profitability. Therefore, H_2 (d) is supported. The positive effect of CPMs on operational performance (β=0.231, p<0.001) suggests that CPMs are effective in improving operational efficiency and operational service quality, which supports H_2 (e). For example, increasing materials available through recycling and reducing resource purchasing and processing can lower scrap rate and inventory levels, shorten lead time, and improve on-time delivery.

However, the result shows that CPMs are not related to cost-reduction performance (β=0.081, p=0.081), which rejects H_2 (b). This finding may be explained by the extra expenditure incurred in operating an extended recycling business or conducting take-back operations. Investment in environmental programs can be substantial. For example, PepsiCo Beverages North America invested US$35 million in local recycling (PepsiCo, 2022). Environmental investments in collecting waste from geographically dispersed regions will also result in a loss of scale economy (Bhuiyan et al., 2021). Moreover, environmental investments cannot yield a quick pay-off, thus more benefits might be achieved in the long term (Bhuiyan et al., 2021). Environmental expenditures arise from inefficient recycling operations, such as the inclusion of defective products or materials in the recycled items that require additional labor or resources for repairing or waste disposal. Besides, outsourcing recycling will also incur extra fees. If the additional expenses exceed the saved costs, firms cannot achieve cost savings by implementing CPMs. Value shrinkage is another challenge as companies may produce inadequate income from take-back schemes to compensate for their investments. The implementation of CPMs may contribute to cost reduction only when the returned products and materials add more value than additional expenses.

We also find a nonsignificant relationship between CPMs and social performance (β=0.036, p=0.465), which rejects H_2 (c). The insignificant relationship may be attributed to the work environment. In the recycling sector, employees who implement CPMs, such as recycling batteries and cables, may face potential health risks associated with lead poisoning and exposure to heavy metals (Poole & Basu, 2017), which threaten occupational health and safety. Employees involved in an adverse working environment are more likely to consider switching jobs (Böckerman & Ilmakunnas, 2009), which will lead to increased employee turnover. Therefore, an adverse working environment will prevent improvements in social performance. Corporate culture may also play a role. Employees' satisfaction and loyalty are higher in companies with a positive corporate culture which reduces turnover, thus resulting in a competent and stable workforce (Abbas et al., 2020). The safety culture of a company contributes to reducing employee exposure to occupational risks and preventing accidents and illnesses (Fernández-Muñiz et al., 2007), thereby enhancing occupational health and safety and ultimately social performance.

4.3 Results of the effects of Hs on firm performance

The effect of Hs on the cost-reduction performance (β=0.385, $p<0.001$) is the largest compared to EWPs and CPMs, although the effect of CPMs on cost-reduction performance is not significant. This implies Hs is more effective in reducing costs. Thus, the result supports H_3(b). The positive relationship between Hs and social performance ($\beta=0.206$, $p=0.001$) indicates that Hs is effective in improving stakeholder well-being and corporate reputation, thus supporting H_3(c). The positive effect of Hs on financial/market performance ($\beta=0.227$, $p<0.001$) indicates that companies that implement Hs can improve profitability and create market opportunities, which support H_3(d). The effect of Hs on operational performance ($\beta=0.325$, $p<0.001$) is the highest compared to EWPs and CPMs, which suggests companies can achieve optimal efficiency in operational performance by implementing Hs. For example, companies can leverage EWPs to reduce scrap rates while implementing CPMs (e.g., increasing the use of available recycled materials) to shorten the lead time and enhance on-time delivery, which can reduce procurement and logistics time and ultimately shorten production time. Therefore, supporting H_3 (e).

However, the results show that Hs are negatively associated with environmental performance ($\beta=-0.142$, $p=0.014$), which rejects H_3(a). The negative effect of Hs on environmental performance can be explained by Hart (1995). The NRBV posits that it is difficult to implement product stewardship (CPMs) without significant progress in pollution prevention (EWPs) (Hart, 1995). Advancements in EWPs help companies to establish reputation and credibility, which are crucial for the successful implementation of CPMs, and suggest the strong dependency of CPMs on EWPs (Hart, 1995). The efforts made through CPMs (which can be symbolic outsourcing of take-back schemes) may be considered as lacking credibility or reported by the media as hypocritical (Hart, 1995). The principle of EWPs is to reduce waste but bring waste back through, such as a take-back scheme can add complexity and more waste in the operations. Redesigning the entire product lifecycle (CPMs) is often less feasible, which makes it difficult to balance between reducing waste in existing operations and changing the operations altogether. This will lead to the failure of Hs and have adverse impacts on environmental performance.

CE practices	Firm performance	Coefficient	p-value	S.E.	Hypothesis
Eliminating waste and pollution practices	H1(a) Environmental performance	0.634	0.000	0.039	Supported
	H1(b) Cost-reduction performance	0.199	0.000	0.041	Supported
	H1(c) Social performance	0.337	0.000	0.043	Supported
	H1(d) Financial/market performance	0.267	0.000	0.040	Supported
	H1(e) Operational performance	0.120	0.004	0.042	Supported
Circulating products and materials practices	H2(a) Environmental performance	0.370	0.000	0.044	Supported
	H2(b) Cost-reduction performance	0.081	0.081	0.047	Rejected
	H2(c) Social performance	0.036	0.465	0.049	Rejected
	H2(d) Financial/market performance	0.224	0.000	0.046	Supported
	H2(e) Operational performance	0.231	0.000	0.047	Supported

Hybrid CE practices	H3(a) Environmental performance	-0.142	0.014	0.058	Rejected
	H3(b) Cost-reduction performance	0.385	0.000	0.061	Supported
	H3(c) Social performance	0.206	0.001	0.064	Supported
	H3(d) Financial/market performance	0.227	0.000	0.059	Supported
	H3(e) Operational performance	0.325	0.000	0.062	Supported

Note: SE= standard error.

Table 5. Meta-analytic regression results of the entire sample

4.4 Theoretical implications

This study shows that the two strategies (i.e., pollution prevention and product stewardship) of the NRBV (Hart, 1995) reflect two CE principles (i.e., eliminating waste and pollution and circulating products and materials), but the two principles vary in their performance effects. The theoretical implications of the findings are as follows:

First, the findings indicate EWPs can largely improve environmental, cost-reduction, social, financial/market, and operational performances. As Hart (1995) argued, EWPs (pollution prevention) are low-hanging fruits that are easier to implement. EWPs rely on familiar capabilities, such as TQEM and continuous improvement. Though Hart (1995) argues pollution prevention may produce limited sustainable advantages, our results show that easier-to-implement (most companies would have adequate experience) makes it possible for companies to reap the benefits across all performance dimensions.

Second, the NRBV suggests that companies can redesign existing product systems or develop new products that can be easily recycled, reused, and composted through product stewardship (CPMs) to lower life-cycle costs and avoid substantial disposal costs and penalties (Hart, 1995). However, the findings reveal that implementing CPMs cannot save on costs. As stated earlier, additional costs may offset the potential savings. Thus, the NRBV needs to consider the additional costs incurred in adopting the product stewardship strategy. It is more difficult to achieve CPMs because companies must pay for the collection of end-of-life products from their customers that may be geographically dispersed, and the additional costs may not be fully compensated by the selling prices of the recycled materials or components.

Third, the NRBV claims that companies can build corporate reputation and brand image through product stewardship (CPMs) (Hart, 1995), thereby improving social performance. However, the findings show that social performance cannot be improved through CPMs. Companies may focus on implementing CPMs to improve social performance, such as recycling products, and they may neglect the corporate context, such as corporate culture and work environment that may affect stakeholders' welfare (e.g., employees). Thus, the argument by Hart (1995) about the product stewardship strategy of the NRBV should reflect how the CE principle on circularity may negatively affect worker welfare.

Finally, Hart (1995) argued that the capabilities of product stewardship (CPMs) are embedded in pollution prevention (EWPs). Our study extends the arguments by showing that the purported synergistic effects of EWPs and CPMs (i.e., Hs) on environmental performance did not occur. This is intriguing as implementing EWPs and CPMs separately could improve environmental performance instead. This finding introduces a new challenge in understanding theorizing synergy (or trade-off) between these two principles of CE. Another interesting result shows using CPMs could not reduce costs but combining it with EWPs could. This suggests synergetic (or trade-off) effects between EWPs and CPMs that vary from one performance to another. This perhaps provides a basis for further research to understand how to best combine the two CE principles.

4.5 Managerial implications

The results suggest that managers implement EWPs, CPMs, and Hs to achieve multiple performance outcomes, including financial/market, operational, cost-reduction, and the triple bottom lines. Focusing on environmental performance, managers could adopt both EWPs and CPMs to mitigate environmental impacts. Besides, managers should consider the strong dependency of CPMs on EWPs when implementing Hs. Concerning cost-reduction performance, managers should be aware that CPMs might incur extra costs due to substantial investments at the beginning. Managers need to prioritize the adoption of EWPs because they strengthen many existing capabilities (e.g., TQEM, and continuous improvements) and help expand their applications to issues related to the environment and social aspects of their operations. Only when EWPs are strengthened, companies can have the capability and knowledge to complement them with CMPs. As Hart (1995) argued, EWPs and CMPs are developed one after another. But our results show there are more nuances in how to create synergies between them.

Concerning social performance, managers need to understand the implementation of CPMs and must consider the work environment and corporate culture in the recycling sectors. It is common for companies to outsource take-back schemes to third parties, but the work conditions in such companies must meet standards adequately in terms of health, safety, pay, and well-being of employees. Companies should consider implementing EWPs and CMPs together with a higher level of control or ownership when their primary objective is to improve their social performance.

Despite low adoption, this study shows that CE principles can help companies mitigate environmental impacts while improving financial performance. However, the root cause of environmental degradation originates from firms prioritizing economic growth and development over implementing the harder parts of CE principles. Therefore, it is imperative to increase environmental awareness of leadership (Li et al., 2023). The implementation of sector-specific education and training programs on environmental issues plays a pivotal role that enables managers to gain an in-depth understanding of environmental issues and relevant regulations, which helps firms formulate environmental strategies that can strike a balance between environmental challenges and economic ambition. While each sector in the manufacturing industry is involved with EWPs, CPMs, and Hs, companies need to adapt their environmental strategies to align with the specific characteristics of each sector to ensure that they can reap maximum benefits from their sustainability efforts.

5 Conclusion, future research, and limitation

This study shows how the NRBV can be applied and extended to explain the effects of CE principles on performance outcomes. The results reveal new ideas and research directions that could be explored in the future as follows:

First, future studies could investigate the role of environmental investments or environmental expenses in the relationship between CPMs and cost-reduction performance. Such an investigation could offer insights into the decision-making process of companies on enhancing environmental strategies and optimizing cost efficiency. Second, future studies could explore the role of corporate contexts, such as corporate culture, in the relationship between CPMs and social performance, which can provide managerial insights that would assist companies in reducing turnovers and forming a stable workforce, thereby improving social performance. Third, future studies could investigate the effects of EWPs, CPMs, and Hs on firm performance in other industries, such as the construction industry. In doing so, empirical insights tailored to specific industries are obtained to determine the types of CE practices that best contribute to improving environmental sustainability, maximizing profit margins, and avoiding unnecessary use of resources and financial losses.

The main limitation of this study is that it is difficult to find constructs that solely measure the three CE principles separately, and empirical evidence on their impacts on performance outcomes. Other limitations, such as regenerating nature principles/practices are not examined since they have received little attention in the literature. A moderator analysis is not performed as there are limitations in the dataset. Future studies can address the limitations of this study.

In sum, CE practices are sustainable operations (Yang et al., 2019) and serve as an effective solution for the sustainable development of companies (Chen, 2023). Embracing CE practices based on CE principles is an appropriate strategy for companies to achieve sustainability goals while improving firm performance. For optimal performance outcomes, companies should prioritize EWPs and Hs. In addition, implementing EWPs and CPMs simultaneously needs to consider the importance of the dependency of CPMs on EWPs.

Supplementary file (Please access the supplementary files by clicking on this link: Supplementary file .docx)

A. Variables in the three types of CE practices

B. Justification of the database use

C. Keywords and search strings

D. Coding process

E. Summary of sample articles

F. Funnel plot (*with trim and fill*)

G. Adjusted average effect size (*with trim and fill*)

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