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RESEARCH ARTICLE

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Circular economy practices and environmental performance: Analysing the role of big data analytics capability and responsible research and innovation

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Abstract

This study employs dynamic capability view theory to comprehend the interplay between big data analytics capability (BDAC), responsible research and innovation (RRI) and circular economy practices (CEPs) as an execution strategy for improving environmental performance. The study uses partial least square structural equation modelling to analyse primary survey data collected from 326 manufacturers. The results indicate that BDAC, RRI and CEPs favourably affect environmental performance. Notably, RRI emerges as the most influential factor among the three. Furthermore, the findings suggest that implementing CEPs serves as a partial mediator for the influence of BDAC and RRI on environmental performance. Surprisingly, the study finds that the moderating impact of resource commitment is not statistically significant in any of the three pairwise interactions involving BDAC, RRI and CEPs with respect to environmental performance. The results have various intriguing implications for how manufacturers can enhance their circular economy strategies to achieve better environmental performance, representing a noteworthy contribution to the foundational theory of the dynamic capability view. Finally, these findings also provide valuable insights to managers, enabling a deeper understanding of the determinants that contribute to deploying CEPs and improving environmental performance within a manufacturing setting.

KEYWORDS
big data analytics capability, circular economy practices, environmental performance, manufacturing, responsible research and innovation

ABBREVIATIONS: AVE, average variance extracted; BDAC, big data analytics capability; CEP, circular economy practice; CMV, common method variance; CR, composite reliability; EP, environmental performance; HTMT, heterotrait–monotrait; ISO, International Organization for Standardization; PLS-SEM, partial least square structural equation modelling; R&D, research and development; RC, resource commitment; RRI, responsible research and innovation; VIF, variance inflation factor.

1 | INTRODUCTION

For the collective human psyche, a look back over the past few years can be overwhelming. We have experienced the warmest years on record, countless species have gone extinct and countries around the globe have proclaimed a climate emergency. Even as we become more worried about the future, the world at large has yet to become more deeply conscious of the consumption habits that have prompted the increase in manufacturing and supply chain activities that is partly responsible for the climate emergency (Snigdha et al., 2023). Because manufacturers represent the majority of commercial transactions globally and are essential drivers of employment generation and world economic development (Chen & Wang, 2023), the ecological aspect has been largely overlooked (Hasegawa et al., 2019; Mangla et al., 2018). This situation motivates this study's investigative scope. Acknowledging that manufacturers are among the most significant contributors to environmental degradation (Gupta et al., 2019; Yu et al., 2022), environmental experts are working on a strategic plan to mitigate their detrimental effects. Although major countries have pledged to achieve carbon neutrality by 2050—as an imperative under the United Nations Sustainable Development Goals—the World Economic Forum has extensively emphasised that manufacturers should embrace circular economy practices (CEPs) in their business operations (Han et al., 2023; Song et al., 2023).

CEPs emphasise a recuperative and rejuvenating strategy fundamentally based on the conservation and protection of natural resources, the recycling of materials and used products and the expounding of negative externalities, all of which contribute to making any established business more climate resilient (Dey et al., 2022; Govindan & Hasanagic, 2018). Adoption of CEPs by manufacturers characterises a substantial departure from traditional business approaches because it places a greater emphasis on acquiring data from multiple sources, with the assertion that each well-informed stakeholder synchronises their participation in the decision-making process for the environmental good (Gupta et al., 2019; Kristoffersen et al., 2021). Therefore, an organisation's capability to analyse voluminous data from diverse functional origins (i.e., big data) with cutting-edge technologies becomes crucial in the ever-changing contemporary economic environment for deploying CEPs effectively in a manufacturing setting (Riggs et al., 2023). Beyond proposing big data analytics capability (BDAC) as a crucial antecedent of CEPs, the current study also proposes responsible research and innovation (RRI) as a postulated antecedent of CEPs. The notion of RRI originated in Europe and has since grown in prominence, especially within the realm of practical research to characterise scientific procedures as technological development that considers the effects and possible repercussions on the environment and society (Schneider et al., 2023). Although researchers have highlighted the need to acclimate RRI in non-European countries and their business environments, the feasibility of this approach remains an open question (Coffay et al., 2022; Fellnhofer, 2022). Because India is the third-largest emitter of greenhouse gases after China and the United States (Garrett, 2022), RRI is relevant and should be a constant component of Science, Technology and Innovation policy, acting as regulation guidance for Indian manufacturers to maintain professional conduct (Srinivas, 2022).

Both BDAC and RRI exhibit significant potential to enhance CEPs by offering novel insights into the production and consumption stages of the entire business cycle. BDAC contributes to the processing of vast amounts of data to identify patterns and optimise processes (Riggs et al., 2023), with RRI emphasising ethical considerations and stakeholder engagement in the innovation process, leading to more sustainable and socially responsible outcomes (Coffay et al., 2022; Ogoh & Fairweather, 2019). This suggests that professionals working in the BDAC and RRI divisions can produce valuable insights that can aid in the comprehension of the functional requirements of various stages of the business cycle (Kristoffersen et al., 2021). Additionally, these insights can be utilised to create a business environment that is both sustainable and resource efficient (Dey et al., 2022).

The current research was conducted in the Indian manufacturing sector, which has long featured one of the world's most convoluted economic environments (Kumar et al., 2020; Sharma & Sehrawat, 2020). India's manufacturing industry has had to navigate various issues—from infrastructural constraints and bureaucratic hurdles to complex tax systems—that have made efficient operation challenging (Kumar et al., 2020; Mangla et al., 2018). In India, functional operations concerning environmental objectives are typically conducted in a fragmented and unintegrated fashion (Mehraj & Qureshi, 2022; Nayak et al., 2021; Seth & Rehman, 2022). Consequently, identifying the antecedents to CEPs is crucial for facilitating their pragmatic deployment and potentially improving the environmental performance (EP) of Indian manufacturers. The dearth of research on this subject is reinforced by the overview of existing investigations pertaining to the circular economy presented in Table 1. In expanding on proposed avenues for future research, scholars have evidently advocated for more empirical investigations to be undertaken across diverse national contexts to identify the functional precursors to CEPs. Meanwhile, scholars in the field of environmental management have recently encouraged more investigation into how manufacturers who have adopted CEPs have strategically enhanced their EP (Ding et al., 2023; Ul-Durar et al., 2023), contributing to the ongoing discussion of the matter. Having considered the topic's contemporary nature and the scarcity of research in the field of CEPs from a multidisciplinary perspective, the current investigation seeks to address such gaps by answering the following research questions:

RQ1. Do BDAC and RRI have a direct effect on the EP of manufacturers?

RQ2. Is the relationship between BDAC, RRI and EP mediated by the adoption of CEPs by manufacturers?

The current study's findings are advantageous for manufacturers who want to feel confident about the role of CEPs in improving their competitiveness in terms of EP. To the best of the author's knowledge, the propositions outlined in the present investigation are distinct and offer insight into a plan of action for deploying BDAC and RRI to develop CEPs. Results from this research may influence policy decisions that encourage the manufacturing sector to implement BDAC and RRI with an eventual aim of incorporating CEPs at the macro level.

The rest of the article is organised as follows. The second and third sections detail the theoretical underpinnings and hypotheses

TABLE 1 Summary of existing studies.

Article	Theoretical foundation	Methodology	Major findings	Suggestions for future research
Liu et al., 2023	• Practice-based view	• This research uses a mixed-method approach to gather data from 255 Chinese manufacturing companies for consideration alongside two explanatory case studies. • The statistical technique of structural equation modelling is employed to analyse the quantitative data. • A case research design is utilised to analyse the qualitative data.	• The quantitative analysis reveals that circular manufacturing is significantly impacted by the adoption of circular economy culture and integrated management systems. • Additionally, the study demonstrates that circular manufacturing directly impacts both financial and environmental performance. • The findings derived from the qualitative investigation corroborate the outcomes obtained from the quantitative analysis.	• The study suggests utilising additional performance parameters, such as social sustainability performance, to provide further insights. • Due to the cross-sectional nature of the study's research design, this article recommends the implementation of a longitudinal research design. • This study also proposes exploring the research propositions in alternative geographical contexts to establish the generalisability of the findings.
Riggs et al., 2023	• Not mentioned	• This research gathers data from 210 companies situated in the European continent, each of which had a minimum of 50 employees. • The data are analysed using structural equation modelling.	• The findings suggest that the effectiveness of big data analytics capabilities does not have a directly favourable effect on sustainable performance. • However, big data analytics capabilities do exert an indirect influence on sustainable performance via the capabilities of supply chain management and the practices of the circular economy.	• The use of a cross-sectional research design is a significant limitation of this study, leading to the suggestion that future investigations utilise a longitudinal research methodology. • Because the researchers evaluate the propositions in their research framework within a specific country and under unique conditions, they recommend that future investigations verify these propositions in various industry and geographical settings.
Schöggl et al., 2023	• Not mentioned	• This study performs descriptive, hierarchical cluster and non-parametric analyses on data from a sample of 132 sustainability managers and chief executive officers who work for Austrian manufacturing companies.	• The research presents a comprehensive analysis of the extent and level of adoption of four critical enabling digital technologies that facilitate the establishment of a sustainable circular economy. • Internet of Things technology is the most prevalent of the four digital implementations considered, followed by big data analytics, artificial intelligence and blockchain technology.	• Further investigation is required to determine how small- and medium-sized enterprises, in particular, can effectively utilise digital technologies in their transition to a circular economy. • Prospective avenues for research could involve developing and authenticating additional concepts for the incorporation of digital technologies into a range of corporate sustainability and circularity management methodologies.
Bag et al., 2022	• Institutional theory • Dynamic capability view	• This research collects data from 240 small- and medium-sized manufacturing enterprises located in South Africa.	• The study observes positive effects of institutional pressures and eco-innovation on green supply chain management practices	• To enhance the comprehensiveness of results, the researchers recommend establishing a

(Continues)

TABLE 1 (Continued)

Article	Theoretical foundation	Methodology	Major findings	Suggestions for future research
		• The data are analysed using structural equation modelling.	and circular economy capabilities, with impacts also noted concerning impact on firm performance. • The research finds that big data-driven supply chains have no moderating effect on the relationship between green supply chain management practices and firm performance, but they do record a potential moderating effect on circular economy capability and firm performance.	longitudinal research design. • Future research endeavours should be undertaken in diverse country contexts and varied industry settings.
Castilla-Polo & Sánchez-Hernández, 2022	• Not mentioned	• This research collects data from 56 managers working in agri-food processing units in Spain. • The data are subsequently analysed using structural equation modelling.	• The study reveals that social capital in conjunction with responsible research and innovation are significant precursors to an organisation's internal orientation towards circular economy practices. In turn, this positively impacts strategic outcomes, such as reputation and performance.	• The authors advise further inquiries in a range of country contexts and varied industry settings and recommend studies that utilise a qualitative research approach.
Dey et al., 2022	• Resource-based view	• The research utilises a mixed-methods approach—including surveys, interviews and case studies—to collect data from a sample of 100 small and medium enterprises located in the European continent. • The data are quantitatively analysed based on correlation.	• The research indicates that implementing circular economy practices within small and medium enterprises is primarily influenced by the function of 'design', with the function 'recover' found to have a comparatively minimal impact. • Research demonstrates that implementing circular economy practices yields favourable outcomes across economic, environmental and social performance categories.	• The research conducted is constrained by the inherent limitations of the sample size and the statistical analysis employed. As such, the authors recommend that future research prioritise the use of a larger sample size and more robust analytical design. • According to the authors, future researchers should prioritise gaining a deeper understanding of the mechanisms and contextual factors that facilitate businesses successfully transitioning from linear economy practices to circular economy practices.
de Sousa Jabbour et al., 2022	• Resource-based view • Complementarity theory	• The research gathers data from 132 Brazilian manufacturing companies. • Structural equation modelling is employed to analyse the data.	• The convergence of Industry 4.0 technologies and the circular economy has yielded a synergistic effect that has favourably impacted various performance parameters, including economic, environmental and operational aspects. However, the impact on social performance has been only partial.	• Further research endeavours could potentially investigate the research proposition utilising a qualitative methodology and potentially augment the reliability of the study's results by incorporating additional control variables in a quantitative analysis.

TABLE 1 (Continued)

Article	Theoretical foundation	Methodology	Major findings	Suggestions for future research
Kristoffersen et al., 2021	• Resource-based view • Resource orchestration view	• The data derive from a sample of 125 companies located in 11 or more European countries. • Structural equation modelling is used to analyse the collected data.	• The research empirically validates the positive impact of business analytics capabilities on resource orchestration capabilities and the successful implementation of circular economy practices. • The study's findings validate that the resource orchestration capabilities and circular economy practices serve as complete mediators in the relationship between business analytics capabilities and firm performance.	• The authors recommend that future research efforts be conducted across diverse country contexts and within a range of industry settings and employ longitudinal research designs. • Future studies may contemplate utilising more objective measures of firm performance—such as circular economy metrics (e.g., environmental performance)—to enhance the accuracy and reliability of the results.
Gupta et al., 2019	• Stakeholder theory	• The study sample includes ten Indian manufacturing companies. • Using an interview-based approach, qualitative data are collected from ten senior management personnel.	• The research findings suggest that big data analytics have the capacity to serve as a facilitator for the implementation of circular economy practices. • The research findings indicate that implementing circular economy practices is impeded by significant obstacles related to the complexities of business operations and stakeholder engagement.	• According to the authors, to ascertain the generalisability of results pertaining to the interplay between big data analytics and circular economy practices, it is imperative to employ a mixed-methods research design (i.e., quantitative and qualitative) and a sizable sample.

that guide the research framework. The fourth section discusses the research methodology, with the fifth section elaborating on the analytical findings. The sixth section addresses the theoretical and practical implications of the results before concluding the paper.

2 | THEORETICAL UNDERPINNINGS

2.1 | BDAC

BDAC refers to the capacity of manufacturers to accumulate, manipulate, scrutinise and extract valuable insights from large quantities of data from diverse sources both internal and external to their organisation (Benzidia et al., 2021). This means utilising sophisticated technologies and tools to extract pertinent information from vast datasets and subsequently transforming that information into practical insights that can enhance decision-making, operational efficiency and innovation (Benzidia et al., 2023; Gupta et al., 2019). BDAC offers various benefits to manufacturers, including but not limited to optimising production processes, predicting equipment failures, improving supply chain management and enhancing customer experience (Dubey et al., 2020; Waqas et al., 2021). Manufacturers can elevate comprehension of their operations and market trends, detect prospects for enrichment and make informed decisions to maintain competitiveness by harnessing data's potential (Kristoffersen et al., 2021). To attain BDAC, manufacturers must possess adequate data infrastructure, which means sufficient data storage, processing power and analytical tools (Kumar et al., 2020; Sahoo et al., 2023). It is also imperative that organisations have access to a proficient workforce that can scrutinise data and extract significant insights (Dubey et al., 2023; Riggs et al., 2023). It may be necessary for manufacturers to engage in collaborative efforts with data analytics firms to devise tailored solutions that align with their distinct requirements and objectives.

2.2 | RRI

The RRI framework is a research and development (R&D) approach that prioritises the ethical, social and environmental considerations of technological innovation (Inigo & Blok, 2019). Within the realm of manufacturing, the concept of RRI involves incorporating these factors into every phase of the innovation cycle, starting with the preliminary R&D phase and culminating in the product design, process design and marketing stages (Coffay et al., 2022; Ogoh & Fairweather, 2019). Organisations that implement RRI demonstrate a proactive stance towards identifying and mitigating the potential risks and unintended consequences associated with their products or processes (Fellnhofer, 2022). Organisations interact with various stakeholders—including customers, regulators and civil society organisations—to obtain feedback and guarantee that their innovations align with the requirements and principles of society at large (Castilla-Polo & Sánchez-Hernández, 2022). RRI entails a dedication to transparency and responsibility, whereby manufacturers are obliged to reveal details about their R&D undertakings, along with any conceivable hazards and consequences linked to their offerings (Coffay et al., 2022; Inigo & Blok, 2019). By adopting RRI, manufacturers can cultivate confidence and reliance from their clientele, enhance their reputation and facilitate the development of a more sustainable and socially accountable innovation framework.

2.3 | CEPs

CEPs encompass a range of methods and strategies that businesses implement to enhance resource efficiency and minimise waste within their production and distribution systems (Lu et al., 2022; Mangla et al., 2018). The transition from the conventional linear economy paradigm of extracting resources, manufacturing goods and disposing of waste to more environmentally conscious approaches incorporating reduction, reuse and recycling measures represents a notable shift (Schulz-Mönninghoff et al., 2023). In the realm of manufacturing, CEPs entail the strategic design of products and packaging to make them readily amenable to reuse, repair or recycling upon reaching the end of their life cycle (Hasegawa et al., 2019; Uhrenholt et al., 2022). Manufacturers prioritise procuring raw materials from sustainable sources, minimising waste generation and establishing closed-loop supply chains to recover and reuse materials from their products and operations (Bag et al., 2022). Implementing CEPs presents a multitude of advantages for manufacturers, such as reducing costs by optimising resources and enhancing customer engagement via the adoption of sustainable practices (Kristoffersen et al., 2021; Ortner et al., 2022). Furthermore, it enables the mitigation of the environmental footprint of manufacturing operations via the conservation of natural resources, the reduction of greenhouse gas emissions and the minimisation of waste that enters landfills.

2.4 | EP

In discussions of an organisation's commitment to sustainable practices, EP indicates the extent of that commitment (Y. Zhang & Wei, 2021). In other words, EP captures how efficiently a manufacturer handles and mitigates the adverse effects of its production and distribution operations on the natural environment in which it operates (Benzidia et al., 2021; Dey et al., 2022). The evaluation of a manufacturer's EP can encompass a variety of criteria, including but not limited to energy efficiency, waste minimisation, utilisation of sustainable materials and adherence to environmental regulations over a substantial period (Shah & Soomro, 2021). A manufacturer that exhibits commendable EP is characterised by the integration of sustainable practices into its operations, the reduction of waste and emissions and endeavours to minimise its environmental footprint (Waqas et al., 2021; Yu et al., 2022). To attain enduring sustainability and uphold social and environmental accountability, it is imperative for manufacturers to establish robust EP.

2.5 | Resource commitment (RC)

RC refers to the allocation of resources by an organisation's senior management to achieve specific goals and objectives (Konadu et al., 2020). This signals dedicating time, finances and other resources to endeavours consistent with an organisation's values and strategic priorities (le Duc & Gammeltoft, 2023). Resource allocation is crucial to success and demands that organisations prioritise their RC (Joshi & Dhar, 2020) by discerning and prioritising objectives, evaluating the resources needed for their attainment and guaranteeing their efficient allocation.

2.6 | Dynamic capability view (DCV)

In empirical research, the use of well-established theories or frameworks as a foundation for developing a research framework and interpreting the findings is referred to as the theoretical underpinning. Theoretical foundations ensure that research is founded on pertinent ideas and hypotheses and that the findings advance or improve upon pre-existing theories or models. Table 1 shows that existing studies have established foundations for their investigations based on various theoretical frameworks, including the practice-based view, the institutional theory, the DCV, the resource-based view, the complementarity theory, the resource orchestration view and the stakeholder theory. The concept of the 'circular economy' describes a dynamic system that aims to optimise resource utilisation by prolonging the circulation of materials before recycling or reusing them (Govindan, 2022; Hasegawa et al., 2019). It is predicated on the notions of minimising the production of unwanted by-products, maximising the lifespan of products and restoring the fitness of ecological systems (Castilla-Polo & Sánchez-Hernández, 2022; Kumar et al., 2020). The current investigation adopts the DCV, which offers a conceptual framework for explaining how manufacturers can sustain a competitive advantage in dynamic and rapidly evolving business contexts (Dubey et al., 2023). The fundamental tenet of the DCV is that an organisation's long-term performance depends on its ability to shift conditions and develop new functionalities (Sengupta & Rossi, 2023). In other words, keeping ahead of the competition depends on an organisation's ability to build structural intelligence that enables it to react effectively to changes in the external environment. According to the

DCV, the three primary types of capabilities that organisations must develop and manage are sensing capabilities, seizing capabilities and transforming capabilities (Panagiotopoulos et al., 2023; Pattanayak et al., 2023). BDAC characterises an organisation's sensing capabilities, which refers to detecting changes in the external environment, including changes in consumer needs, market trends and technological advancements (Dubey et al., 2020, 2023). RRI characterises an organisation's seizing capabilities, which refers to responding to changes by rapidly and effectively developing new products, services and business models (Chatterjee et al., 2023; Pattanayak et al., 2023). CEPs characterise an organisation's transforming capabilities, which refers to reconfiguring existing resources and capacities to adapt to the changing environment (Bag et al., 2022; Lu et al., 2022). According to the DCV, adaptable skills can only be successfully developed within an environment where learning and innovation are prioritised at all organisational levels (Pattanayak et al., 2023; Sengupta & Rossi, 2023). Additionally, organisations must be willing to take risks and invest strategically in cutting-edge technologies and capabilities (Dubey et al., 2023; Panagiotopoulos et al., 2023). In essence, the DCV represents an insightful paradigm for identifying how organisations can develop and preserve their competitive edge in the highly competitive contemporary environment by nurturing BDAC, RRI and CEPs.

3 | HYPOTHESES DEVELOPMENT

3.1 | CEPs and EP

CEPs refer to the methods and processes that promote the efficient use and reuse of resources in a closed-loop system (Kristoffersen et al., 2021). According to scholars Bag et al. (2022), CEPs characterise an organisation's capacity to transform from linear to circular practices. This has been demonstrated to have a substantial effect on EP. The three Rs of reduce, reuse and recycle represent the most fundamental and well-known tenet of CEPs (Govindan, 2022; Govindan & Hasanagic, 2018). By reducing waste, reusing products and recycling materials, manufacturers can conserve natural resources, reduce greenhouse gas emissions and divert waste from landfill. Product design for circularity is the second principle that CEP reinforces (Ortner et al., 2022). Designing products with circularity in mind can reduce the environmental impact of a product across its entire life cycle. This includes designing products that are easy to repair, disassemble and recycle. Another tenet of CEP is closed-loop production, which refers to using waste from one process as a resource in another process (Schulz-Mönninghoff et al., 2023). By closing the loop on materials and resources, manufacturers can reduce the need for virgin resources, minimise waste and diminish their environmental impact. The fourth tenet of CEP is resource recovery and upcycling, which involve recovering valuable materials from waste streams and repurposing them into new products or materials (Romani et al., 2023). By recovering valuable materials that would otherwise be lost or discarded, businesses can reduce the need for virgin resources and minimise waste. Although manufacturers can benefit from adopting CEPs, doing so can also have unintended negative effects on their EP. For example, CEPs may necessitate the movement of recyclable or reusable products or materials over greater distances from a diversity of locations, potentially increasing emissions associated with transportation (F. Zhang & He, 2022). CEP sceptics also argue that it may consume more energy to process and prepare recycled materials than virgin materials (Khosravani & Reinicke, 2020; Wang et al., 2022). This potentially negates the environmental benefits of recycling in the first place. These divergent perspectives on how CEPs and EP interact lead to the following hypothesis for the Indian manufacturing context:

H1. CEPs positively impact EP.

3.2 | BDAC, CEPs and EP

The DCV understands BDAC to represent an organisation's sensing capability, which enables it to acquire, organise and assess large amounts of data from various sources to recognise patterns and trends (Dubey et al., 2020; Riggs et al., 2023). These insights can be used to functionally prioritise resource efficiency and sustainability via waste reduction, material reuse and product recycling (Gupta et al., 2019; Kristoffersen et al., 2021). By implementing CEPs, organisations can reduce their reliance on virgin resources and minimise waste generation (Dey et al., 2022; Lu et al., 2022). This indicates that an organisation's BDAC can be used to effectively deploy CEPs across the manufacturing value chain by optimising resource usage and minimising waste (Riggs et al., 2023). The causative interaction of BDAC on CEP has the potential to be especially influential for EP (Kristoffersen et al., 2021). For example, an organisation's BDAC can be used to identify areas where CEPs can be most effective, such as identifying waste streams that can be repurposed or identifying opportunities for product redesign to increase durability and recyclability (Gholami et al., 2022; Schöggl et al., 2023). Also, CEPs can provide new data sources that enhance an organisation's BDAC (Hallioui et al., 2022). For instance, tracking the use and reuse of materials in an organisation's circular economy model can provide insights into resource efficiency and environmental impact that can be used to plan and execute further improvements (Govindan, 2022; Taddei et al., 2022). That is, an organisation's BDAC is used to monitor and evaluate the efficacy of CEPs, offering feedback that can be applied to improve and refine circular economy strategies. Implicitly premised upon existing studies (Nayal et al., 2022; Riggs et al., 2023), CEPs can be positioned as a mediator between BDAC and EP, providing a framework for data-driven decision-making that achieves enhanced EP. However, practitioner discourse contends that BDAC can sometimes mislead manufacturers into thinking they must make the best possible decisions, leading to an overabundance of information decelerating the decision-making process (Konanahalli et al., 2022). Furthermore, developing BDAC can be capital-intensive, requiring specialised technical expertise, workforce acceptance and exacting socio-economic feasibility, all of which pose challenges and may undermine effective execution (Muchenje & Seppänen, 2023; Qi et al., 2023). Despite these barriers, most researchers indicate that manufacturers can significantly improve their EP (Benzidia et al., 2021, 2023; Waqas et al., 2021) and contribute to a more sustainable future by leveraging their BDAC to effectively deploy CEP within the production system (Gupta et al., 2019; Kristoffersen et al., 2021; Riggs et al., 2023). In light of this discussion, the following hypotheses are proposed to better understand the interaction between BDAC, CEPs and EP in the Indian manufacturing context.

H2. BDAC positively impacts CEPs.

H3. BDAC positively impacts EP.

H4. CEPs mediate the relationship between BDAC and EP.

3.3 | RRI, CEPs and EP

RRI describe a strategy that organisations use to ensure that they are considering public interests, consumer needs and social ideals in the conduct of their scientific research and innovation activities (Castilla-Polo & Sánchez-Hernández, 2022; Coffay et al., 2022). RRI signals incorporating societal values and concerns into the R&D process and collaborating with stakeholders to ensure that outcomes are socially desirable (Fellnhofer, 2022; Ogoh & Fairweather, 2019). In other words, this strategy emphasises the importance of addressing ethical, social and environmental concerns throughout R&D processes. RRI and CEPs are inextricably intertwined: RRI endeavours to contribute to a more sustainable and resilient environment, setting the stage for CEPs (Castilla-Polo & Sánchez-Hernández, 2022; Inigo & Blok, 2019). This can be achieved by considering the potential environmental impact of new technological advances and innovations from the onset of R&D processes (Coffay et al., 2022; Schneider et al., 2023). RRI can also help organisations recognise and address ethical and social issues related to the deployment of CEP in manufacturing settings. This includes ensuring that new technologies are accessible and affordable to all strategic partners and that their benefits are distributed equitably to ensure the continuity of EP at all stages of the manufacturing value chain (Liu et al., 2023; Shah & Soomro, 2021). RRI can also facilitate stakeholder engagement and collaboration (Inigo & Blok, 2019), enabling a more comprehensive and inclusive approach to developing circular economy strategies that address environmental issues related to manufacturing operations (Fellnhofer, 2022; Schneider et al., 2023). This makes it apparent that RRI represents a promising antecedent to CEPs, with CEPs serving as a bridge between RRI and EP. By involving stakeholders in the development and execution of CEPs, manufacturers can ensure that processes and products meet social needs and concerns. As such, CEPs can also serve as a platform for RRI to advance sustainable methods and technologies to achieve EP. Considering the novelty of the proposition and building on the preceding discussion, the following hypotheses are proposed:

H5. RRI positively impacts CEPs.

H6. RRI positively impacts EP.

H7. CEPs mediate the relationship between RRI and EP.

3.4 | Moderating role of RC

In the context of organisations, RC refers to the allocation of resources (time, money and personnel) to support strategic goals, projects or initiatives (Konadu et al., 2020; Sinkovics et al., 2018). This can involve investing in new technologies (Sahoo et al., 2023), hiring and training employees (Joshi & Dhar, 2020), developing marketing campaigns (Luoma et al., 2017) or expanding into new markets (le Duc & Gammeltoft, 2023). RC connotes top management taking a methodical approach to defining, budgeting and administering resources to ensure that they are used responsibly and productively (Joshi & Dhar, 2020; Sahoo et al., 2023). In the context of the current investigation, RC may be crucial for developing BDAC, practising RRI and deploying CEP, all of which have been proposed as crucial antecedents to improved EP. RC ensures that the necessary resources are available to complete tasks and achieve objectives. A lack of RC can precipitate delays, poor quality work and even the inability to meet strategic objectives (le Duc & Gammeltoft, 2023; Sahoo et al., 2023; Sinkovics et al., 2018). This discussion prompts the following hypotheses:

H8. RC moderates the effect of (a) BDAC, (b) CEPs and (c) RRI on EP.

Figure 1 visualises the research framework for the current investigation, which is built upon the theoretical underpinnings of DCV. Later sections discuss the interactions between variables.

4 | RESEARCH METHODOLOGY

4.1 | Participants and procedure

The sample comprises 326 Indian manufacturers categorised as large companies based on the nature of their investment in fixed assets. Data have been collected via an online survey that was administered to respondents by the research team via a virtual teleconference platform to ensure adequate explanation of questions and active participation by respondents. The research team has taken special precautions to ensure that respondents are qualified

FIGURE 1 Research framework.

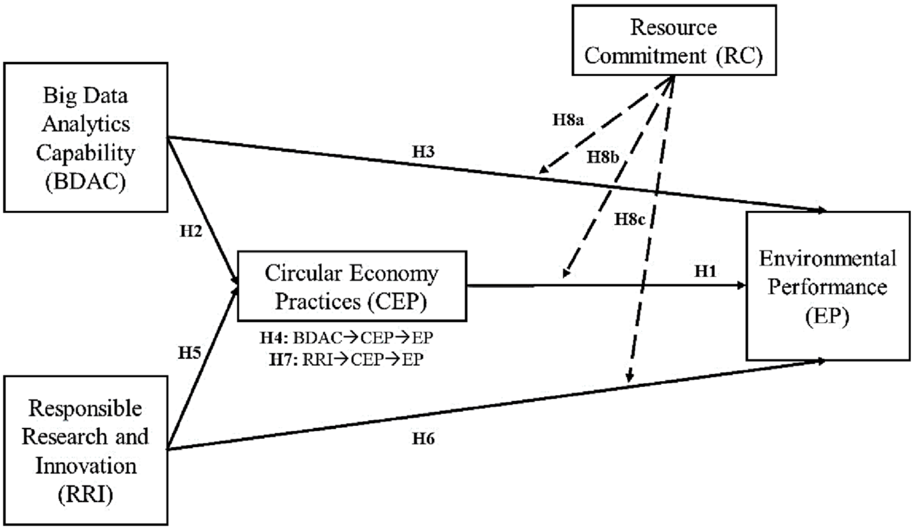

TABLE 2 Profile of respondents.

Operating sector	*N* (%)	Certification of firm	*N* (%)
Pharmaceuticals	131 (40.18%)	ISO 9001	326 (100%)
Precision engineering	101 (30.98%)	ISO 14001	326 (100%)
Agro/food processing	61 (18.72%)		
Textile and garments	33 (10.12%)		
Functional area of respondents (managers)	***N* (%)**	**Working experience of respondents (managers)**	***N* (%)**
Environment	122 (37.42%)	5–10 years	44 (13.50%)
Production	94 (28.83%)	11–15 years	97 (29.75%)
Product design	74 (22.70%)	16–20 years	91 (27.92%)
Supply chain/logistics	21 (6.44%)	>20 years	94 (28.83%)
Quality	15 (4.61%)		

Note: *N*—frequency; %—percentage.

to respond to survey questions. First, the research team ensured that the respondent organisations are members of the ISO-9001 quality management system and the ISO-14001 environmental management system. RRI is not a regulated practice in India, but features of RRI can be seen in the business conduct of manufacturers who pertain to the International Organization for Standardization (ISO). The research team used a judgement sampling method to determine the respondent companies after carefully analysing their background via a secondary investigation. Once a company was assessed to be suitable, a point of contact with experience in either environment, production, production design, supply chain, logistics and quality was identified using a multitude of platforms like social media, a directory of large manufacturers and the Centre for Monitoring Indian Economy database. A brief summary of the respondents appears in Table 2, which demonstrates that most respondent companies belong to the fields of pharmaceutical and precision engineering, and most individual respondents have more than 10 years of experience.

4.2 | Measurement

Reflective measures have been used to formulate the key constructs used in the current study. The literature strongly advocates using the chosen multi-item scales for construct formation and assessing them on a 5-point Likert scale (ranging from *strongly disagree* to *strongly agree*). Appendix A contains a complete list of the scales used and the accompanying items. Each of the five constructs pertaining to the research framework (Figure 1) is described by five items drawn from earlier studies, with the developed questionnaire validated by three specialists in environmental management studies (two from academia and one from the industry).

4.3 | Common method variance (CMV)

CMV describes a disparity in responses that is induced by the measurement model rather than the constructs represented by the

TABLE 3 Internal consistency reliability and convergent validity.

	Item 1	Item 2	Item 3	Item 4	Item 5	α	CR	AVE
BDAC	.754	.583	.748	.731	.724	.757	.780	.505
CEP	.637	.790	.924	.800	.888	.867	.877	.662
EP	.704	.838	.802	.795	.698	.826	.827	.592
RC	.775	.832	.774	.609	.663	.790	.814	.541
RRI	.708	.656	.747	.711	.765	.769	.785	.516

Abbreviations: AVE, average variance extracted; BDAC, big data analytics capability; CEP, circular economy practice; CR, composite reliability; EP, environmental performance; RC, resource commitment; RRI, responsible research and innovation; α, Cronbach's alpha.

TABLE 4 Correlation and discriminant validity.

	BDAC	CEP	EP	RC	RRI
Fornell–Larcker criterion					
BDAC	**.711**				
CEP	.503	**.814**			
EP	.535	.595	**.769**		
RC	.417	.700	.498	**.735**	
RRI	.566	.567	.657	.469	**.718**
Heterotrait–monotrait ratio					
BDAC					
CEP	.593				
EP	.651	.698			
RC	.515	.823	.593		
RRI	.730	.659	.803	.560	

Note: The numbers in bold are the square roots of the AVE values (of respective constructs), which are shown in the diagonal.
Abbreviations: BDAC, big data analytics capability; CEP, circular economy practice; EP, environmental performance; RC, resource commitment; RRI, responsible research and innovation.

TABLE 5 Structural model—results of model fit.

	R^2	Q^2	VIF
BDAC			1.963
RRI			1.959
CEP	.370	.239	2.679
EP	.531	.299	2.092

Abbreviations: BDAC, big data analytics capability; CEP, circular economy practice; EP, environmental performance; NFI, normed fit index = .928; RRI, responsible research and innovation; SRMR, standardised root mean square residual = .085; VIF, variance inflation factor.

measurement parameter (Dubey et al., 2020; Konadu et al., 2020). Harman's single-factor test has been used to identify CMV because it represents the most popular test for this purpose (Benzidia et al., 2021; Sinkovics et al., 2018). This evaluation sees all measurement items entered into a factor analysis to determine whether a single factor appears or whether a single factor accounts for the preponderance of covariance between measures (Kristoffersen et al., 2021; Sahoo et al., 2023). This study sees the first unrotated factor capture only 21% of the variation in data, which is less than the acceptable requirement of 50% (Sinkovics et al., 2018). Consequently, CMV is not a significant issue for this study because no single factor has emerged.

4.4 | Data analysis

To examine the survey data, partial least square structural equation modelling (PLS-SEM) has been used. Before analysing the direct, mediating and moderating hypotheses depicted in the research framework, the constructs must be assessed to check whether they meet the required reliability and validity thresholds. As Table 3 shows, the results demonstrate that factor loading values of items in each construct exceed .5, the Cronbach's α value for each construct exceeds .7, the composite reliability (CR) value for each construct exceeds .7 and the average variance extracted (AVE) value for each construct exceeds .7. These results are consistent with the recommendation of a rule-of-thumb assessment of measurement models found in the prior literature (Hair et al., 2019; Shmueli et al., 2019), suggesting satisfactory internal consistency and convergent validity for the constructs. In addition to assessing convergent validity (Table 3), the Fornell–Larcker criterion and heterotrait–monotrait (HTMT) ratio have been used to assess the discriminant validity of all latent constructs within the model. Table 4 (Fornell–Larcker criterion) shows that the correlation values between constructs (off-diagonal values) are lower than the square root of AVE of each construct (diagonal values and underlined), indicating that each construct features satisfactory discriminant validity (Henseler et al., 2015). In addition to these observations, Table 4 (HTMT ratio) shows that the HTMT ratio is below .9, suggesting the measurement model's good fit (Roemer et al., 2021).

5 | RESULTS

Having verified the reliability and validity of the constructs, it is possible to evaluate the structural model to test the hypotheses using PLS-SEM, a statistical analysis technique that can model relationships between latent (unobserved) variables (Henseler et al., 2015). Because PLS-SEM algorithms employ the iteration method to follow multiple regression series, the path coefficient interpretation in PLS-SEM is

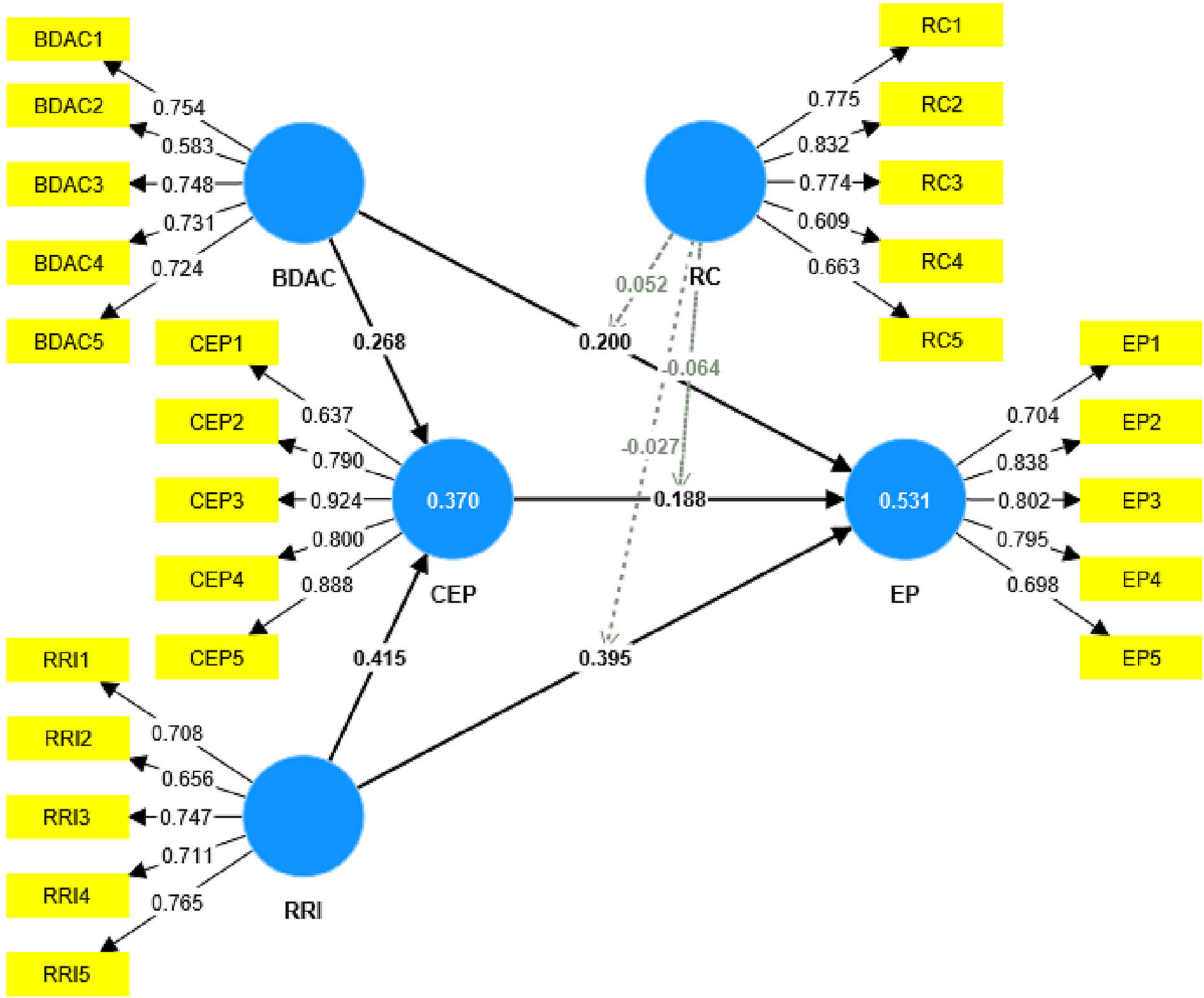

FIGURE 2 Results of hypotheses testing—structural model.

equivalent to the standardisation of the regression coefficient. The PLS-SEM algorithm has been applied together with bootstrapping to derive the R^2, the variance inflation factor (VIF) and the predictive relevance (Q^2) to check for each model's explanatory capacity (Hair et al., 2019; Shmueli et al., 2019). Table 5 and Figure 2 summarise the findings. In PLS-SEM, the R^2 value indicates the amount of variance in the dependent variable that is explained by the independent variable(s). The Q^2 value estimates the predictive accuracy of the model. Table 5 and Figure 2 show R^2 values of .370 for CEP and .531 for EP. Q^2 has also been evaluated to predict R^2 accuracy, with a Q^2 value above 0 indicating that the structural model has predictive power, which is confirmed by the results presented in Table 5. Next, VIF measures the collinearity between independent variables in regression analysis, indicating how much the variance of the estimated regression coefficients increases due to collinearity between independent variables. A high VIF value indicates a high degree of multicollinearity between independent variables, which can affect the accuracy of the regression model. A general rule of thumb is that VIF values above 5 may indicate significant collinearity between independent variables (Henseler et al., 2015). Table 5 shows that the observed VIF values for all variables are below 5, indicating that collinearity is not a concern for the results. In terms of goodness of fit metrics generated by the structural model, the normed fit index exceeds .9 and the standardised root mean square residual is below .10, indicating no disparities between an inferred model and the observed association.

5.1 | Direct hypotheses

In accordance with PLS-SEM recommendations, the testing of direct hypotheses must precede the testing of mediation effect hypotheses (Hair et al., 2019; Shmueli et al., 2019). The results have been obtained via a bootstrapping process featuring 5000 resamples and a 95% bias-corrected confidence interval. As Table 6 shows, the impact of CEPs on EP has a path estimate value (β) of .188 and is significant ($t = 2.845$, $p = .004$), supporting H1. With path estimate values (β) of .268 and .200, BDAC significantly impacts both CEPs ($t = 3.797$, $p = .000$) and EP ($t = 2.925$, $p = .003$), corroborating H2 and H3. With path coefficient values (β) of .415 for CEP ($t = 5.920$, $p = .000$)

TABLE 6 Results of hypotheses testing (direct effects).

Hypothesis	Path	Path estimate (β)	t	p	Outcome
H1	CEP → EP	.188	2.845	.004	Supported
H2	BDAC → CEP	.268	3.797	.000	Supported
H3	BDAC → EP	.200	2.925	.003	Supported
H5	RRI → CEP	.415	5.920	.000	Supported
H6	RRI → EP	.395	6.121	.000	Supported

Abbreviations: BDAC, big data analytics capability; CEP, circular economy practice; EP, environmental performance; *p*, probability value; RRI, responsible research and innovation; *t*, *t* value.

TABLE 7 Results of hypotheses testing (mediating effects).

Hypothesis	Path	Indirect effect	t	p	CI	Outcome
H4	BDAC → CEP → EP	.050	2.244	.025	[0.013–0.100]	Supported Partial mediation
H7	RRI → CEP → EP	.078	2.579	.010	[0.023–0.139]	Supported Partial mediation

Abbreviations: BDAC, big data analytics capability; CEP, circular economy practice; CI, confidence interval (2.5% to 97.5%); EP, environmental performance; *p*, probability; RRI, responsible research and innovation; *t*, *t* value.

TABLE 8 Results of hypotheses testing (moderating effects).

Hypothesis	Path	Estimate	t	p	CI	Outcome
H8a	RC * BDAC → EP	.052	0.900	.368	[−0.080–0.149]	Not supported
H8b	RC * CEP → EP	−.064	1.086	.277	[−0.173–0.052]	Not supported
H8c	RC * RRI → EP	−.027	0.435	.664	[−0.135–0.112]	Not supported

Abbreviations: BDAC, big data analytics capability; CEP, circular economy practice; CI, confidence interval (2.5% to 97.5%); EP, environmental performance; *p*, probability; RC, resource commitment; RRI, responsible research and innovation; *t*, *t* value.

and .395 for EP ($t = 6.121$, $p = .000$), RRI substantially affects these variables, supporting H5 and H6.

5.2 | Mediating hypotheses

Analysing how CEPs mediate the relationship between BDAC and EP (H4) and between RRI and EP (H7) represents the next step of this investigation. First, the mediating effect of CEPs on the BDAC–EP relationship is significant (Table 7), implying that H4 can be accepted (indirect effect = .050, $t = 2.244$, $p = .025$). Second, as Table 7 shows, the mediating effect of CEPs on the relationship between RRI and EP is significant (indirect effect = .078, $t = 2.579$, $p = .010$), supporting H7. Given that the direct effects of BDAC and RRI on EP have been significant when CEP is introduced as a mediating variable, it can be inferred that the mediating role of CEPs is partial in both cases.

5.3 | Moderating hypotheses

The final step in the analysis is to assess the moderating impact of RC on the relationships between BDAC and EP, CEP and EP and RRI and EP. Surprisingly—as Table 8 shows—none of these relationships was significant, precluding support for H8a, H8b and H8c. Analysing the simple slope analysis shown in Figure 3 may provide additional insight into these findings. Ignoring the *p*-value metrics, it is clear that there is a positive effect of interaction between RC and BDAC on EP, with increased EP observed with higher interaction, suggesting that higher levels of RC may be advantageous. When RC and CEPs interact to impact EP, there is a negative effect, with EP nearly equal for both higher and lower interaction values. This implies that a higher level of RC at advanced stages of CEPs may not be useful and that a lower RC can still produce the same outcomes. Finally, when considering the effect of the interaction between RC and RRI on EP, the lines are almost parallel, indicating that there is no significant moderating effect.

6 | IMPLICATIONS

6.1 | Theoretical implication

Given the distinctive nature of the investigation, the results build upon DCV theory by developing an operational capability framework for achieving EP. Considering the results for both the direct and mediating hypotheses, the present study can draw statistical inferences that lend credence to the possibility of generalising the theory and even provide some fresh perspectives. First, in accordance with

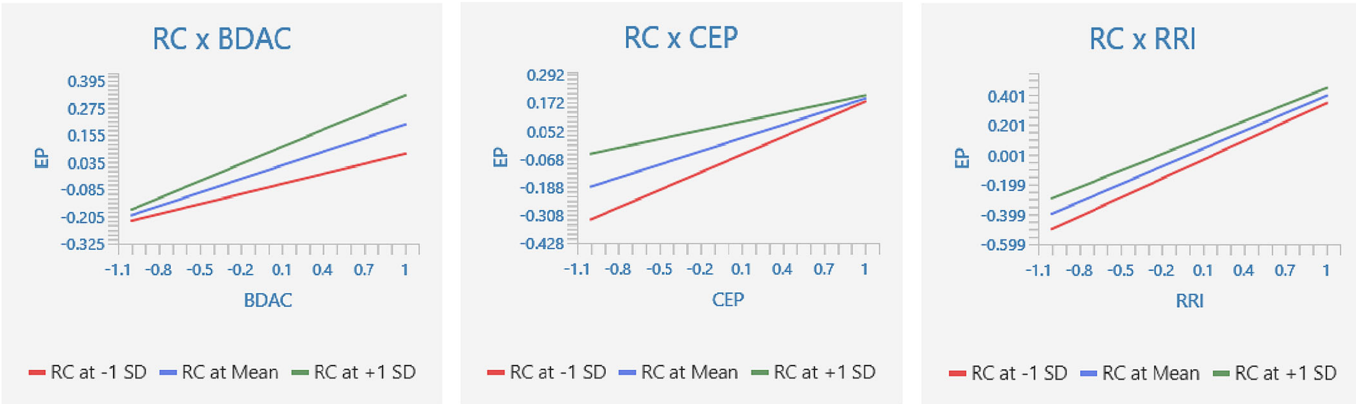

FIGURE 3 Simple slope analysis—interaction plot (moderating effect of resource commitment).

several earlier investigations (Dey et al., 2022; Riggs et al., 2023; Shah & Soomro, 2021), we find that CEPs favourably impact EP, supporting the theoretical generalisability of H1. By adopting CEPs, manufacturers can reduce their environmental footprint, conserve resources and improve competitiveness. The findings for H2 and H3—which concern analysing the effect of BDAC on CEPs and EP—are consistent with several previous studies (Kristoffersen et al., 2021; Riggs et al., 2023; Schöggl et al., 2023). This suggests that manufacturers can make well-informed decisions by using their BDAC to improve their CEPs to achieve enduring sustainability goals. This aligns with the results analysing the impact of RRI on CEP and EP (H5 and H6), a novel perspective from the current investigation that suggests that RRI can help manufacturers identify and support innovative CEPs with a stakeholder-inclusive strategy that resolves environmental operational challenges and creates societal value. Another fresh perspective arising from the current study is empirical evidence on the mediating function of CEPs on the relationships between BDAC and EP (H4) and RRI and EP (H7). This emphasises that by deploying CEPs with BDAC and RRI, manufacturers can accomplish sustainable development objectives, including reducing their impact on the environment. Because CEPs serve as a mediator to a certain degree (partial mediation), it stands to reason that circular business models that use the BDAC of an organisation to initiate them can ensure minimal waste generation and efficient resource utilisation (Liu et al., 2023). Monitoring the consumption of natural resources via cutting-edge software programs is also essential for effective resource administration. Advanced technologies (e.g., automation and artificial intelligence) can significantly reduce manufacturing's negative effects on the environment (de Sousa Jabbour et al., 2022). Similarly, RRI strategies can be used to create new environmentally responsible products, processes and services as part of CEPs. These can potentially benefit society while also increasing company viability, confirming the position of CEPs as mediator. Departing from the findings of studies suggesting that RC acts as a major mediator (H8a–H8c; Joshi & Dhar, 2020; Konadu et al., 2020; le Duc & Gammeltoft, 2023). This has more thought-provoking theoretical ramifications that have produced cognitive changes in management practice, with these results lending credence to multiple theories of the economics of resource allocation, theories predicated on the proposition that there exists an ideal combination of resources that enables maximal production with minimum inputs. Further research could break further ground by representing the economic viewpoint of assigning optimal resources to deploy BDAC, CEPs and RRI practices in the context of manufacturing to achieve EP as a competitive strategy.

6.2 | Managerial implications

Alongside the theoretical implications, this study's advancement of the DCV has important implications for managers at manufacturing organisations, suggesting the need to focus on developing organisational structures, processes and cultures to facilitate learning, experimentation and innovation. By doing so, managers can build a more agile and adaptable organisation that can stay ahead of its competitors in dynamic and rapidly changing markets. To successfully deploy CEPs, companies must engage in exhaustive operational planning and demonstrate a comprehensive understanding of both their own capabilities and the current state of CEPs within the organisation (Govindan, 2022; Shah & Soomro, 2021). To begin with, organisations intending to deploy CEPs must have a department dedicated solely to big data analytics and RRI, with specialised functionalities for managing assets, product and process design, logistics and auditing (Dey et al., 2022; Kristoffersen et al., 2021). This requires that personnel from both the BDAC and RRI departments identify inefficiencies in their consumption of resources at various phases of operation. Meanwhile, they must devise strategies to reduce waste and conserve resources by holding frequent meetings and providing staff training (Joshi & Dhar, 2020; Sahoo et al., 2023). To offer further guidance for practitioners in upper management, Table 9 presents an implementation framework for manufacturers to consider when adopting BDAC and RRI across their organisations. This is based on findings and qualitative discussions with the interviewees engaged in the context of the present investigation. Another significant managerial implication that manufacturers may consider is that increasing the allotment or over-

TABLE 9 Deployment framework for managerial practices.

Stages	Deployment framework for building BDAC	Deployment framework for practising RRI
Stage 1	**Define your goals:** Before deploying big data analytics for CEPs, it is important to define your organisational goals. What are you trying to achieve with this initiative? What circular economy practices do you want to implement? How will developing BDAC help you achieve these goals (Gupta et al., 2019)?	**Define the scope:** Clearly define the scope of the RRI department's responsibilities and the goals it is expected to achieve. Identify the stakeholders who will be impacted by the department's activities (Ortner et al., 2022).
Stage 2	**Identify the data sources:** In order to germinate BDAC, you need to identify the data sources that are relevant to your goals. This could include data from sensors, production systems, customer feedback and other sources (Qi et al., 2023; Sahoo et al., 2023).	**Develop a strategy:** Develop a strategy for the RRI department that aligns with the organisation's overall business strategy. This strategy should address the specific challenges of CEPs in the manufacturing sector (Coffay et al., 2022; Inigo & Blok, 2019).
Stage 3	**Choose the right tools:** There are many big data analytics tools available on the market. You need to choose those that are best suited to your goals and data sources. Some popular tools include Hadoop, Spark and Apache Cassandra (Benzidia et al., 2023; Muchenje & Seppänen, 2023).	**Assess the current state:** Conduct a comprehensive assessment of the organisation's current practices and policies related to CEPs. Identify areas where improvements can be made and opportunities for innovation (Ogoh & Fairweather, 2019).
Stage 4	**Set up a data infrastructure:** To analyse big data, you need to set up data infrastructure that can handle large amounts of data. This could include a data warehouse, data lake or a cloud-based storage solution (Benzidia et al., 2023; Dubey et al., 2020).	**Engage stakeholders:** Engage stakeholders across the organisation, including employees, suppliers, customers and partners. This engagement should involve collaboration and dialogue to ensure that everyone's needs and perspectives are considered (Dubey et al., 2023; Gupta et al., 2019; Konadu et al., 2020).
Stage 5	**Hire skilled personnel:** You need skilled personnel who can manage your big data analytics initiative. This could include, for example, data scientists, data engineers or other technical experts (Riggs et al., 2023; Schöggl et al., 2023).	**Implement best practices:** Implement best practices for CEPs, such as design for circularity, waste reduction and sustainable sourcing. The RRI department should work with relevant departments to ensure that these practices are integrated into the organisation's processes and procedures (Coffay et al., 2022; Fellnhofer, 2022).
Stage 6	**Analyse the data:** Once you have set up your data infrastructure and hired skilled personnel, you can start analysing the data. This involves using statistical and machine learning techniques to identify insights and patterns in the data (Konanahalli et al., 2022; Waqas et al., 2021).	**Monitor and evaluate:** Monitor and evaluate the RRI department's activities and progress regularly. Use this information to make improvements and adjustments to the department's strategies and practices (Dubey et al., 2020).
Stage 7	**Implement CEPs:** Once you have identified insights from the data, you can start implementing CEPs. This could include, for example, reducing waste, optimising resource use or implementing sustainable production practices (Gupta et al., 2019; Kristoffersen et al., 2021).	**Communicate and report:** Communicate the organisation's commitment to CEPs to all stakeholders and report regularly on the department's activities and achievements (Fellnhofer, 2022; Inigo & Blok, 2019; Ogoh & Fairweather, 2019).
Stage 8	**Monitor and optimise:** Finally, it is important to monitor the impact of your CEPs and optimise them over time. This involves measuring [KPIs] and using the insights to improve your practices (Lu et al., 2022).	

Abbreviations: BDAC, big data analytics capability; CEP, circular economy practice; KPIs, key performance indicators; RRI, responsible research and innovation.

allocating resources might undermine EP, suggesting that they instead experiment with various combinations of resources to identify the strategy that best suits them.

7 | CONCLUSION

The current research is significant for the Indian manufacturing sector because it provides insight into the complicated processes and structures involved in shifting from a linear, 'take-make-dispose' economy to a circular economy that places greater emphasis on resource efficiency, waste reduction and the repurposing of materials. The present research addresses the gap in the research on this matter by resolving the research questions with the intention of providing evidence that manufacturers can leverage their BDAC and RRI practices to identify crucial areas for action in the pursuit of more restorative and regenerating operations in a manufacturing setting. BDAC facilitates the identification of functional areas where CEPs can be implemented and provides insights into the effectiveness of these practices. The combination of these two approaches creates a synergistic effect that ultimately improves EP. Additionally, this study emphasises the significance of integrating RRI principles (e.g., transparency, inclusiveness and ethical considerations) into manufacturing processes such that CEPs may be designed and conducted in ways that benefit society and the environment. The outcomes of this research can be used to influence policy decisions about CEPs, including the regulations, incentives and financing mechanisms that can enable governments more broadly to transition to a more holistically circular economy.

Empirical research is predicated on using observations and data to either corroborate or disprove a hypothesis. However, numerous factors that risk the validity of such research should be considered by researchers. These threats encompass selection bias, measurement bias, maturation bias, history bias, experimental mortality bias, the Hawthorne effect and experimenter bias. The presence of biases in research can engender erroneous outcomes that lack generalisability to the target population. To mitigate potential threats to the validity of their research, scholars must exercise caution in the selection of study participants, employ measurement instruments that are both reliable and valid, account for extraneous variables and remain cognisant of their own biases and preconceptions. Accordingly, these research findings should be viewed in light of their limitations. First, because of the positioning of the different components as independent variables in the framework, the current study does not provide insight into how manufacturers might develop competent BDAC and cooperatively practise RRI in the manufacturing value stream. Hence, further research should work to improve our knowledge of the antecedents to the effective deployment of BDAC and RRI. Second, because the investigation considered how CEP mediates the impact of BDAC and RRI on EP based on cross-sectional data, future research should explore this relationship using a longitudinal research design. Finally, future research should be conducted in various countries to provide fresh perspectives.

CONFLICT OF INTEREST STATEMENT

There is no conflict of interest among authors.

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APPENDIX A

Big data analytics capability (Dubey et al., 2020; Kristoffersen et al., 2021)

- Our organisation has invested in automated systems to ensure that all pertinent strategic information is always accessible throughout the lifecycle of our product and service offerings. (Automated systems)
- Our organisation has invested in parallel computing technologies to manage voluminous data that pertain to different functional areas, including inventory planning, supplier analysis, customer behaviour analysis, warehouse operations, transportation planning and demand projections. (Computing technologies)
- Our organisation has invested in data integration technologies to consolidate data from multiple sources into a data repository for easy access by various functional divisions whenever required. (Integrating technologies)
- Our company has invested in data visualisation technologies to enable quick analysis of the business environment, potentially facilitating effective decision-making. (Visualisation technologies)
- Our organisation has invested in training programmes on a regular basis to ensure that analysts employed by different functional departments are always up to date on analysis techniques that contribute to effective decision-making for the company. (Competency building)

Responsible research and innovation (Castilla-Polo & Sánchez-Hernández, 2022)

- Our organisation routinely undertakes research on one or more of the economic, social and environmental prospective (or consequence) of our strategic members and their use of technology for conducting business. (Anticipation)
- Our organisation involves our stakeholders in workshops, debates or training sessions regarding utilising and engaging with advanced technologies. (Inclusion)
- Our organisation advocates for transformative mutual learning via co-innovation, open innovation or user-centric design. (Inclusion)
- Our organisation actively collaborates with reputable regional (or international) businesses to develop research and development projects while adhering to best-practice guidelines. (Reflexion)
- Our organisation can transform its operational orientation or technological deployment based on our direct and permanent association with our strategic partners and other stakeholders. (Responsiveness)

Circular economy practices (Govindan & Hasanagic, 2018)

- The five Rs (reduce, reuse, recycle, recover, redesign and remanufacture) have all resulted in improved manufacturing productivity for our organisation. (Cleaner production)
- Our organisation encourages visionary thinking and incentivises technological innovation to adopt the five Rs in the supply chain. We also routinely organise education and awareness events for the majority of the strategic participants in the manufacturing value chain. (Knowledge management)
- Our organisation has developed a set of performance metrics for assessing our recycling, reuse and remanufacturing practices and those of strategic partners in the manufacturing value chain/supply chain. (Governance initiatives)
- Products designed by our organisation are designed for recurrent use and can be dismantled for recycling. (Product development)
- Our organisation prioritises socio-economic project opportunities with a low ecological footprint, which influences the price of our product line by incorporating the costs associated with reuse, recycling and remanufacturing. (Economic initiatives)

Environmental performance (Shah & Soomro, 2021)

- Over the past 3 years, our organisation has made significant progress in reducing pollution and waste.
- Over the last 3 years, our organisation has improved its adherence to environmental regulations.
- Over the last 3 years, recycling endeavours at our organisation have increased.
- Over the last 3 years, our organisation's reputation as environmentally responsible has improved.
- Our organisation has done more than our competitors to promote ecological sustainability.

Resource commitment (Sinkovics et al., 2018)

- Upper management in our organisation plans and budgets a portion of the revenue generated for environmental management initiatives.
- Upper management in our organisation offers sufficient financing to ensure that environmental management projects receive the consideration and resources they deserve.
- Upper management in our organisation prioritises providing the required physical resources, facilities and machinery to ensure the success of environmental management projects.
- Upper management in our organisation prioritises providing the managerial resources (assignment of personnel) required to ensure the success of environmental management projects.
- Upper management in our organisation emphasises deploying internal resources to mentor and technologically upscale the sustainability performance of our key long-term strategic partners.