Examining the Influence Extent of I4 Technologies and Circular Economy Practices on Firm Organizational Effectiveness: Ecological Modernization Theory and Practice-Based View

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Abstract

Industry 4.0 (I4) technologies are primarily focused on addressing the issue of limited resources and enhancing productivity by offering solutions to maximize the use of rare resources and identify alternative raw materials. The explanation for the mounting pressure on environmental rules, resource price instability, and supply unpredictability is the circular economy (CE); however, the connection between I4 technologies, CE, and organizational performance (OP) has not yet been fully analyzed. To understand how I4 technologies promote the change in CE practices and what impact they have when combined with OP, a deeper conceptual and experimental examination is required. Using a survey of 351 Saudi industry experts, the study examines the mediating and moderating role of CE practices in the connection between I4 technologies and OP. Seven items pertaining to the I4 technologies' current state of implementation were covered, (cloud computing, big data analytics, IoT, augmented reality, cyber-physical systems, 3D printing, and robotic systems). The measurement scale for CE practices utilized in this study has sixteen items on it that were divided into three categories: microenvironment management, eco-design, and investment recovery. The measurement items for OP were divided into two categories: economic performance (8 items), and environmental performance (6 items). The results show that Industry 4.0 (I4) technologies have a significant direct impact on OP, Industry 4.0 (I4) technologies have a significant direct impact on CE, CE has a significant direct impact on OP, CE practices are mediated the relationship between I4 technology and OP, and CE practices have not moderated the relationship between I4 technology and OP. Moreover, the results show that establishing a CE environment is not necessary before adopting I4 technology. In general, the results demonstrate that Industry 4.0 has increased circular economy practices, in turn boosting businesses' economic and environmental performance and enhancing their organizational performance. Thus, this study has prepared the framework for participating countries or businesses to use Industry 4.0 to implement circular economy practices and achieve both economic and environmental goals. The study includes ramifications for professionals as well as guidelines for future research.

Keywords: I4 Technologies, Circular Economy, Ecological Modernization Theory, Practice-Based View

1. Introduction

The German federal government introduced the "Industry 4.0" idea in 2011 (Upadhyay et al., 2021). This fourth industrial revolution began at the start of the 21st century and represents a paradigm shift in the industrial sector. Industry 4.0, or I4, can be defined as a scientific process in which highly advanced technological equipment is integrated, such as smart sensors, 3D printing, internet of thinking technologies, big data analytics, and artificial intelligence (Weaver, 2021; Goodell et al., 2021).

Altogether these technological advancements are set up so that they work together with people and each other (Jabeen et al., 2020; Gupta et al., 2021). Industry 4.0 strongly supports the circular economy (CE), which can be used for concepts that incorporate natural resources, such as reuse, recycling, repair, remanufacturing, green purchasing, and eco-product design, as all of these are crucial for business sustainability (Schroeder et al., 2019).

Through the integration of circular economy principles with established business models known as Industry 4.0, production flexibility, efficiency, and environmental sustainability have all been significantly improved (Kouhizadeh et al., 2019; Chien et al., 2021; Latif et al., 2021; Yumei et al., 2021; Iqbal et al., 2021b). The circular economy is associated with numerous technological developments and artificial intelligence under the support of Industry 4.0, including blockchain technology, software as a service, industrial modeling, big data analytics, e-commerce, and additive manufacturing (Dalenogare et al., 2018). These technological advancements improve the current infrastructure by fostering creative approaches to environmental and economic sustainability (Huynh et al., 2020).

The circular economy gained prominence when it was added to the United Nations' Sustainable Development Goals (SDGs). By using "reuse, recycling, and recovery" methods, the circular economy promotes the most effective use of resources (Khanfar et al. 2021). Specifically, the circular economy provides an innovative viewpoint in regards to the organizational and operational frameworks for recovering old and discarded items. Its effectiveness and association with productivity have been crucial elements in the conversion of conventional company models into longer-term models (Abbas et al., 2021; Khoso et al., 2021;

Liu et al., 2021a, b). The circular economy should indeed be adopted via policy-driven and strategic developments in order to produce efficient consumer products by employing resources from Industry 4.0 (Kumar et al., 2021).

Implementing Industry 4.0 and the circular economy can help supply chain operations achieve operational excellence when combined with an effective "information-sharing approach" (Alkhuzaim et al., 2021). The incorporation of Industry 4.0 technology will support companies' long-term technical advancement, which will in turn have a variety of favorable effects on profit and environmental preservation. However, for the circular economy to be adopted, it is necessary for suppliers, producers, and buyers to work together. Adopting smart technology in a circular economy will increase efficiency, transparency, and trackability for all parties involved but can be expensive for a company (Bag et al., 2021; Huang et al., 2021).

According to the Circularity Gap Report (2018), only 9.1% of the global economy is circular, indicating a significant lack of circularity. However, it is possible to shift from a well-established industry production process to something akin to a circular economy by incorporating Industry 4.0 principles that address climate change, environmental inequality, and increased environmental degradation—all of which have emerged as a result of conventional manufacturing systems and technologies.

Industry 4.0 is receiving a great deal of attention in terms of enhancing organizational performance. However, there are only a few experiential revisions that take the Industry 4.0 component into account at the corporate level. As a result, there exists a dearth of data analyzing Industry 4.0's effects on organizational, economic, and environmental performance. In order to evaluate a company's performance, it is crucial to look at these companies' efficacy because doing so can provide a baseline for future study.

The theoretical background and hypothesis development of this study are covered in the literature review below, while the third section covers the research techniques used. The fourth section, "Discussion" contains a description of the study's findings and analysis, and managerial ramifications are addressed. The implications, conclusions, and limitations of the study are covered in the fifth section.

2. Literature review

According to the ecological modernization theory (EMT), environmental problems brought on by economic growth can be reduced by increasing resource productivity through technological advancements like green supply chain (SC) practices, which boost an organization's economic and environmental performance simultaneously. In this scenario, environmental protection is seen as an opportunity rather than a problem, supporting the ideas of "economizing ecology" and "decolonizing economics."

The practice-based view (PBV), a more advanced and powerful variant of the well-established resource-based view theory, endorses green SC practices in order to improve the socioeconomic and environmental outcomes of organizations. The practice-based perspective, which also identifies business procedures as recognized and proven guidelines within an organization, emphasizes differences in organizational performance caused by the use of transferable and distinct business procedures. In the practice-based view, organizational performance is the dependent variable.

In recent years, research scholars and experts from a range of fields have examined the standards by which businesses can integrate environmental issues into their organizational concerns. These standards have been based on theoretical frameworks such as ecological foot-printing, triple-bottom-line, ecology in industry, environmental efficiency, and life cycle management. Company executives can incorporate sociological, economical, and environmental changes into their business strategy with the aid of these theoretical frameworks. The numerous conceptual frameworks describe different facets of the same concept rather than fundamentally replacing one another. As a result, rather than relying on a single theory, environmental and socioeconomic stewardship may be described using a variety of theories. The current study adheres to the ecological modernization theory (EMT) and practice-based view (PBV), two coherent theoretical frameworks.

With EMT, environmental preservation is not an "issue" but an "opportunity" that promotes the ideas of "apologizing economics" and "economizing ecology." PBV, on the other hand, advocates for environmentally friendly supply chain methods to assist firms in achieving better socioeconomic and environmental results. PBV, which is a more advanced variant of the prevailing resource-based perspective theory, was made popular by Crossan and Apaydin (2018). Variations in business performance are explained by the use of interchangeable and non-substitutable corporate practices, the established and recognized guidelines of a company.

This study developed a thorough SEM framework in accordance with the theoretical underpinnings of the resource-based view and ecological advancement, through which the industry 4.0 environment has pushed circular economy processes that transform into company eco-environmental results that contribute significantly to organizational effectiveness.

2.1.Industry 4.0 technologies

Industry 4.0 is claimed to be a modern smart and independent industrial model that deepens the incorporation of communication infrastructure, information, and knowledge networks into manufacturing activities (Wang et al., 2017; Jeschke et al., 2017). Industry 4.0 provides profitable market strategies, higher efficiencies, and optimized standards for production businesses among its litany of advantages (Hofmann and Russels, 2017). Because of all of the possible advantages, Industry 4.0 has attracted substantial interest from researchers and clinicians alike (Liao et al., 2017). However, the decision to implement and evaluate Industry 4.0, which addresses challenges to technological blocks, for example, comes with drawbacks, including lack of awareness, prices, alters in legacy systems, and future energy disadvantages.

Industry 4.0 innovations can be grouped into physical and digital technologies. Physical devices are used primarily for manufacturing technologies, such as additive production or sensors and drones (Gibson et al., 2014; Morrar et al., 2017). Digital innovations relate specifically to current ICTs, including cloud computing, blockchain, analysis of big data, and simulation (Liao et al., 2017). In developed countries and in small and medium-sized businesses, these Industry 4.0 developments are relatively recent. Therefore, a further in-depth understanding of it, including the sustainable effects of Industry 4.0, is needed for widespread growth and acceptance, particularly in under-represented communities (Müller et al., 2018).

2.2.Circular economy

The first to introduce the term *circular economy* (CE) were Stahel and Reday (1976). CE involves a regenerative method based on the principle of zero waste. The idea is that waste generated in one organization can be used by another organization as a productive resource. In Geng and Doberstein (2008), CE is defined as halting the flow of new materials within an economic system. Webster (2015) states that CE is built upon increasing the usefulness of goods, elements, and materials to the greatest extent possible.

The key mechanisms of CE at work are performance economics (Stahel, 2010), industrial ecosystem, cradle-to-cradle architecture (Braungart et al., 2007), commodity service organizations (Tukker, 2015), capitalism by nature (Hawken, et al., 2008), industrial symbiotic relationships, biomimicry (Benyus, 2003), and circulatory content movement (Lieder, 2008). In the cradle-to-cradle paradigm, a recycling and reuse principle is applied. This model can be used for science-based or biological nutrients in industrial products. Technical nutrients are non-poisonous, non-hazardous, and frequently used industrial materials, whereas biological nutrients are organic materials that break down and imitate the nature of innovation in process and product design while not affecting the environment.

As the substantive importance of CE will long be maintained, organizational sustainability is important for CE (Kazancoglu et al., 2018). The sustainability of activities can be measured by calculating various pollution types, such as SO2, NO, effluent, and solid waste, and the ingestion of dangerous and toxic substances (Paulraj et al., 2017; Zhu et al., 2017). The introduction of reverse logistics and other practices of resource circularity within the supply chain ensures sustainability (Pourjavad and Schahin, 2018; Sharma et al., 2017). In order to help ensure the continuity of activities, companies should also be able to maximize capital productivity, and product consistency, and reduced scrap (Geng et al., 2017; Sharma et al., 2017). For example, it is safe to manufacture goods of stable consistency for daily use if they are environmentally friendly. Green product production minimizes energy usage and waste disposal, but green products need green content and degradable/reusable environmentally safe packaging materials (Foo et al., 2018; Jabbour and Jabbor, 2016; Wu et al., 2015). To that end, Papadopoulo and Giama (2007) emphasize the certificates and accreditation practices of the supply chain 3Rs (recycling, reusing, and reducing). A stable supply chain not only strengthens social services, but also decreases prices and improves market share and resource consumption, margins of income, and profit (Younis et al., 2016).

CE provides a new economic approach to society that turns waste into circular chains as raw materials and processes. This approach has several advantages, such as the selection of municipal waste in order to encourage sustainable logistics (Islam & Huda, 2018; Shaik & Abdul-Kader, 2017) and the elimination of electrical hardware recycling costs out of use in urban areas (Burlakovs et al., 2018). Both the benefits and obstacles need to be taken into account during CE practice for the sake of corporate sustainability and modern circular supply chain management; this can be done through new sustainable management systems which accept a wide range of materials and implement environmentally friendly manufacturing technology (Genovese et al., 2017), encouraging the production of new waste. Therefore, in order to promote a sustainable supply chain (SSC) for waste prevention to avoid the waste that will otherwise end up in landfills and marine environments, it is important to track CE activities regardless of socioeconomic background. Therefore, the SSCM needs to be paired with CE activities in order to achieve real circularity, observance, and demand optimization of products for production in terms of their supply and competitive goals (Zamora et al., 2018; Pultrone, 2018).

How effectively CE is implemented depends on how well the various practices are performed at different levels, i.e., at the micro, meso, and macro levels (Geng & Doberstein, 2008). The goal is to implement CE strategy at the organizational, or micro, level (single enterprise). Cleaner production, eco-design (ED), sustainability, and product recycling or reuse are the primary elements of CE practices at the micro level (Ghisellini et al., 2016; Liu et al., 2018). At the macro level, CE practices aim to understand how regional or national physical resources and materials could be managed and utilized successfully outside of their immediate context (Murray et al., 2017). The current study, though, focuses on CE practices at the micro, or organizational, level and on the techniques used by industrial enterprises.

2.3.The relationship between circular economy and Industry 4.0

In 2011, Germany made the initial proposal for Industry 4.0. Industry 4.0 technology includes cloud computing, the Internet of Things (IoT), blockchain technology (BCT), cloud platform services (CPS), and artificial intelligence (AI). Higher degrees of accuracy, precision, and automation have been made possible by these Industry 4.0 technologies, which have also transformed both economic and organizational performance. Supply chain management has also been impacted by Industry 4.0 technologies, which also provide benefits including reaction time optimization and reduced carbon emissions. Industry 4.0 and CE are new organizational and technology advancements that boost a company's long-term output. Additionally, due to their recent explosive growth and high levels of attention, Industry 4.0 and CE are important topics in the current digital era. The necessity of employing Industry 4.0 technology has increased as a result of ongoing pressure on domestic and foreign industries to achieve sustainability. The adoption of Industry 4.0 increases the supply chain system's transparency and integration, thereby enhancing the company's operational, environmental, economic, and production performance. Researchers have discovered a significant relationship between Industry 4.0 and CE with regard to the impact of Industry 4.0 on CE. On the other hand, experts contend that the use of inter-organizational systems can leverage and improve supply chain performance in light of the influence of Industry 4.0 on operational, environmental, economic, and supply chain performance. Because immediate operations and strategic information increases SC capability and improves CE, implementing Industry 4.0 can help digitize the production chain.

Additionally, CE's connectivity to Industry 4.0 promotes economic growth. According to Latan et al. (2018), cutting-edge technology can assist firms in earning money and saving money in exchange for long-term advantages. The circular economy, which is supported by digital economy technologies like blockchain, will support economic growth while fostering social and environmental sustainability. According to Jabeen et al. (2021b), sustainable development is only achievable when social and environmental sustainability can support the economic sustainability and vice versa. However, because deploying these technologies requires substantial capital expenditure, businesses such as those within the palm oil industry are unable to do so. This paper makes the claim that in order for circular economy collaborations to strengthen their emphasis on Industry 4.0 and achieve long-term development, there must be distinct and efficient driving forces.

2.4.Environmental performance

Putting circular economy strategies into practice can lessen how damaging corporate operations are to the environment (Madueke et al., 2020). The circular economy is based on the idea of protecting natural resources, and producers can do this by recycling waste items and remanufacturing old products by implementing green circular purchasing practices through the industrial manufacturing system (Sakthivadivel et al., 2021).

These advances produce a more environmentally friendly atmosphere and have a favorable socioeconomic impact on the host businesses and financial system. Examining the special connection between pollution, green manufacturing, energy efficiency, and economic growth, Jabeen et al. (2021b) argued that by generating jobs in the waste industry and promoting environmental sustainability, green manufacturing helps to produce more green economic output. Additionally, they argued that recycling preserves finite resources by employing pre-existing materials in manufacturing. Recycling also decreases the amount of space required for the dumping of industrial or municipal garbage and removes dangerous greenhouse gasses that are released during disposal.

Another study found that adopting circular economy principles lowers system waste and production costs considerably, while also boosting productivity, protecting the environment, and improving a company’s financial success. Khan et al. (2021) claim that waste management eliminates CE barriers. The circular design of the goods is principally responsible for their excellent socioeconomic and environmental performance. Furthermore, energy utilizing emissions is associated with increased environmental and health concerns; these environmental and health concerns can only be reduced by switching to green energy sources.

2.5.Economic performance

Practices that promote the circular economy boost manufacturing effectiveness, which in turn boosts financial performance. This financial performance is supported by remanufacturing, recycling, circular design, and, most importantly, circular purchasing.

The circular economy allows for the simultaneous realization of both economic and environmental benefits. According to Zhang et al. (2021), ineffective CE practices cause inconsistencies and higher overhead costs, all of which can be reduced by adopting manufacturing techniques and a supply chain that is driven by innovation. Rehman Khan et al. (2021) looked into the relationship between a company's environmental performance and profitability and their environmental supply chain practices and circular economy techniques. According to their research, many industries are boosting their financial returns by using circular economy techniques, which also assist them in improving their market standing. Environmental practices boost economic performance and energy efficiency, according to Yu et al. (2021), who state that municipal waste management motivates waste treatment companies to construct green infrastructures such as waste mitigation and management, while also creating jobs. They argue that by encouraging resource efficiency and green growth, circular economy techniques improve overall financial performance. In the wake of such a green revolution, customers preferred carbon-free items and are more prepared to pay extra for them, according to Fatima et al. (2021). On the other hand, green methods, according to Zhu and Li (2021), boost environmental sustainability while simultaneously raising material costs, which may also have an impact on a company's financial success.

2.6. Organizational performance

Any corporate entity's ultimate goal is to maximize organizational performance (OP). While ensuring environmental stewardship, the company's organizational effectiveness is primarily determined by sales volume, operational costs, and market share. Pal and Yasar (2020) investigated how an organization's performance in regards to the environment, the economy, and operational effectiveness is impacted by information technology (IT) capabilities and green supply chain strategies. Their findings show that a company's operational and technological capabilities increase its market competitiveness, revenue, and profitability. Eluubek kyzy et al. (2021) discovered comparable outcomes when applying different supply chain coordinating techniques. In all, a company's operating costs and environmental performance are improved by circular economy techniques including eccentricity and traceability (Goseki et al., 2020).

Zhang et al. (2021) claim that the stock prices of manufacturing companies that adopted circular economy principles in organizational operations increased due to implementation of CE. According to Mori et al. (2021), based on data from real testing results, serviceability, and feedback, CE practices are revolutionizing the automotive industry; similarly, according to Friedman and Ormiston (2022), pricing models and circular design increase a company's market share and favorable reputation. According to Irfan and Ahmad (2021), circular economy techniques in supply chain management increase host companies' competitiveness by producing environmental and economic benefits. Finally, Industry 4.0 and circular economy practices enable greater long-term organizational performance by reducing manufacturing waste, conserving energy and resources, boosting positive brand awareness and market share, and gaining government recognition and support.

Based on the aforementioned debate and findings, we formulate the following hypotheses:

H1. Industry 4.0 (I4) technologies have a significant direct impact on CE,

H2. Industry 4.0 (I4) technologies have a significant direct impact on OP,

H3. CE has a significant direct impact on OP

H4. CE practices have mediated the relationship between I4 technology and OP.

H5. CE practices moderate the relationship between I4 technology and OP.

3. Research techniques

Table 1. List of the Traits for Sample.

Item description	Frequency	[%]
Type of business		
Automobiles and automotive parts	24	6.8
Manufacturing, plastic, and chemicals	42	12
Equipment for communication and electronics	53	15.0
Equipment for ships and precision equipment	20	5.7
Metal substance	32	9.1
Equipment that is mechanical and electrical	35	10.0
Assembled metal products	16	4.6
Pharmacological	55	15.7
Paper and pulp	19	5.4
Shoes, pelts, and textiles	33	9.4
Other	22	6.3
Total	**351**	**100**
Number of years in business		
1-5	١٧	4.٨
6-10	٥٨	1٦.٥
11-20	١٠٥	29.٩
21 or more	١٧١	4٨.٨
Total	**٣٥١**	**100**
Location of responding firms in Saudi Arabia		
Eastern Province	191	54.4
Southern Province	160	45.6
Total	**٣٥١**	**100**
Size of firms (Number of employees)		
51-100	١٢٠	3٤.٢
101-300	١٠٧	3٠.٥
301-500	٤٦	1٣.١
501-5000	٧١	20.٢
More than 5000	٧	٢,٠
Total	**٣٥١**	**100**

Position of the respondent in the organization		
Executive level (i.e., Chair, CEO, Vice President)	3٤	9.٧
Upper management (i.e., Executive, Senior Manager, Manager)	28٦	8١.٥
level of supervision (i.e., Senior Officer, Officer, Coordinator)	1٦	4.٥
Non-managerial (i.e., Examine**r**, Subordina**te**, Specialist, etc.)	15	4.3
Total	**351**	**100**
Number of years working in the current organization		
Less than 5 years	55	15.7
5-10 years	58	16.5
10-15 years	164	46.7
More than 15 years	74	21.1
Total	**351**	**100**

Saudi manufacturing companies provided the study's data sources. In Saudi Arabia, the manufacturing industry is expected to grow at a fast rate. The current study offers insight on Industry 4.0 (I4) implementation status, the degree to which circularity is ingrained in production practices, and the sustainability of Saudi industrial firms. The study's methodology was an online survey. Overall, 750 industrial professionals from 50 industrial companies were chosen using a simple random selection method; professionals were selected equally from the records of the Chambers of Commerce and Industry in the Eastern Province in Dammam and the Southern Province in Al-Baha, Saudi Arabia. Within three months and after two follow-up reminders, we received 351 finished questionnaires. With all of the questionnaires being valid, because defective submissions were not accepted, the response rate was 46.8%. The sample characteristics of the chosen respondents are shown in Table 1, together with the features of the manufacturing businesses.

3.1.Scales of measurement

Using a five-point Likert scale, all of the replies were tallied. The scale of the I4 measurement items went from 1 (not implementing) to 5 (implemented). By consulting earlier literature, the items for I4 technologies were created (Kamble & Gunasekaran, 2021; Kamble et al., 2018a). Seven items pertaining to the I4 technologies' current state of implementation were covered. The ideas of green supply chain management and CE overlapped and reinforced each other on the dimensions of sustainability, which was seen in the literature when establishing the metrics for the CE practices that were most relied on (Kamble &

Gunasekaran, 2021). Green supply chain management is more concerned with boosting environmental performance than economic performance, in contrast to CE, which is advertised as an organizational method to increase economic performance by mitigating ecological and resource constraints (Liu et al., 2018; Geng et al., 2009). The literature review found that created organizational-level measures for CE practices initially before they were employed in other studies (Silva et al., 2019). The measurement scale for CE practices utilized in this study has seventeen items on it that were divided into three categories: microenvironment management, eco-design, and investment recovery. On the basis of earlier investigations, the measurement items for OP were created (El-Garaihy et al., 2022; Kamble et al., 2018a). The items were rated from 1 (strongly disagree) to 5 (strongly agree), and were divided into two categories: economic performance (8 items), and environmental performance (8 items).

The generated measurement tool underwent subjective validity testing to see whether the measures were ambiguous, clear, and accurate, as well as to determine whether to keep the items. A group of ten experts, including academics who teach operations management or supply chain management, senior executives with experience in industrial technology, senior consultants with experience in the industry, and executive experts with experience in environmental management, performed the subjective validity. Pilot research involving 25 postgraduate supply chain students came next. We were able to establish the measurement scales' content validity with the help of the pilot study and the experts' subjective validity. We were also able to pinpoint the elements that caused concern due to confusion, simplicity, or appropriateness thanks to the expert recommendations and Cronbach alpha (α) values (above 0.70). These elements were changed and reframed to create the finished instrument.

3.2.Analyses and results

Following the determination of the scales' content validity, the data analysis process moved on to routinely utilized convergent and discriminant validity examinations, including confirmatory factor analysis, average variance extraction, Cronbach's alpha, and composite reliability tests (CFA). The association between I4 technologies and OP was then examined using structural equation modeling (SEM), which tested the mediation and moderation effects of CE. To examine the impact of I4 technologies on the relationship with OP, a mediation three-step method was employed (Baron & Kenny, 1986). The Sobel test was used to determine the validity of the mediating effect (Sobel, 1982). Finally, using Cohen and Cohen's criteria, the moderating impact of CE procedures was investigated (Cohen & Cohen, 1983).

In addition to the analyses mentioned above, Table 2 provides the statistics for the measurement items. Because the information was gathered online, no incomplete responses were permitted, which eliminated the problem of missing values. However, a two-sample Kolmogorov-Smirnov test was used to compare the mean values of all the components for both early and late respondents in order to assess the impacts of the response submission delay (Wallace & Mellor, 1988). The first 20% of responses made up the early respondent group, and the last 20% of responses made up the late respondent group.

Table 2. Measures of Validity and Descriptive Statistics.

Construct	Items		Mean	Std. D	Factor Loadings	CA	CR	AVE
I4 technologies	CC	Cloud computing	2.97	1.45	0.736	0.837	0.846	0.598
	BDA	Big data analytics	3.01	1.36	0.757			
	IoT	IoT	2.99	1.42	0.709			
	AR	Augmented reality*	2.34	1.40	0.530			
	CPS	Cyber-physical systems	3.01	1.51	0.679			
	SDP	3D printing	2.72	1.35	0.670			
	RS	Robotic systems	3.11	1.48	0.586			
CE Practices								
Microenvironment management (MM)	MM1	Total quality environmental management	3.50	1.28	0.672	0.935	0.953	0.667
	MM2	Programs for environmental inspection, such as ISO 14000 certification	3.33	1.31	0.541			
	MM3	Product eco-labeling	3.48	1.32	0.639			
	MM4	Programs to prevent pollution	3.52	1.36	0.686			
	MM5	Environmental considerations in the internal performance evaluation system	3.48	1.31	0.683			
	MM6	Environmental reports are produced for internal evaluation	3.37	1.37	0.597			
Eco-design (ED)	ED1	The creation of things with a focus on minimizing material and energy usage	3.22	1.36	0.855	0.921	0.946	0.698
	ED2	Designing goods to reuse materials, recycle waste, and recover parts	3.31	1.29	0.835			

	ED3	Product design that minimizes or eliminates the usage of hazardous materials	3.33	1.37	0.829			
	ED4	Design of waste minimization processes	3.65	1.18	0.850			
	ED5	Suppliers employ green packaging (degradable and non-hazardous)	3.25	1.34	0.825			
Investment recovery (IR)	IR1	Investment recovery (selling) of surplus materials or inventory on a regular basis	3.46	1.31	0.597	0.887	0.899	0.603
	IR2	Frequent sales of second-hand and waste materials	3.62	1.35	0.651			
	IR3	A surplus of capital equipment is sold	3.31	1.43	0.744			
	IR4	Obtaining and reusing used goods and materials	3.43	1.43	0.614			
	IR5	Technique for recycling used and faulty goods	3.41	1.38	0.631			
Organizational Performance (OP)								
Economic Performance (ECP)	ECP 1	Less expensive production	3.67	1.01	0.780	0.907	0.932	0.607
	ECP 2	Higher profit	3.89	1.11	0.779			
	ECP 3	Reduced NPD expenses	3.57	1.18	0.795			
	ECP 4	Decreased energy use	3.72	1.27	0.714			
	ECP 5	Decrease in inventory costs	3.71	1.14	0.736			
	ECP 6	Lower expenses for product rejection and rework	3.66	1.13	0.678			
	ECP 7	Reduced expenses for buying raw materials	3.63	1.21	0.726			
	ECP 8	Reduction of industrial waste treatment expenses	3.43	1.16	0.527			
Environmental Performance (ENP)	EVS1	Reduced production of solid trash	3.56	1.29	0.695	0.962	0.978	0.774
	EVS2	Reduced production of liquid waste	3.52	1.34	0.811			
	EVS3	A reduction in gas emissions	3.49	1.39	0.810			
	EVS4	Decreased energy use	3.47	1.23	0.648			
	EVS5	Reduced use of potentially dangerous or Poisonous substances	3.45	1.30	0.804			
	EVS6	Enhanced environmental performance of the business	3.54	1.29	0.814			

* Excluded

There were no discernible variations between the two groups' mean values, ruling out the possibility of non-response prejudice (sig. level of 0.10). The existence of common method prejudice was evaluated using Harman's one-factor test. Exploratory factor analysis (EFA) showed that there was no common method bias because only 41.23% of the total variance could be described by a single factor, as opposed to 78.31% by 10 different factors with eigenvalues larger than 1. All of the elements were compressed into a composite measure to test the structural model, and the existence of multicollinearity inside the elements was tested using the variance inflation factor (Boßow-Thies & Alber, 2010). The variance inflation factor values for each of the formative items varied from 1 to 5.027, which was lower than the threshold value of 10; hence, no multicollinearity problems were seen (Hair et al., 2014). With an omission distance of 7, Stone-Q2 Geisser's cross-validated redundancy technique was used to test the model's predictive validity (Chin, 2010). The constructs utilized to research the effects of I4 technologies and CE practices on OP had significant predictive validity, as shown by the value of Q2 achieved for the OP (endogenous variable) of 0.299. Power analysis (1-) was used to determine whether the sample size of 351 was appropriate (Cohen, 1992). A significant correlation only with a magnitude of the power of 0.87, which was over the end point of 0.80, was found using the post-hoc test utilizing the package G*Power 3.1 (Faul et al., 2009), with a sample size of 351 and a level of significance of 0.05 (Cohen, 1992).

3.3.Model for measurement

The unidimensionality of such theoretical constructs was assessed using CFA (Gerbing & Anderson, 1988). A reasonable model fit index with 2/df = 3.41, root-mean-square error of approximation (RMSEA) = 0.074, comparative fit index (CFI) = 0.873, and incremental fit index (IFI) = 0.884 ensured that the data were one-dimensional (Hair et al., 2014). Scale reliability was shown by the CA and CR values for all the constructs above 0.70 (O'Leary-Kelly & Vokurka, 1998). To evaluate the convergent validity, EFA was utilized. With the exception of augmented reality (AR), all of the items had factor loadings that were above 0.50 and t-values that were higher than 2. By excluding the AR items from the final analysis, convergent validity was attained (Hair et al., 2014). Convergent validity was demonstrated by the AVE values of all the constructs, which were more than 0.5. To assess the discriminant validity, the correlation between components and the square root of AVE was tested (Fornell & Larcker, 1981). As opposed to the correlations between this construct and the other constructs, each construct's AVE values were higher, which supported the validity of the discriminant (Fornell & Larcker, 1981). Table 2 displays the construct-wise CA, AVE, and CR values. Table 3 lists the composite means for each component employed in the study, along with their associations.

Table 3. Combined Average Cuts and Correlation Coefficients.

	Mean	SD	I4T	MM	ED	IR	ECP	ENP
I4T	3.01	0.99	**0.876**					
MM	3.64	0.82	0.383	**0.821**				
ED	3.07	0.78	0.374	0.739	**0.859**			
IR	3.27	0.99	0.373	0.746	0.599	**0.897**		
ECP	3.11	0.87	0.311	0.381	0.394	0.387	**0.761**	
ENP	3.25	0.89	0.599	0.476	0.476	0.498	0.464	**0.787**

3.4.Structural model

SEM was used to test the structural model on SmartPLS. Given the wide range of model fit indices, the SEM suggested a good fit of the model without any consideration for multicollinearity. The threshold value of 3 was found to be exceeded by the 2 values of 31.27 and the 2/df ratio of 2.87 (Carmines & McIver, 1981).

Table 4. Average Scores and Correlation Coefficients Added Together.

Model-fit statistic	Recommended value	Obtained value
χ^2/df	< 3	2.87
Significance (p)	≤ 0.05	0.003
GFI	> 0.90	0.937
RMSEA	< 0.10	0.081
CFI	> 0.90	0.961
IFI	> 0.90	0.959

The standards for extra fit indices including GFI, RMSEA, CFI, and IFI are shown in Table 4. It was discovered that all model fit indices had values more than the advised threshold level (Hair et al., 2014). Table 5. indicate significant relationships.

Table 5. indicate significant relationships

Relationships	***β values***
I4 Technologies - CE	0.49
I4 Technologies - OP	0.11
CE - MM	0.93
CE - ED	0.79
CE - IR	0.91
CE - OP	0.67
OP - ECP	0.89
OP - ENP	0.92

3.4.1. The direct impact of I4 technologies on CE (H1)

The direct effect of I4 technologies on CE was revealed to have a negligible effect with a meager standardized beta coefficient of 0.07 (t-value = 1.87, p = 0.14). Our initial theory would have been to look at how directly CE affected OP. For the direct path CE→OP, a significant standardized beta coefficient of 0.381 (t-value = 5.675, p = 0.000) was attained. The first element of our hypothesis (H1), which suggested that the industry 4.0 (I4) technologies have a significant direct impact on CE, was therefore proven.

3.4.2. The direct impact of I4 technologies on OP (H2)

With just a standardized beta coefficient of 0.06 (t-value = 1.51, p = 0.13), the direct impact of I4 technologies on OP was shown to be minimal in the presence of the mediating variable. However, in the absence of CE standards, our first hypothesis would have been to examine the direct impact of I4 technologies on OP. In the absence of the mediating variable (CE practices), a significant standardized beta coefficient of 0.374 (t-value = 5.798, p = 0.000) was achieved for the direct path I4 technologies → OP. Thus, this confirmed the second part of our hypothesis (H2) which stated that the OP directly benefited from I4 technologies.

3.4.3. The direct impact of CE on OP (H3)

The direct impact of CE on OP was shown to be minimal, with a standardized beta coefficient of 0.05 (t-value = 1.73, p = 0.11). Our initial hypothesis would have been to investigate the direct impact of CE on OP. The direct path CE→OP achieved a significant standardized beta coefficient of 0.377 (t-value = 5.547, p = 0.000). As a result, the third part of our hypothesis (H3), that the CE has a significant direct impact on OP, was confirmed.

3.4.4. The mediation role of CE practices between I4 technologies and OP (H4)

The path coefficients of the direct and indirect impacts of I4 technologies on the OP were used to examine the mediating role of CE practices on the link between I4 technologies and OP. The presence of one of the three following conditions was confirmed using the SEM data (Hoyle & Kenny, 1999): (1) Full mediation: In the existence of CE practices, there is no substantial direct association between I4 technologies and OP, but there is a strong indirect influence of I4 technologies on OP; (2) Partial mediation: The influence of I4 technologies on OP, both directly and indirectly, is negligible; and (3) No mediation: Minimal direct and indirect effects of I4 technologies on OP, minimal direct effects of I4 technologies on CE practices, and minimal direct impacts of CE practices on OP. The study's findings showed that the association between I4 technologies and OP is totally mediated by CE practices. Without the mediating variable (CE practices), the direct effect of path I4 technologies → OP has been observed to be significant with a standardized beta coefficient of 0.337 (t-value = 5.789, p = 0.00), but in the existence of the mediating variable (CE practices), the direct effect of path I4 technologies → OP was found to be insignificant with a standardized beta coefficient of 0.06 (t-value = 1.31, p = 0.22). The mediated link between I4 technologies, CE practices, and OP was found to be significant by the Sobel test (Sobel, 1982), with a standardized beta coefficient of 0.337 (z-value, 5.869, standard error, 0.06, and p-value, 0.000). In light of this, we draw the conclusion that CE practices influence the interaction between I4 technologies and OP, hence promoting H2.

3.4.5. The moderation role of CE practices between I4 technologies and OP (H5)

We employed the hierarchy-moderated correlation to examine the moderating impact of CE practices on the association between I4 technologies and OP (Cohen & Cohen, 1983). In order to calculate the interaction term (I4 technologies * CE practices), we first multiplied the I4 technologies and CE practices together before centering them. From there, we evaluated the significance of the paths I4 technologies → OP, CE practices → OP, and I4 technologies * CE practices → OP separately. According to the results of the moderated model, the path I4 technologies → OP had a significant standardized beta coefficient of 0.39 (with $R^2 = 0.19$ and $Q^2 = 0.17$, $p = 0.01$), whereas the path CE practices had a significant standardized beta coefficient of 0.775 (with $R^2 = 0.59$, $Q^2 = 0.601$, $p = 0.00$). With such a standardized beta coefficient of -0.169 and $R^2 = 0.039$, $Q^2 = 0.019$ at $p = 0.064$, the interaction route I4 technologies * CE practices was discovered to be negligible. In order to confirm the results of the moderating effects, we also ran an incremental f-test. I4 technologies * CE practices had a negligible or minimal impact on OP, according to the f^2 obtained values for the components I4 technologies ($f^2 = 0.005$), CE practices ($f^2 = 0.979$), and I4 technologies * CE practices ($f^2 = 0.021$) (Cohen, 1988). As a result, we reject H3 and come to the conclusion that CE practices do not mitigate the link between I4 technologies and OP. Table 6 gives an overview of the findings of the hypotheses.

Table 6. Results of the Hypotheses Summarized.

Hypothesis	**Hypothesis statement**	**Estimate**	**S.E.**	**C.R.**	**Sig.**	**Result**
H_1	Industry 4.0 (I4) technologies have a significant direct impact on CE,	0.381	0.07	5.675	***	Supported
H_2	Industry 4.0 (I4) technologies have a significant direct impact on OP,	0.374	0.06	5.798	***	Supported
H_3	CE has a significant direct impact on OP,	0.377	0.05	5.547	***	Supported
H_4	CE practices have mediated the relationship between I4 technology and OP,	0.337	0.06	5.869	***	Supported
H_5	CE practices moderate the relationship between I4 technology and OP.	-0.169	-	-	0.064	Rejected

4. Discussion

The study's findings indicate that I4 technologies have an immediate and positive impact on the OP, lending support to the theoretical suggestions advanced in earlier studies (Blunck and Werthmann, 2017; Kamble, 2018; Luthra and Mangla, 2018). The research examines the potential of I4 technologies to help organizations achieve their long-term goals (Stock and Seliger, 2016; Kiel et al., 2017). The top I4 technologies implemented by Saudi manufacturing companies were robotic systems (mean=3.11), cyber-physical systems (mean=3.01), big data analytics (mean=3.01), IoT (mean=2.99), and cloud computing (mean=2.97). The main outcome for Saudi organizations was found to be the environmental dimension of organizational performance (β=0.90), followed by the economic (β=0.84). The findings show that CE practices play an important role in mediating the connection between I4 technologies and OP, supporting the earlier studies' hypotheses (Tseng et al., 2018b; de Sousa Jabbour et al., 2018; Antikainen et al., 2018). The study's findings identify I4 as an important information communication technology that facilitates the actual implementation of CE practices, resulting in improved OP (de Sousa Jabbour et al., 2018; Jabbour et al., 2017). Microenvironment management (β=0.93) was discovered to be an important component of CE practices, followed by investment recovery (β=0.91) and eco-design (β=0.79). The findings, however, indicate that the relationship between I4 technologies and OP is not moderated by CE practices. This implies that the relationship between I4 technologies and OP is unaffected by the extent to which organizations have adopted CE practices. In those other words, Saudi manufacturing experts believe that successful I4 technology implementation can lead to OP even in the absenteeism of CE practices. The study's findings are concise; successful I4 technology employment leads to efficient CE practices (denoted by hypothesis 1), and successful I4 technology application leads to enhanced OP (denoted by hypothesis 2). Successful CE practices lead to enhanced OP (denoted by hypothesis 3), successful I4 technology employment leads to effective CE practices, and effective CE practices lead to improved OP (denoted by hypothesis 4). Because the combined effect of I4 technologies and CE practices on OP is inconsequential, Manufacturing companies must first make final their CE and OP targets before approving the suitable I4 technology to help them accomplish these goals. It must not be the case that organizations implement I4 technology first and then attempt to align it with the accomplishment of explicit CE or OP objectives (denoted by hypothesis ٥). The discoveries back up earlier research and recognize the role of CE practices in accomplishing stable economic, and environmental performance growth for organizations that are not dependent on I4 technologies (Ghisellini et al., 2016; Geissdoerfer et al., 2017). The results, however, indicate that a well-planned I4 technology and CE practice strategy and action plan will result in significant improvements in the OP of manufacturing organizations. Generally, the results support the influence of I4 technologies on OP when CE practices are present as a mediating variable.

5. Conclusions

The study's conclusions provide crucial information for managers in the field about how I4 technologies are used in Saudi industrial organizations and how they affect OP in a CE setting. According to the data, I4 technologies are becoming more widely accepted and used in Saudi industrial enterprises. The practitioners recognize I4 technologies as the engine for attaining sustainability, as evidenced by the favorable direct impact of I4 technologies on the OP. I4 technologies' full sustainability potential, however, cannot be realized until the implementing organizations have carefully weighed both the advantages and risks. Thus, it follows that the experts in these organizations should clearly and completely examine the potential, as well as risk, and undertake a feasibility study as to which particular I4 technologies will contribute to their defined sustainability goals. It is crucial for practitioners and consultants to comprehend that the firm might not need to employ all I4 technologies. To that end, it is necessary to critically assess each technology that is now accessible and determine how much it contributes to the objectives of OP. It is also important for practitioners to understand that despite the fact that these technologies show enormous promise, the implementation of I4 technologies can be hampered by a number of factors, including high investment costs and a shortage of effective demonstration of use in other industries (Kamble & Gunasekaran, 2021). Therefore, it is crucial that experts and advisors in Saudi industrial organizations recognize the obstacles of adopting I4 technologies and work to remove such obstacles by looking at how they are related to one another (Kamble et al., 2018b; Kamble & Gunasekaran, 2021).

The positive relationship between I4 technologies and SP necessitates that practitioners develop a thorough change management strategy. This strategy should include educating employees on the advantages of I4 technologies, upgrading their skills and competencies, reviewing the current business model, and, most crucially, persuading them to adopt I4 technologies. This study discovered that I4 technologies promote sustainability in the economic, social, and environmental domains, suggesting that practitioners may intend to pursue all three sustainability domains concurrently (Kamble et al., 2018a). The results have confirmed that CE practices exist as a key mediating factor connecting I4 technologies and OP. A scenario where CE practices function as a third variable (mediating), which is influenced by the I4 technologies and ultimately results in the OP, is implied by the mediation. For professionals, it suggests that I4 technologies contribute to the growth of the CE environment, which furthers the achievement of OP. It follows that Saudi industrial organizations' practitioners should recognize how I4 technologies serve as a catalyst for the CE, in turn resulting in long-term performance enhancements. The I4 technologies give CE plan implementation a goal and momentum, which must be understood by practitioners. I4 Technologies, which are a data-driven ICT innovation, can assist the CE strategy by supplying massive amounts of data through the use of big data analytics, IoT, and other systems. Robotic systems and other I4 technologies have been found to help with the CE approach by lowering human error, product rework, and waste. By enhancing the just-in-time creation of needed components, additive manufacturing may reduce inventory costs and minimize the risk of obsolescence. Therefore, practitioners must make sure that the aims of CE practices and the objectives of adopting the I4 technologies are compatible. The results, however, do not support the existence of CE practices as a moderating variable, indicating that the presence of a CE environment is not required for the adoption of I4 technology to have a beneficial impact on OP. As a result, it is advised that practitioners base their implementation plan for I4 technologies on the CE and OP goals of the firm. The establishment of sustainable goals or the design of CE practices by organizations should not occur after the implementation of I4 technologies.

6. Implications and limitations

This study offers opinions from professionals who have developed or applied Industry 4.0, or I4, technology in Saudi industrial organizations. The results can be used as a learning tool by enterprises that intend to use I4 technology to improve performance over the long term. Additional information about how CE practices can be incorporated into the I4 technologies implementation strategy is also provided by the study. The results demonstrate how I4 technologies may influence CE procedures and OP, inspiring industrial companies to use I4 technology. Before extrapolating the results to other contexts, though, we have listed the following study limitations that need to be taken into account. IoT, robotic systems, augmented reality, additive manufacturing, and big data analytics are all included under the umbrella of I4 technologies. We have utilized it as a broad term in the current investigation, but it might be necessary to perform studies that are application-specific in the future. In Saudi Arabia, I4 technology adoption is currently in its early phases. This study assesses the degree of I4 technology adoption in Saudi industrial enterprises, not the degree of I4 technology adoption success. To that end, once we've successfully validated I4 technologies in Saudi industrial organizations, we recommend validating the study's conclusions. The CE procedures taken into account in this study are organizational in nature. Future research should ideally include businesses from particular industrial areas or eco-parks so that we may create a range of viewpoints on CE practices and their potential to mediate relationships. The study acts as a reminder for governing bodies, working managers, environmentalism, and logisticians to include technological innovation in their environmental legislation.

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الملخص بالعربي:

تركز تكنولوجيا الصناعة ٤,٠ (I4) بشكل أساسي على معالجة الموارد المحدودة وتعزيز الإنتاجية من خلال تقديم حلول لتعظيم استخدام الموارد النادرة وتحديد المواد الخام البديلة. لتفسير أثر الضغط المتزايد من القوانين البيئية، وعدم استقرار أسعار الموارد، وعدم القدرة على التنبؤ بالتوريد فإننا نحتاج لتبني ممارسات الاقتصاد الدائري (CE)، وعلى الرغم من دورهما السابق الإشارة إليه، فإن العلاقة بين تكنولوجيا (I4) و(CE) والأداء التنظيمي (OP)، لم يتم تحليلها بشكل متكامل حتى الأن. كي نتمكن من فهم كيف تعزز تكنولوجيا (I4) التغيير في ممارسات (CE) وما هو تأثيرهما عند دمجهما مع (OP)، يلزمنا إجراء تحليل وفحص مفاهيمي وتجريبي بشكل أعمق. باستخدام دراسة استقصائية شملت ٣٥١ ممارساً سعوديًا في مجال الصناعة، بحثت الدراسة في دور الوساطة والاعتدال لممارسات (CE) في العلاقة بين تكنولوجيا (I4) و(OP). تم اعتماد سبعة أبعاد تتعلق بحالة التنفيذ الحالية لتكنولوجيا (I4)، وكانت تلك الأبعاد هي، (الحوسبة السحابية، وتحليلات البيانات الضخمة، وإنترنت الأشياء، والواقع المعزز، والأنظمة الفيزيائية الإلكترونية، والطباعة ثلاثية الأبعاد، والأنظمة الروبوتية). يحتوي مقياس ممارسات (CE) المستخدم في هذه الدراسة على ستة عشر عنصرًا تم تقسيمها إلى ثلاث فئات: الإدارة البيئية، والتصميم البيئي، واسترداد الاستثمار. تم تقسيم عناصر قياس (OP) إلى بُعدين رئيسيين: الأداء الاقتصادي (٨ عناصر)، والأداء البيئي (٦ عناصر). أظهرت النتائج أن تكنولوجيا (I4) لها تأثير مباشر كبير على (OP)، كما أن لها تأثير مباشر كبير على (CE)، من ناحية أخري، فأن (CE) لها تأثير مباشر كبير على (OP)، يتم توسط ممارسات (CE) في العلاقة بين تكنولوجيا (I4) و(OP)، بينما لا يقوم (CE) بدور المُعدل في العلاقة بين تكنولوجيا I4 و(OP)، علاوة على ذلك، تُظهر النتائج أن إنشاء بيئة (CE) ليس ضروريًا قبل اعتماد تكنولوجيا (I4). بشكل عام، توضح النتائج أن تكنولوجيا (I4) زادت ممارسات (CE)، مما أدى بدوره إلى تعزيز الأداء الاقتصادي والبيئي للشركات وتعزيز (OP). وبالتالي، قدمت هذه الدراسة إطار عمل لاستخدام تكنولوجيا (I4) لتنفيذ ممارسات (CE) وتحقيق الأهداف الاقتصادية والبيئية. تتضمن الدراسة توجيهات وتوصيات للمهنيين بالإضافة إلى إرشادات للبحوث المستقبلية.

الكلمات المفتاحية: تكنولوجيا I4، الاقتصاد الدائري (CE)، الأداء التنظيمي (OP)، نظرية التحديث البيئي، النظرية القائمة على الممارسة