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ORIGINAL RESEARCH

Achieving Sustainability of SMEs Through Industry 4.0-Based Circular Economy

Manish Mohan Baral[1] · U. V. Adinarayana Rao[1] · K. Srinivasa Rao[1] · Girish Chandra Dey[1] · Subhodeep Mukherjee[1] · M. Arun Kumar[1]

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Abstract

Industry 4.0 and circular economy are two energetic aspects of operations management and production economics. The current study extracts the factors for adopting an industry 4.0-based circular economy to measure sustainability in SMEs. Eight hypotheses are proposed by identifying one independent variable, four mediating variables and one dependent variable. Survey-based research is carried out, and the sample size for the current study is 296 from different SMEs. The structural equation modeling approach is utilized for testing the hypotheses. The construct identified is industry 4.0-based circular economy; the four mediating variables are: economic performance, environmental performance, social performance, and operational performance, and the dependent variable is sustainability. The mediating variables have a positive impact on the dependent variable. The study is unique as the joint adoption of industry 4.0 and circular economy is tested, and also it reveals the importance of sustainability achievement in the operating firms. The prior studies have not considered the joint adoption of industry 4.0 and circular economy.

Keywords Industry 4.0 · Circular economy · Sustainability · Environmental performance · Operational performance

Introduction

Industry 4.0 will necessitate the development of new business models and partnerships. These models will make value-added services and software licenses available to SMEs (Singh et al., 2008). Furthermore, this approach will allow for establishing business networks in which revenues are equitably distributed among all value chain participants and all partners comply with expanded regulatory requirements for products and production (Dutta et al., 2020). Industry 4.0 will increase the productivity potential for both small and medium-sized businesses (Singh & Kumar, 2020). SMEs can benefit from actionable insights from their data by utilizing cloud technology, Big Data, and analytic systems. This means that they can transition from reactive to predictive maintenance, identify areas for improvement, reduce waste, and increase yield (Kumar et al., 2021; Singh et al., 2022). Utilizing long-lasting, renewable, and recyclable materials can help SMEs in a circular economy become less reliant on scarce and expensive resources and less susceptible to supply chain disruptions (Mishra et al., 2022). Building long-lasting products may reduce warranty and production costs (Kirchherr et al., 2017). The transition to a circular economy is also expected to generate new jobs and revenue streams, such as reverse cycle activities, such as sorting, collecting, refurbishing, and remanufacturing. Unheard of in the linear economy, these novel activities might create new jobs and provide SMEs with fresh avenues for growth (Mukherjee et al., 2022d).

Currently, manufacturers involved in international markets are adopting different green initiatives for sustainable products, attracting more clients (Siqin et al., 2022). But most firms fail to achieve sustainability goals because of failure in sustainable recycling, remanufacturing, and reusing operations. These failures are due to a lack of visibility, flexibility and poor resilience. The prior literature on industry 4.0 (I4.0) technologies (Choi et al., 2022) and circular economies (CE) (Rossi et al., 2020) debated mainly on the theoretical impact of Industry 4.0 technologies on the adoption of CE (Kazancoglu et al., 2021). I4.0 technologies help a firm's digitalization to achieve sustainable development

✉ Manish Mohan Baral
manishmohanbaral.31@gmail.com

[1] Department of Operations, GITAM School of Business, GITAM (Deemed to Be University), Visakhapatnam, India

goals (Fatimah et al., 2020). The current study focuses on adopting I4.0-based CE to achieve sustainability, and this advanced technology will completely change the architecture of traditional manufacturing (Patyal et al., 2022). I4.0 is a new technology and not yet matured, so SMEs face many difficulties, such as finance and skill gaps (Yadav et al., 2020). Hence, a proper I4.0 delivery system is needed to overcome these challenges (Kurniawan et al., 2022). It will give a perfect opportunity for learning organization (Kusi-Sarpong et al., 2021) using remanufactured, recycled and refurbished components for running the production lines. I4.0 implementation will help optimize the operations in the SMEs and help standardize the business and manufacturing processes (Mukherjee et al., 2022c). It will help in a significant reduction in lead times and resources (Khan et al., 2021a; b). Most SMEs are unaware of the latest technologies which can help increase the firm performance. Creating awareness workshops can effectively demonstrate the benefits and scope of adoption (Mukherjee et al., 2022a). Chauhan et al. (2022) found that both IoT and AI play an important part in the process of shifting towards CE. Gebhardt et al. (2022) examined the interaction of the CE, collaboration in the SC, and Industry 4.0. This transformation's extraordinary technological integration may eventually lead to more robust and resilient business models at the corporate level and throughout the world's economies. Sahu et al. (2022) performed a thorough evaluation of the literature on integrating Industry 4.0 and the CE.

The global economy is only 9% circular (Khanzode et al., 2021). The value clearly states that the present consumption and production systems cannot restore these naturally available resources consumed to produce goods (Kumar et al., 2020). Therefore, the prior literature also points out the need for circulating the natural resources in the system, which will lead to sustainable development (Kumar et al., 2021). In business uncertainty and disruptions, firms practicing recycling and remanufacturing face problems such as production losses, supply-related bottlenecks, and excess inventory. Disruptive situations highly influence the decision-making capacity of the management and staff of the firm. It also leads to high spending and a reduction in profit margins. In addition, a bad vision leads to lower level customer satisfaction, sales forecasting and production losses. Firms create a high inventory level so they do not lose any customer's order, but high inventory storage creates a blockage of working capital. The increased inventory makes products obsolete in the market due to technological advancements. In addition, delay in the delivery of the orders causes dissatisfaction among the clients, which may result in losing customers and business (García-Muiña et al., 2021). Adoption of I4.0 can improvise both the bottom and top line simultaneously, and the firms can expect an increase of 10% in terms of efficiency. Its adoption will help increase operational efficiency, flexibility and effectiveness (Jiang et al., 2016).

Manufacturing firms have a significant role in sustainable development and are a primary concern for higher oriented technologies (Gould & Colwill, 2015). This I4.0 will help create value by permitting visibility and flexibility (Genovese et al., 2017). The major problem in emerging economies is the lack of proper infrastructure. Still, these SMEs have the potential to adopt advanced technologies like I4.0, which can cause improvement in the performance of these firms (Rattalino, 2018). SMEs lack an understanding of the applications of I4.0. Therefore, there is a need to create focus and awareness among these firms as they are significant contributors to the country's economy (Corsini et al., 2019). These firms consume a massive share of resources and produce vast waste material while manufacturing the products. The current study focuses on measuring the firm performance to achieve sustainability by adopting I4.0-based CE (Zink & Geyer, 2017). The present scenario has led to a discussion of linking I4.0 with CE to enhance firm performance. The current study used the resource-based view theory (RBV) and positive effects theory for linking I4.0 and CE for value creation as these theories helped in understanding the effective use of resources which aims to increase the efficiency of the firm when compared to the competitors (Kawai et al., 2018). The difference in management practices might explain firm performance differences (Telukdarie et al., 2018). To our knowledge, the identified components have not been utilized in past studies for Indian SMEs. This study aims to identify the construct I4.0-based CE; the four mediating variables are: economic performance, environmental performance, social performance, and operational performance, and the dependent variable is sustainability. The mediating variables have a positive impact on the dependent variable. The study is unique as the joint adoption of industry 4.0 and circular economy is tested, and also it reveals the importance of sustainability achievement in the operating firms. Hence, the current study has used the RBV theory to examine the following research question.

Bag et al. (2018) stated that the adoption and implementation of I4.0 help to increase positive results in manufacturing operations. In developed nations, there is a massive demand for adopting these advanced technologies within SMEs (Cagliano et al., 2019). Similarly, one can adopt I4.0 technologies in developing nations like India by creating awareness among the firms, which will boost confidence in the adoption process. In addition, there is a need to identify the factors that play an essential role in adopting these latest innovative technologies. Prior studies (Cagliano et al., 2019; Chen et al., 2015; Kovacs, 2018; Rajput & Singh, 2019) have analyzed the interaction of I4.0 and CE only through a conceptual or exploratory viewpoint. Therefore, the current study has provided empirical validity for the same. Therefore, the second research question developed is:

The proposed mediating variables helped test the empirical validity of the sustainability of SMEs (Raj et al., 2020). These firms face a lot of challenges in adopting these technologies and also face sustainability issues. Therefore, the current study measures the firm's sustainability through an I4.0-based CE. The data have been collected from SMEs, and a structural equation modeling approach has been used to test the proposed hypotheses.

The current study has identified factors which impact the adoption of industry 4.0-based CE for SMEs. The study also contributes to the literature in CE and I4.0 utilizing empirical evidence provided. A survey was conducted in Indian SMEs, and the investigation is unique as the joint adoption of industry 4.0 and circular economy is tested. In addition, it reveals the importance of sustainability achievement in operating firms. The rest of the paper is as follows: the next section discusses the literature review, the third section discusses the research methodology, the fourth section discusses the data analysis, the fifth section provides a discussion, and the last section includes the conclusion.

Literature Review and Development of Hypotheses

The relationships between I4.0-based CE and performance measures are presented here. The relationship between the mediators, performance and sustainability measures is discussed, and hypotheses are developed to conceptualize the study.

Theoretical Unpinning

RBV also supports the synergy between I4.0 technologies and CE as it helps understand the effective use of resources, increasing efficiency compared to the peers existing in the marketplace (Khanra et al., 2022). These two concepts are merged to improve performance (Chiappetta Jabbour et al., 2020a). If a firm's objective is to implement new technology like I4.0 for success, then there is a need to consider various factors before adopting this technology (Huo et al., 2016). In addition, it was found that adopting I4.0 and lean manufacturing practices creates a high level of performance (Bag & Pretorius, 2022). In addition, complementary effects explain that the combined impact of two different resources is more than when a single resource is adopted (Müller et al., 2018). It relays how one resource impacts the other and how their relationships impact the other identified factors for adopting I4.0-based CE to achieve SC sustainability (Lopes de Sousa Jabbour et al., 2022; Mastos et al., 2021). The complementarity effect has been applied in management to find various ways to improve firm performance and achieve sustainability (Chari et al., 2022). If two resources can be combined, they will provide results in a more desired manner and back to the performance enhancement of the firm (Pinheiro et al., 2022). Hence, the perspective of the complementary effects is applied to CE and checks the joint effect of I4.0-based CE to enhance SMEs' operational performance sustainability. Most prior studies (Abdul-Hamid et al., 2021; Bag & Pretorius, 2022; García-Muiña et al., 2021; Patyal et al., 2022; Rajput & Singh, 2019, 2022; Rosa et al., 2020) have analyzed the exploratory or conceptual perspective of I4.0-based CE.

As per Bromiley and Rau (2016), the practice-based view (PBV) as applying RBV is not always a good option to explain firm performance. For adoption-based studies, PBV helps explain the firm's plant or industry-level performance. PBV assumes a high deviation in a firm performance by adopting beneficial practices. Still, all firms do not adopt all the practices which are best for them to improve their performances. Hence, the use of practices can elucidate performance deviations. PBV can also eliminate several difficulties associated with RBV. In the current study, I4.0-based CE has been adopted to increase the sustainability of SMEs. The present study applied PBV and complementary perspective to adopt I4.0-based CE through four mediating variables to attain a firm's sustainability. To the best of our knowledge, PBV and complimentary perspective theories have not been used in a developing country context to determine SMEs' sustainability. The following sub-section states the proposed hypotheses in the study. Figure 1 shows the research framework for this study.

Development of Hypotheses

I4.0-Based CE and Economic Performance (EP)

I4.0 is a technological advance that helps improve efficiency and increases the economy's performance. Higher efficiency lessens the relative price, which also increases the demand for the resource (Zink & Geyer, 2017). For recycling, there is a need for energy and the production of waste products and by-products through the entropy phenomenon. The circular usage of resources decreases the environmental-economic steadiness of an ecosystem. According to Chen et al. (2015), technology usage reduces the risk of damaging products and enhances manufacturing process accuracy. A decrease in defects reduces the wastage of materials. In addition, the I4.0 usage helps improve the recycling of products and services. Robots and sensors will help recycle the products and reduce manufacturing costs. Hence, the proposed hypothesis is:

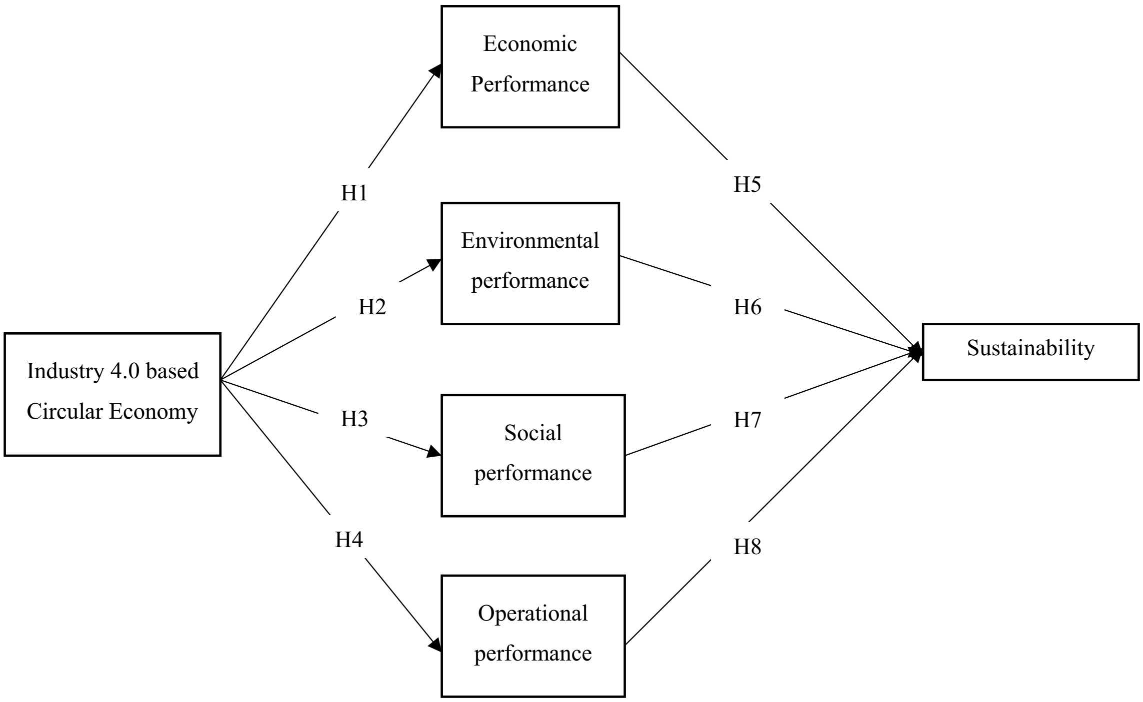

Fig. 1 The research framework

I4.0-Based CE and Environmental Performance (EVP)

As per Braccini and Margherita, (2018), autonomous material handling reduces the risk of damaging the products and enhances the manufacturing processes' accuracy. The decrease in defects results in reduced waste materials and avoids extra energy consumption for repairing environmental factors. Integrating I4.0-based CE positively impacts environmental performance (Yadav et al., 2020). I4.0 adoption includes high contributions and limitations from an environmental point of view. This technology can reduce the emission of resources and energy consumption across the SC during the manufacturing processes in SMEs. It helps lower the emission of CO_2 or wastage during the production process. In addition, it can lead to disassembling the components into reuse, recycling, or remanufacturing the resources (Bag et al., 2020; Sung, 2018; Tortorella et al., 2020). Thus, the proposed hypothesis is:

I4.0-Based CE and Social Performance (SP)

There are many advantages of adopting I4.0-based CE for social issues related to working and health conditions, like handling detrimental materials for recycling (Schröder et al., 2019). In addition, Dai et al. (2017) stated that changing traditional manufacturing to intelligent manufacturing using the latest technologies seriously impacts society as upgraded skills are required to work after technology adoption. Social issues such as customers, community, and employees constitute SP. The social parameters focus mainly on the local communities, employees, and laborers. Prior studies (Lu, 2017; Xu et al., 2018) stated that developed nations primarily focused on the social performance for the sustainability of SMEs. Therefore, the following hypothesis is proposed,

I4.0-Based CE and Operational Performance (OP)

I4.0 will contribute to the firm's sustainability by improving operational efficiency by managing the production system in estimating demand and inventory control (da Silva et al., 2019). Decentralization of resources may increase the lead time of the manufacturing processes. A recent study by Buer et al., (2020) stated that there is a higher role of I4.0 on operational performance as this latest technology will help enhance the system's operating performance. Pinheiro et al., (2022) investigate the impact that the CE has on the operation of the organization. Nascimento et al., (2019) investigated how emerging technologies from Industry 4.0 can be combined with CE practices to create a business model that reduces, reuses, and recycles waste material such as scrap metal and electronic waste. da Silva and Sehnem, (2022) critically examine research that has focused on the intersection of CE and I4.0. To better grasp how I4.0 technologies can appropriately support the CE from the stakeholders' perspective, and to detect the variables for putting those theoretical fields onto supply chains, the authors provide five new paths and problems in the interaction between CE and I4.0. These include applying those technologies to clean production, leveraging blockchain and big data in the circular supply chain, increasing the impact of additive manufacturing on the CE, and so on. Yu et al. (2022) investigated how industry 4.0 might boost the performance of businesses by influencing CE practice's and SC capability. There is evidence that behaviors associated with CE have a favorable connection with both operational and economic performance. Thus, the proposed hypothesis is:

Economic Performance and Sustainability

Economic performance plays a significant role in achieving the sustainability of SMEs. It helps in employment creation in the region. In developing countries, SMEs like India provide cheaper items than those in developing countries. In addition, it has been identified that manufacturing SMEs are consumers for the more significant part of resources (Goel et al., 2021). SMEs are also responsible for a more considerable proportion of water and air pollution and also the generation of wastage (Rodríguez-Espíndola et al., 2022). SMEs must use the resources efficiently, which will help improve economic performance and result in the firms' sustainability (Chiarini, 2021). Hence, the proposed hypothesis is:

Environmental Performance and Sustainability

As per Fontana et al. (2015), although their environmental footprint may be relatively less, manufacturing SMEs in several areas generate environmental harm than their larger counterparts. SMEs must use resources efficiently, and economic growth must be environmentally friendly. Latan et al. (2018) stated that relational and technological capabilities play a critical role in supporting SMEs in pursuing sustainability of the SMEs. There is a need to engage SMEs to adopt sustainability practices to improve environmental performance. This will also help develop the firm's competitive advantage (Marrucci et al., 2021). Therefore, there is a need to identify whether there lies any positive impact of environmental performance on the sustainability of the firm. Harris et al., (2021) aim to look at the recent research on the CE that focuses on figuring out how products and services can affect the environment. Khan et al. (2021) investigated the significance of blockchain technology in circular CE practices and their influence on eco-environmental performance, which impacts organizational performance. Higher eco-environmental performance has a substantial positive effect on organizational performance. Rehman Khan et al. (2021) investigated the function of blockchain technology in the circular economy in order to improve organizational performance. In addition, green practices were found to have a good relationship with the environmental and economic routes to firm performance, while environmental performance was found to have a positive relationship with the business's economic health. Hussain and Malik, (2020) found the literature on organizational sense making to determine what factors influence the environmental performance of SC and what role organizations play in facilitating circular SC.

Hence, the proposed hypothesis is:

Social Performance and Sustainability

Social performance related to social initiatives and practices is generally driven by the corporate social responsibility or adoption of environmentally friendly practices (Liu et al., 2011; Odoom et al., 2017; Qalati et al., 2021; Wulandari et al., 2020). As SMEs contribute to any country's economy, they have the unique responsibility to uplift society. Lean manufacturing also helps improve the social performance and sustainability of the firms. Adopting the latest technologies like I4.0 helps improve a firm's performance differently. Dey et al., (2020) connected CE practices with sustainability performance in order to expose the current condition of CE practices inside SMEs. The concerns and challenges, tactics, resources, and competencies needed to implement CE in SMEs are all laid bare by this study. Chiappetta Jabbour et al., (2020b) tested a research framework that can capture the complicated links between stakeholder pressure, barriers to and drivers of the CE, circular business models, and firms' sustainable performance. Fatimah et al., (2020) analyzed the underlying problems and prospects, as well as to design a waste management system that is both sustainable and intelligent on a national scale, making use of technology related to industry 4.0. Hence, the proposed hypothesis is:

Operational Performance and Sustainability

Operational performance is a critical component when considering any manufacturing process of SMEs (Chan et al., 2017; Dubey et al., 2020). Adopting the latest technology, like I4.0, helps improve the operational performance of SMEs and supports the firm's sustainability in the marketplace. SMEs are essential to the economy and contribute to the nation's growth and development. Improvement in OP will also help increase the efficiency of the business processes and result in profits for the organization (Altay et al., 2018). In addition, using I4.0 will further help improve the efficiency and sustainability of the firm. Agrawal et al., (2021) conducted a complete review and network-based analysis by examining future research prospects in the nexus of CE and sustainable business performance within the framework of digitalization. Dev et al., (2020) presented a combination of I4.0 and CE constitutes a real-time decision model for the sustainable reverse logistics system. Marrucci et al., (2021) showed how absorptive capacity and organizational performance are linked. According to the findings of the study, a company's absorptive ability as well as the organizational activities that lie beneath its surface substantially ease the incorporation of a circular economy and the internalization of an environmental management system, both of which ultimately contribute to an improvement in the overall performance of the organization. (Bag & Rahman, 2021) investigated the following relationships: the connection between engagement and alliance capability, with data analytics capability serving as a mediator; the connection between alliance and data analytics capability and sustainable supply chain flexibility, with industry dynamism serving as a moderating variable; and the connection between sustainable supply chain flexibility and the performance of circular economy targets.

Hence, the proposed hypothesis is:

Research Methodology

Measurement Scales and Survey Items

Measurement items were created following the PBV and complimentary perspective theories. The present study identified items from different sources like I4.0-based CE construct based on publications by the National Confederation of Industry (2016) and Tortorella et al. (2020); the economic, environmental and social performance constructs are based on Paulraj (2011); the operational performance construct is based on Flynn et al., (2010) and the sustainability construct is based on Kirchherr et al., (2017). An exhaustive literature review was conducted the identifying the latent variables. Six experienced academicians assessed the questionnaire and suggested modifications to the identified constructs and associated items after receiving it. They were resent for confirmation and input when the improvements were made. Hence, content validity was achieved by the above procedure. Afterwards, the questionnaire was sent to the SMEs for data collection purposes. Table 2 provides the measurement scales and its references. The questions in Section A addressed a wide range of subjects, including the respondents' gender, educational background, job title, business type, and number of employees. In Section B, the responders were asked to fill in their views on I4.0-based CE, social, environmental, operational performances and sustainability. For this study, a 7-point Likert scale ranging from "strongly disagree" to "strongly agree" was used.

Data Collection and Sampling

A questionnaire was prepared with the help of academicians and working professionals working in various manufacturing SME sectors in India. The questionnaire implemented all the recommendations before the data collection process started. Employee opinions from a variety of Indian manufacturing SMEs were obtained. Most respondents were directors, plant managers, operation managers, and SC managers. Simple random sampling was used as the sampling method to ensure that the study was biased-free. Sources of databases were the Automotive Component Manufacturers Association of India (ACMA), Indian Industry (CII), and the Federation of Indian Chambers of Commerce and Industry (FICCI). The data was collected from April 2022 to September 2022. Only 355 of the 856 respondents who received the questionnaire returned it to us. Only 296 responses can be used for further data analysis after proper screening and data cleaning because the remaining ones were not correctly completed. After data collection, the Harman single-factor test was used to verify the common approach's bias.

Demographics of the Respondents

A cross-sectional design and analysis were used per Leedy and Ormrod's (2014) recommendation. Table 1 shows the demographic details of the respondents.

Table 1 Demographics of the respondents

Classification/profile	Number of respondents	Percentage
Gender		
Male	151	51
Female	145	49
Educational qualification of the respondents		
B. Tech/BSC	131	44
M.Tech/MSC/MBA	165	56
Respondent's current position		
Director	57	19
Plant manager	79	27
Sc manager	93	31
Operation manager	67	23
Type of firm		
Micro-organizations	82	28
Small organizations	102	34
Medium organizations	112	38

Table 2 Values of Cronbach's alpha (α), factor loadings, and measurement items

Variables	Measures	Sources	Cronbach's alpha (α)	Factor loadings	Tolerance	VIF
I4.0-based CE	I4CE1: using sustainable raw resources in place of non-renewable raw materials	(García-Muiña et al., 2021)	0.816	0.721	0.443	2.257
	I4CE2: reducing waste and rework by utilizing innovative technologies and working ways			0.780	0.343	2.912
	I4CE3: initiatives for reuse, recycling, and remanufacturing			0.727	0.380	2.633
	I4CE4: replacing outdated machinery and technology with newer, cutting-edge, and effective ones			0.570	0.515	1.940
Economic performance	EP1: reduction in money spent on raw materials	(Paulraj, 2011)	0.852	0.722	0.395	2.530
	EP2: expenditure reduction on electricity costs			0.854	0.302	3.312
	EP3: expenditure reduction on sewage and water treatment costs			0.850	0.330	3.029
	EP4: enhanced profitability			0.531	0.637	1.571
Environmental performance	ENVP1: decreased emissions of harmful gases	(Paulraj, 2011)	0.866	0.783	0.408	2.449
	ENVP2: decreased wastage			0.885	0.280	3.568
	ENVP3: decreased use of hazardous materials			0.888	0.304	3.294
	ENVP4: most practical use of natural resources			0.594	0.643	1.556
Social performance	SP1: increased involvement of stakeholders	(Paulraj, 2011)	0.924	0.863	0.303	3.301
	SP2: decreased risks to the firm's perception by the public			0.908	0.224	4.468
	SP3: increased worker safety and health			0.854	0.268	3.735
	SP4: enhanced associations with the community			0.834	0.321	3.118
Operational performance	OP1: our organization promptly modified products to satisfy our principal clients' demands	(Flynn et al., 2010)	0.885	0.423	0.841	1.190
	OP2: new goods from our company have been promptly presented to the market			0.534	0.741	1.350
	OP3: our business has reacted promptly to changes in market demand			0.660	0.727	1.376
	OP4: The punctuality of deliveries to important clients has increased for our business			0.446	0.805	1.242
Sustainability	S1: CE capabilities facilitate the shift to sustainability and transform the economy	(Kirchherr et al., 2017)	0.868	0.801		
	S2: CE transforms and strengthens society			0.834		
	S3: CE helps in transforming the environment			0.857		
	S4: CE helps in transforming the operational process of the firms			0.653		

Data Analysis

Reliability and Validity

Common Method Bias and Multicollinearity

Harman developed the single-factor test was used to measure common method bias. After exploratory factor analysis, the results showed that the first component could only fully explain 17.193% of the variation, much below the required threshold of 50% (Mukherjee et al., 2022e; Podsakoff, 2003). All the tolerance values are more significant than 0.2, which meets the condition (Nunnally, 1978), shown in Table 2. Second, the VIF for all the statements is shown in Table 2. All the values are less than 5, which is the acceptance level (Nunnally, 1978). The condition index for all the variables is less than 15, which satisfies the condition. Therefore, the values for the latent variables meet the requirement that the data is not multicollinear (Nunnally, 1978).

Cronbach's Alpha

The degree of the internal consistency between its measurement items for the variable and its freedom from error is examined via reliability evaluation (Baral et al., 2022; Kline, 2000). Cronbach's alpha values are displayed for each component in Table 2. The values need to be higher than 0.70 (Nunnally, 1978).

Exploratory Factor Analysis

The computed Kaiser–Meyer–Olkin (KMO) value was 0.751, more significant than the 0.60 minimal level (Hair et al., 2010). The components were extracted using a varimax rotation with the principal component analysis. 71.114% of the total variance could be accounted for by all six components, which is well above the threshold level, i.e., 60% (Pal et al., 2021). Table 2 displays the factor loadings for each item, the construct's Cronbach's alpha, tolerance, and VIF values.

Confirmatory Factor Analysis for Latent Variables

The measurement model assessed discriminant validity, composite reliability, and convergent validity using CFA (Mukherjee et al., 2022b). The goodness of fit indices was analyzed to assess the model fit. The goodness of fit indices was $\chi^2 = 446.990$ with $df = 237$, χ^2/df (CMIN/DF) = 1.886, RMSEA = 0.055, IFI = 0.940, CFI = 0.939, TLI = 0.929, PCFI = 0.807, PNFI = 0.756 and GFI = 0.911 are in the threshold level as suggested by Byrne, (2010).

Composite Reliability

For each component, composite reliability (CR) was evaluated. Internal consistency is estimated because of its capability to deliver better results (Hair Jr, 2006). The approved threshold level for the CR of the constructs is more than 0.70 (Hair et al., 2012). The values are displayed in Table 3.

Convergent Validity

A given structure's indicators must have a wide distribution of variance. It is calculated using the average variance extracted (AVE) (Mukherjee et al., 2021). The approved threshold level for the AVE for the constructs is more than 0.50 (Fornell & Larcker, 1981). The AVE extracted for the factors is shown in Table 3.

Discriminant Validity

The degree to which the constructions differ from one another is examined. Table 3 shows the discriminant validity matrix for the components. To evaluate discriminant validity, the correlation for each component was compared to the square roots of the AVEs (Fornell & Larcker, 1981).

Structural Model and Testing of Hypothesis

In AMOS 22.0, the structural model was evaluated for hypothesis testing. The structural model for assessing the

Table 3 Discriminant validity matrix

	CR	AVE	MSV	MaxR (H)	SP	ENVP	S	EP	I4CE	OP
SP	0.925	0.755	0.032	0.93	**0.869**					
ENVP	0.873	0.637	0.008	0.906	− 0.05	**0.798**				
S	0.871	0.631	0.032	0.885	0.178**	− 0.076	**0.794**			
EP	0.859	0.61	0.26	0.899	− 0.003	− 0.088	0.048	**0.781**		
I4CE	0.818	0.533	0.26	0.836	0.042	− 0.068	0.067	0.510***	**0.73**	
OP	0.712	0.545	0.061	0.633	0.015	− 0.084	− 0.015	0.246**	0.098	**0.527**

The values are correlations including the bold values

Significance of correlations: **$p < 0.010$ and ***$p < 0.001$

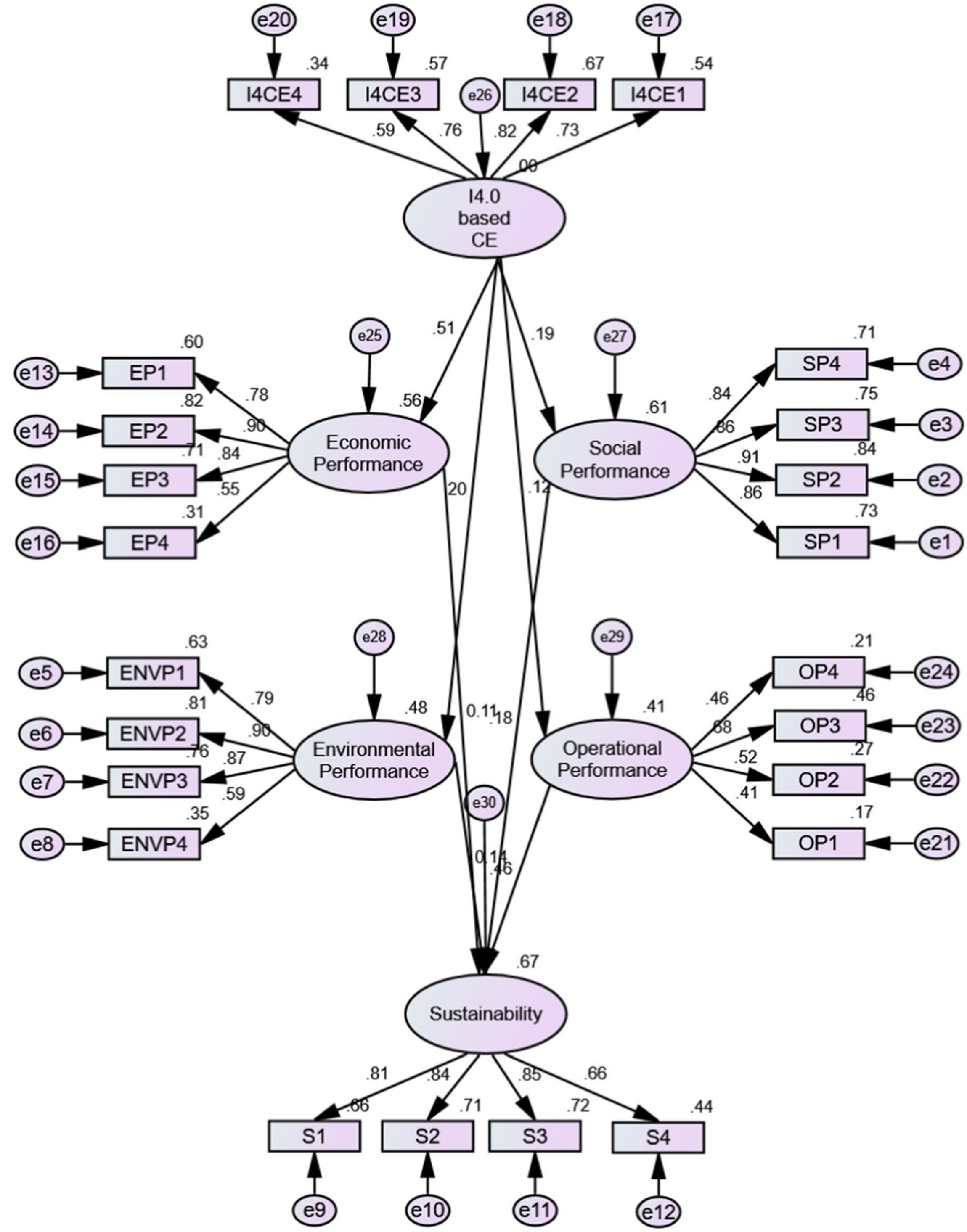

Fig. 2 Final structural model for achieving the CE capability

performance of a firm is shown in Fig. 2. The goodness of fit indices was analyzed to assess the model fit. The goodness of fit indices was $\chi^2 = 457.636$ with $df = 244$, χ^2/df (CMIN/DF) = 1.876, RMSEA = 0.054, IFI = 0.939, CFI = 0.938, TLI = 0.930, PCFI = 0.830, PNFI = 0.776 and GFI = 0.927 are in the threshold level as suggested by Byrne, (2010).

The standard error values fall between − 2.5 and + 2.5. Critical ratio levels have greater significance than 1.96. Therefore, all the components have a favorable effect on the company's performance. The structural model explains R^2 to be 56% for economic performance, 48% for environmental performance, 61% for social performance, 41% for operational performance, and 67% for sustainability variance for significant factors. The results of path estimates obtained are displayed in Table 4.

Hypothesis 1, I4.0-based CE that positively influences economic performance is supported ($\beta = 0.51$, $p = 0.000$; $p < 0.05$). Hypothesis 2, I4.0-based CE that positively influences the environmental performance is supported ($\beta = 0.20$, $p = 0.000$; $p < 0.05$). Hypothesis 3, I4.0-based CE that positively influences the social performance is supported ($\beta = 0.19$, $p = 0.000$; $p < 0.05$). Hypothesis 4, I4.0-based CE that positively influences the operational performance is supported ($\beta = 0.12$, $p = 0.003$; $p < 0.05$). Hypothesis 5, economic performance that positively influences the sustainability is supported ($\beta = 0.11$, $p = 0.002$; $p < 0.05$). Hypothesis 6, environmental performance that positively impacts sustainability is supported ($\beta = 0.14$, $p = 0.000$; $p < 0.05$). Hypothesis 7, social performance that positively impacts sustainability is supported ($\beta = 0.18$, $p = 0.000$; $p < 0.05$). Hypothesis 8, operational performance that positively impacts sustainability is supported ($\beta = 0.46$, $p = 0.000$; $p < 0.05$).

Discussion

The proposed framework is based upon PBV and complimentary perspective theories. The model is tested empirically by collecting data from various manufacturing SMEs of India. For adoption-based studies, PBV helps explain the firm's plant or industry-level performance. PBV assumes a high deviation in a firm performance by adopting beneficial practices. Still, all firms do not adopt all the practices which are best for them to improve their performances. Hence, the use of practices can elucidate performance deviations. PBV can also eliminate several difficulties associated with RBV (Bag et al., 2021). In the current study, I4.0-based CE has been adopted to increase the sustainability of SMEs. Hence, in the present study, PBV and complementary perspective was applied to adopt I4.0-based CE. The discussion of the hypotheses is given below:

The production scheduling and machine loading parameters are impacted when the demand cannot be accurately predicted due to a poor sales forecast and limited visibility in the supply lines. This eventually has an impact on sales order shipments, which raises customer dissatisfaction levels. Hypothesis 1 states that I4.0-based CE positively influences economic performance. I4CE has four sub-components: I4CE1, I4CE2, I4CE3, and I4CE4. I4.0-based CE has a direct and favorable effect on economic performance ($\beta = 0.51$; P-value $= 0.000$). Govindan et al. (2020) conducted research which utilized a psychometric meta-analysis to integrate the findings of 167 effect sizes gathered from 129 papers to understand better the impact of various sustainability practices (environmental, social, and mixed) on business performance (Financial and Operational).

Hypothesis 2 states that I4.0-based CE positively influences environmental performance ($\beta = 0.20$; p-value $= 0.000$). Despite continued criticism of its oversimplification and lack of consideration for socio-ethical issues, it is today seen as a powerful answer for sustainability (Inigo & Blok, 2019). Lopes de Sousa Jabbour et al. (2020) examined the elements that influence the environmental, social, and financial performance of Asian SMEs in the manufacturing sector. This article analyses and explores the components contributing to manufacturing SMEs' quest for sustainable development.

Hypothesis 3 states that I4.0-based CE positively influences social performance. I4.0-based CE positively and directly impacts social performance ($\beta = 0.19$; P-value $= 0.000$). Sarc et al. (2019) found that the systems and techniques employed in waste management are presented with technology that has previously been effectively implemented in other industrial sectors and will continue to be important in the waste management sector in the future.

Hypothesis 4 states that I4.0-based CE positively influences operational performance ($\beta = 0.12$; P-value $= 0.03$) (Braccini & Margherita, 2018). We focused on implementing I4.0 in a manufacturing organization, which we examined as a single case study. Rajput and Singh, (2019) aimed

Table 4 Path analysis result

	Estimate	Standard errors	Critical ratios	P	Hypothesis
EP < ---I4CE	0.51	0.09	5.711111	0.00	Supported
SP < ---I4CE	0.19	0.042	4.428571	0.00	Supported
ENVP < ---I4CE	0.20	0.086	2.302326	0.00	Supported
OP < ---I4CE	0.12	0.026	4.692308	0.03	Supported
S < ---EP	0.11	0.044	2.545455	0.02	Supported
S < ---ENVP	0.14	0.043	3.186047	0.00	Supported
S < ---OP	0.46	0.215	2.12093	0.00	Supported
S < ---SP	0.18	0.087	2.022989	0.00	Supported

to uncover the supply chain's hidden role in the relationship between CE and Industry 4.0. The elements responsible for connecting CE with Industry 4.0 are explored from two perspectives: enablers and impediments. Hypothesis 5 states that Economic performance positively influences sustainability ($\beta = 0.11$; P-value = 0.02).

Hypothesis 6 affirms environmental performance impacts sustainability ($\beta = 0.14$; P-value = 0.000). Kovacs (2018) examined the Fourth Industrial Revolution through the lens of more complicated economics. Doing this will focus on the intricate interactions forming as Industry 4.0 and the Digital Economy evolve. Chen et al. (2015) comprehensively compared direct digital manufacturing to numerous traditional manufacturing paradigms from many angles. Hypothesis 7 states social performance positively impacts sustainability ($\beta = 0.18$; P-value = 0.000). Dalenogare et al. (2018) investigated how adopting various Industry 4.0 technologies are connected with predicted advantages for the product, operations, and side effects aspects using secondary data from a large-scale survey of 27 industrial sectors covering 2225 Brazilian enterprises.

Hypothesis 8 states operational performance positively impacts sustainability ($\beta = 0.46$; P-value = 0.000). Millar et al., (2019) identified various problems in conceptual definition, economic growth, and execution that impede the use of the circular economy as a tool for sustainable development in its current form. Technology is evolving quickly and could cause such stocks to become obsolete, resulting in a company's revenue loss.

Theoretical Implications

The theoretical framework is based on PBV theory and complimentary perspective. The model is statistically validated using data from Indian businesses. The study hypotheses are tested and confirmed acceptable in the Indian environment. The firms with a high degree of I4.0 acceptance rate can have advanced manufacturing capacity. But the firms with a lower acceptance rate of I4.0 will have lower manufacturing capacity. Lastly, high-tech manufacturing skills have a positive impact on sustainability.

To summarize, CE engages with Industry 4.0, changing the formerly insignificant connection between Industry 4.0 and performance. As a result, the complementary influence may expand beyond boosting the organization's performance to transforming a negative relationship into a positive one. The social pillar of sustainability has frequently been overlooked in the CE discussion. Whenever investigated, it is often viewed through the lens of creating new positions or industries due to closed-loop or reversing logistics activities or the effects of the corporate sharing model.

Practical Implications

Managers should implement I4.0 technology from the factory floor to the executive level. Managers must put I4.0 technology in place at their businesses' plant, divisional, and functional levels. Second, the I4.0 delivery mechanisms must be carefully reinforced. When working on I4.0 projects, it is vital to use the proper project management tools and procedures. These competent team leaders must develop a suitable and realistic schedule for I4.0 deployment. Managers must collaborate with service providers to remove impediments to industry adoption. 4.0. Managers must work with higher ups to support the adoption process. Managers must persuade higher ups of the importance of industry adoption. 4.0. They should endeavor to gather the resources needed to implement industry. 4.0.

Managers must organize employee training and skill development programs. Managers must oversee employees' industry-related training and learning programs. 4.0. Managers must consider the compatibility of adopting the industry. 4.0. Managers must consider the demands of their staff to implement industry 4.0. I4.0 will improve operational excellence in manufacturing by improving visibility, adaptability, and responsiveness. Finally, modern manufacturing capabilities must maximize resource utilization and fulfill a company's long-term development goals. The resources will remain in the closed loop, extending their useful life, which is essential for maintaining circular economy processes.

Conclusion

This research measures the sustainability of the firm and industry 4.0 impact on sustainability. Both the objectives of the study are achieved. This study is conducted in the Indian manufacturing SMEs, requiring a significant changeover regarding technology adoption. This study took one independent variable, four mediating variables and one dependent variable. The survey was performed in the manufacturing SMEs of India. The identified factors helped us understand the intention for adopting an industry 4.0-based circular economy within SMEs. In addition, the firm's sustainability is measured through an industry 4.0-based circular economy. Eight hypotheses were proposed, and eight got accepted. A model is developed which had been tested using SEM. The empirical evidence provided is a unique contribution in this study. This study uses two theories, mainly PBV and complimentary perspective and provides many theoretical and managerial implications.

Limitations and Future Research Directions

This study had some limitations which need to be fulfilled in future research. This research survey was limited to manufacturing SMEs, which can be extended to other sectors. This study measured only sustainability, which can also be developed to its elements. The current study is based on a cross-sectional research design and a future study can be planned based on a longitudinal research design.

Future research can identify some control variables that may impact CE capability. In future studies, they can also consider the initial investment for I4.0 before taking a decision to implement this I4.0. In addition, several other factors can be identified from the exhaustive literature review and added along with the current identified factors so that the model can be more robust. Apart from the four identified mediating variables, i.e., economic performance, environmental performance, social performance, and operational performance, more variables can be identified which will help in improving the sustainability of the firms. In addition, similar studies can be conducted in other developing countries to validate the current findings. Case study-based research can be achieved, which will help capture the relationship between Industry 4.0, CE capability and sustainability in other sectors. In addition, various interdisciplinary theories can be adopted to promote more ambitious views regarding CE.

Key Questions Reflecting Applicability in Real Life

1. How does the identified factors impact the adoption of I4.0 in SMEs of a developing country?
2. How these factors going to have a significant impact on the sustainability of SMEs?
3. How I4.0 can help in waste management through circular economy perspective?
4. How the current set of objectives can be useful for other sector study such as healthcare and education?

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Declarations

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Dr. Manish Mohan Baral is working as an Assistant Professor in Department of Operations, GITAM School of Business, GITAM (Deemed to be University), Visakhapatnam. He is Ph.D. in Management from Birla Institute of Technology Mesra, Ranchi. He has publications in reputed journals and high indexed book chapters. He has published in reputed journals like International Journal of Logistics Management, Annals of Operations Research, Benchmarking: An International Journal, etc. He has presented more 20 papers in various conferences. His research areas include Information Technology, Cloud Computing, Supply Chain Management, Artificial Intelligence, and Sustainability. He has expertise in statistical techniques like Structural Equation Modeling and MCDM techniques.

Dr. U.V. Adinarayana Rao is a Professor in Department of Operations, GITAM School of Business, GITAM (Deemed to be University), Visakhapatnam, India. He is an Engineering and Management Postgraduate, having more than 26 years of teaching and research experience including four years of international teaching exposure. He has published more than 28 articles in various journals of repute. Most of the journals are indexed in SCOPUS and Web of Science. His research interest includes supply chain management, IT and sustainable supply chain, etc. He is a consultant to NTPC, Need Assessment and Social Impact Assessments under CSR CD programs across India. Till now he has completed seven consultancy projects.

Dr. K. Srinivasa Rao is working as an Assistant Professor at the GITAM School of Business, GITAM (Deemed to be University), Visakhapatnam, India. He obtained his PhD in Faculty of Science from GITAM (Deemed to be University), Visakhapatnam India. His research interests include Operation Research, Fuzzy set Theory, and Optimization. Total teaching experience is 19 years.

Dr. Girish Chandra Dey is an Assistant Professor of Operations in GITAM School of Business, GITAM (Deemed to be University), Visakhapatnam, Andhra Pradesh, India. He holds a PhD from the Department of Industrial and Systems Engineering, Indian Institute of Technology Kharagpur. His current research interests include Critical Infrastructure Protection Planning, Supply Chain Design for Disruptions, Sustainability, and Industry 4.0. Formerly, he was a lecturer in the Department of Mechanical Engineering, Rajiv Gandhi University of Knowledge Technologies, Andhra Pradesh for more than three years.

Subhodeep Mukherjee is working as an Assistant Professor in Department of Operations, GITAM School of Business, GITAM (Deemed to be University), Visakhapatnam, India. He has submitted his Ph.D. at the GITAM School of Business, GITAM (Deemed to be University), Visakhapatnam, India. His research papers are published in Benchmarking: An International Journal, Management Decision, Management of Environmental Quality, Journal of Humanitarian Logistics and Supply Chain Management, and Decision. He has presented several papers in various conferences. His main research interests include food supply chain management, retail supply chain, cloud computing, artificial intelligence, and blockchain technologies. He has expertise in statistical techniques like SEM, etc.

M. Arun Kumar is working as an Assistant Professor in Department of Operations, GITAM School of Business, GITAM (Deemed to be University), Visakhapatnam. He is an MBA graduate and has more than 20 years of industry experience. His research area includes sustainable supply chain, emerging technologies, etc.