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RESEARCH PAPER

# Impact of Industry 4.0 on firms' sustainable development in the GCC economies: a mediation and moderation approach

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## ABSTRACT

**Goal:** This paper utilizes a practice-based view (PBV) and technology-organization-sustainable framework to create and evaluate a research model. The model examines how industry 4.0 (I4.0) affects sustainable development, focusing on the mediating role of 10R advanced manufacturing capabilities. Furthermore, the study also analyzes the moderating influence of environment dynamism (ED). Sustainable development is assessed based on two key factors - financial performance (FP) and sustainable performance (SP).

**Design / Methodology / Approach:** The data is collected by surveying upper management in the GCC manufacturing sector through questionnaires. A total of 232 responses were included in the primary analyses. Data analysis was carried out with the help of SPSS 25.0 and SmartPLS 3.2.8. The dependability and path analysis were established using structural equation modeling (SEM).

**Results:** The results show that I4.0 increases FP, whereas the I4.0-SP relationship is statistically insignificant. However, the I4.0-SP insignificant relationship is moderated by ED. Further, ED also moderates the relationship between I4.0 and 10R advanced manufacturing capabilities, as well as 10R advanced manufacturing capabilities and sustainable development (FP and SP). The 10R capabilities partially mediate the I4.0-FP relationship, whereas the study finds full mediation for the I4.0-SP association.

**Research limitations:** The study employed Google forms to conveniently collect data from GCC industrial senior management using a cross-section design.

**Originality / Value:** This study has identified a business model that impacts sustainable development by integrating I4.0 technologies, ED, and 10R. The study findings have significant implications for managers and policymakers.

**Keywords:** Industry 4.0; 10R advanced manufacturing capabilities; Environment dynamism; Financial performance; Sustainable performance.

## 1 INTRODUCTION

I4.0 has made digital technology development and adoption a famous academic and professional topic. I4.0 defines "digital technologies" as advanced and innovative technologies Big data analytics, IoT, and cloud computing enable connection, communication, and automation. Modern technologies track material and process data throughout the product life cycle (Ren et al., 2019). They also improve vertically and horizontally linked production systems (Cimini, Pirola, Pinto, & Cavalieri, 2020). Digital technologies provide industrial companies with opportunities and threats for sustainable development. Integrating digital technologies in manufacturing has led to a digital revolution, significantly transforming production and operations management processes. This revolution can enhance product creation, boost production efficiency, and improve customer service (Adimuthu, Muduli, Ray, Singh, & Ahmad, 2022). These advanced technologies may improve

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revolution, significantly transforming production and operations management processes. This revolution can enhance product creation, boost production efficiency, and improve customer service (Adimuthu, Muduli, Ray, Singh, & Ahmad, 2022). These advanced technologies may improve resource allocation and sustainability. Emerging technologies may increase manufacturers' competitiveness and sustainable performance (Kiel et al., 2017). This condition may impede sustainable development with digital technologies. Presently, studies are insufficient about the impact of I4.0 on sustainable development, particularly in emerging economies with relatively lower technological progress and where management does not prioritize sustainable issues.

In addition, the linkage between I4.0 and sustainable development may be indirect, as mere adoption of technologies does not guarantee sustainable development. Manufacturers globally suffer resource limitations due to excessive production and consumption (Bag, Gupta, & Kumar, 2021). Most organizations do not remanufacture, recycle, or reuse their products, which impedes sustainable development. They failed because they lacked flexibility, visibility, and resilience (Bag et al., 2021; Bousdekis, Lepenioti, Apostolou, & Mentzas, 2019). I4.0 technology may assist companies in achieving sustainable development goals via digital transformations (Bastos & Teixeira, 2023). Industry 4.0 can effectively improve advanced production processes and help accomplish sustainable development goals (Dias and Silva, 2022). However, manufacturing companies face skill shortages, financial constraints, and operational issues (Sung, 2018; Raj et al., 2019). These concerns need a proper I4.0 mechanism (Bag et al., 2018b) as its consoles provide administrators with real-time supply-and-demand data from supply chain networks. This might allow organization learning (Lopes de Sousa Jabbour, Jabbour, Godinho Filho, & Roubaud, 2018) and manufacturing line utilization of recycled, refurbished, and remanufactured parts. Manufacturing companies that use I4.0 front-end and base technologies will be more flexible, efficient, and practical (Bag et al., 2021). Using product design, services, and transportation measures can alleviate the effects of global warming and enhance businesses' competitive advantage (Dubey, Gunasekaran, & Ali, 2015). Advanced 10R-based manufacturing capabilities enable the manufacture of goods in a cleaner circular economy, providing firms with a competitive advantage (Hartley, Roosendaal, & Kirchherr, 2022). Manufacturing and competitive tactics are favorably associated (Amoako-Gyampah & Acquaah, 2008). Although I4.0 provides flexibility and visibility (Lopes de Sousa Jabbour et al., 2018), there is no infrastructure and information on how developing economy enterprises anticipate I4.0 technologies to boost sustainable development (Dalenogare, Benitez, Ayala, & Frank, 2018). I4.0 technology may help organizations accomplish sustainable development objectives via digital transformations (Dalenogare et al., 2018). I4.0 adoption may assist industries in improving advanced manufacturing and satisfy sustainable development objectives. In addition, these advanced technological capabilities (10R) impact sustainable development. Thus, 10R capabilities provide ways to improve business operations and save resources and lead times (Dalenogare et al., 2018), and their role in sustainable development is crucial because it may improve sustainable performance. However, industrial businesses implementing I4.0-10R may boost their profits and bottom line. Advanced manufacturing employing 10R-based manufacturing skills like reject, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover may allow cleaner circular economy production and provide enterprises a competitive advantage (Hartley et al., 2022). Competitive and manufacturing strategies correlate positively. I4.0 improves flexibility and visibility (Amoako-Gyampah & Acquaah, 2008). Still, there is little infrastructure and information on the expectations of emerging economy firms about how I4.0 technologies will improve performance (Dalenogare et al., 2018).

Numerous studies (Mohammad, 2019; Vithessonthi & Thoumrungroje, 2011) have posited that strategic change is best left to large corporations with dedicated planning divisions. Environmental dynamism (Dess & Beard, 1984) is the main factor that looms over a company's performance, so strategic adaptation is a significant development. Businesses should learn to undertake a strategy shift appropriate for the business's environment (Thoumrungroje, 2015). There is a need to align technological developments and ED to maximize adoption benefits (Wamba, Dubey, Gunasekaran, & Akter, 2020). I4.0 improves the company's ability to compete (Somohano-Rodríguez & Madrid-Guijarro, 2022). Thus, I4.0 adoption improves firm agility, expertise, and stakeholder emphasis. The developments improve product quality, giving the organization a competitive advantage in the market (Ed-Dafali, Al-Azad, Mohiuddin, & Reza, 2023). The question is whether a company's sustainable development would be impacted by the I4.0 adoptions, with ED as a moderator. The study also looks at how ED might alter the effects of digital technology in a novel way. External factors, such as the environment, might impact the efficiency with which cutting-edge digital technologies and supply chain platforms are implemented (Li, Dai, & Cui, 2020; Sun, Hall, & Cegielski, 2020). The study suggests that the influence of digital technology on financial and SP is contingent upon the degree of ED. ED pertains to the level of instability in the corporate environment (Mohammad, 2019). The current study focuses on manufacturing firms, which boost economies worldwide (Jabbour et al., 2019). Manufacturing firms' sustainability study is essential since they utilize more resources and produce more waste (Jabbour et al., 2019). Due to sustainable production and resource use, manufacturers worldwide face resource shortages (Bag et al., 2021). Recent firms are implementing green efforts for sustainability and client attraction (Bag et al., 2021). Remanufacturing, recycling, and reusing activities fail most organizations, preventing them from meeting sustainable development targets. They failed owing to inflexibility, visibility, and resilience (Bousdekis et al., 2019).

The paper has several significant contributions to the current body of literature. First, this study shows that I4.0 directly impacts FP. However, I4.0 adoption does not influence firms; sustainable performance. These findings show contrasting effects of I4.0 adoption. Furthermore, the study also examined the role of ED as a moderator. The findings indicate a robust moderating impact on the relationship between 14.0 and enterprises' SP. This suggests that the ED in which firms operate impacts I4.0 and sustainable development relations. Third, the study shows the mediation role of 10R advanced manufacturing capabilities in the relationship between I4.0 and sustainable development. Fourth, the study is conducted on manufacturing firms since they are crucial in adopting I4.0 technologies and sustainable development. In emerging markets, they use most resources and negatively impact sustainable performance. Lastly, a managerial perspective is viewed as the concept of sustainability constantly being brought up in conversations across all spheres of life. As a process, management for sustainable development involves businesses making the most of their existing assets while enhancing their infrastructure to meet the demands of future generations. This is the only method to align technological adoption and raise living standards. In this light, it becomes clear that managers are at the heart of sustainable development. The author is mainly interested in their views since he has practical exposure to demonstrate the reality of I4.0 adoption and its practical concerns. In brief, this study implies that ED and 10R advancements are essential to reap digital technology's sustainability advantages.

The present research has numerous goals. I4.0's influence on GCC enterprises' sustainable performance is examined first. Second, environmental dynamism is examined as a moderator. Third, the research examines how 10R advanced manufacturing skills mediate I4.0-sustainable development.

The rest of the paper follows this pattern. This section covers GCC and I4.0 adoption. Section 3 introduces the theoretical framework, followed by a literature review and hypotheses in section 4. Section 5 describes the research techniques, analyses them, discusses the outcomes, and concludes.

## 2 THEORETICAL BACKGROUNDS

Adopting theoretical examination enhances researchers' capability to create credible hypotheses in operations management. Although the anticipated theory is merely a framework, it must fulfill Dubin's five pre-requisites (Meredith, 1993): it must enhance our consideration, it must be captivating, it must incorporate factors and their interconnections, it must not involve multiple variables, and it must encompass the border criteria.

### 2.1 Practice-based view (PBV)

In the context of I4.0, the PBV and the resource-based view (RBV) have essential roles. The PBV underlines the significance of organizational practices as an important source of competitive advantage. So, PBV reveals the entrenchment of these practices with knowledge, skills, and capabilities, which leads a firm to operate efficiently. Regarding I4.0 adoption, PBV provides useful insight into how a firm incorporates innovative technologies to enhance its operations and accomplish strategic goals.

However, the PBV tends to gain more prominence for various reasons. I4.0 is defined by the fast-paced evolution of technology (Bromiley & Rau, 2016b). In such a dynamic environment, it is crucial to have the ability to adapt and innovate through practices. Practices involve physical resources and intangible elements, which can be easily adjusted and adapted. I4.0 highlights the importance of connecting and integrating different processes and technologies (Bromiley & Rau, 2016b). PBV examines how these procedures are implemented and stakeholder interactions (Belhadi, Kamble, Gunasekaran, & Mani, 2022).

This approach is essential to understanding Industry 4.0 ecosystem complexity. I4.0 is crucial to revolutionization, but other resources are also needed. I4.0 shapes and uses resources well, according to the PBV (Bianco et al., 2023). In I4.0, where resource interaction is critical, understanding techniques to maximise performance and stimulate innovation is essential (Bag et al., 2021). By studying practices, academics may learn how organisations adapt, produce, and flourish in I4.0 (Bag et al., 2021). I4.0 creates complex ecosystems by blurring the lines between enterprises, suppliers, consumers, and other stakeholders (Awan, Gölgeci, Makhmadshoev, & Mishra, 2022). The PBV covers practice sharing, transfer, and co-creation in various ecosystems.

This is key to understanding Industry 4.0 cooperation and value generation. Strategically managing physical assets and capabilities requires acknowledging the RBV's importance. Both perspectives harmonize, and a holistic approach that considers both practices and resources is often the most enlightening when studying Industry 4.0 phenomena.

(Bromiley & Rau, 2016b) revealed that RBV may not help operations management researchers match their study goals. RBV presumes certain things, such as managers in perfectly rational enterprises and businesses that seek to maximize profit margins. Two other assumptions in RBV are that resources are immobile and heterogeneous (Bromiley & Rau, 2016a). Operations management academics can better understand the interconnected nature of company and unit performance through PBV (Bromiley & Rau, 2016a). Firm, plant, or other business unit adoption or use of a particular practice and examining intermediate or financial performance results are all examples of dependent variables in PBV (Bromiley & Rau, 2014).

### 2.2 Dynamic capability view (DCV)

The Dynamic RBV offers a valuable framework for comprehending how companies can utilize dynamic resources and capabilities to attain operational excellence within Industry 4.0 (Alkaraan et al., 2024) . By embracing agility, flexibility, and innovation in operational management practices, firms can effectively navigate the complexities of Industry 4.0 and thrive in a rapidly changing business environment. Operations management scholars have used dynamic capabilities theory to execute strategy choices under diverse business scenarios (Bititci et al., 2011). Teece (2007) defines dynamic capabilities as "the ability to anticipate and shape opportunities and threats, seize opportunities, and sustain competitiveness through improving, integrating, defending, and, fourthly, when necessary, reconfiguring the firm's tangible and intangible assets." According to the researchers, 10R's advanced manufacturing capabilities are critical for making strategic moves ahead of the competition, and entering more markets with remanufactured/recycled items at a competitive cost (Bag et al., 2021). The organizations may reallocate physical and non-physical resources in 10R advanced manufacturing to achieve their commercial goals (Bag et al., 2021). The 10R capabilities effectively integrate I4.0 and sustainable development.

## 3 LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

### 3.1 Industry 4.0 and sustainable development (FP and SP)

The advent of the I4.0 has significantly transformed the operational landscape of businesses in the twenty-first century. It encompasses various advanced technologies, including cyber-physical systems (CPS), big data analytics, Internet of Things (IoT), 3D printing, and cloud computing. These technologies bring about a distinct transformation in this sequence of activities within the framework of I4.0. Many academics have proposed reasons for I4.0. According to a study conducted by (Xu, Xu, & Li, 2018), Implementing current information and communication technology in the manufacturing business, known as I4.0, enhances production efficiency and competency (Masood & Sonntag, 2020). The literature on I4.0 shows that I4.0 will increase customer experience, efficiency, and production.

Greater agility and flexibility provided by I4.0 will boost profitability. I4.0 enables organizations to create international connections in production, warehousing, and CPS-based machinery systems(Khin & Kee, 2022). As a result, many industrial processes have been considerably improved, including engineering, life cycle management, production, material use, and supply chain management (Khin & Kee, 2022). Additionally, I4.0 allows customers to alter their products as necessary, boosting profitability and lowering industrial waste (Khin & Kee, 2022). With the help of I4.0, firms and engineering procedures could make alterations at the last minute and achieve end-to-end transparency throughout the manufacturing process, facilitating better decision-making (Narula, Prakash, Dwivedy, Talwar, & Tiwari, 2020). I4.0 will eventually stimulate new approaches to developing business models and values. It also offers enormous potential to address major contemporary societal concerns such as resource efficiency, population change, and urban production (Narula et al., 2020).

Implementing I4.0 enables an understanding efficiency gains and ongoing improvement in resource productivity throughout the value network (Awan et al., 2022). The working conditions will undergo unique modifications, leading to increased attention towards social concerns and population changes. Machines will carry out repetitive tasks, while humans will be incentivized to engage in distinctive activities that contribute additional value (Narula et al., 2020). The flexibility of enterprises and organizations will aid their employees in attaining improved work-life equilibrium. Although the majority of research on Industry 4.0 has been on its implications for the industrial sector, its influence extends beyond this domain. Industry 4.0 can integrate accomplishments across an entire organization (Nagy, Oláh, Erdei, Máté, & Popp, 2018). Companies aiming to grow must acknowledge the significance of Industry 4.0 (Pinheiro, Jugend, Lopes de Sousa Jabbour, Chiappetta Jabbour, & Latan, 2022; Raj, Dwivedi, Sharma, de Sousa Jabbour, & Rajak, 2020). I4.0 is revolutionizing how businesses produce, improve, and distribute goods and services, affecting everything from factory operations to service delivery to how people contribute to the economy (Raj et al., 2020). In a nutshell, I4.0 improves a firm's profitability. Thus, the study develops the following hypothesis:

H1a: Adopting I4.0 technologies improves a firm's FP.

This research examines I4.0 and SP's effects. SP requires integrating sustainability into product development and manufacturing. (Dalenogare et al., 2018; Pinheiro et al., 2022). I4.0 can deliver effective solutions for green product design, manufacturing, and maintenance activities, resulting in lower hazardous emissions and lower natural resource use throughout the product life cycle (Dalenogare et al., 2018; Khan, Ahmad, & Majava, 2023). Innovation in eco-design and the creation of eco-friendly goods are greatly assisted by technological developments like the Internet of Things, cloud-based design, and big data analytics. Firms employ digital technology to acquire and process accurate consumption data, which allows them to develop products utilizing the 10 R's strategy (Bag et al., 2021; Raj & Jeyaraj, 2023). Digital technologies facilitate the development of eco-friendly product designs and optimize product performance to minimize negative sustainable impacts.

Digital technology may also help with data collection and processing, improving control over energy efficiency, water quality, air pollution, and heavy metals by automatically optimizing industrial operations (Raj & Jeyaraj, 2023). A digitally equipped manufacturing system allows companies to collect production data and make real-time adjustments to sustainable conditions by integrating sensors and radio frequency identification technology into Internet-connected production equipment or lines (de Sousa Jabbour, Jabbour, Foropon, & Godinho Filho, 2018; Raj & Jeyaraj, 2023). Digital technology like data-driven carbon footprint evaluations reduce greenhouse gas emissions (Peukert et al., 2015). The promise of ecologically responsible manufacturing might be unlocked by digital technologies in I4.0 (de Sousa Jabbour et al., 2018). As a result, digital technologies can potentially improve SP by enabling green manufacturing processes and developing sustainable goods. Thus, it can be hypothesized as follows:

H1b: The adoption of I4.0 technologies improves SP.

### 3.2 I4.0 and 10R capabilities

A circular economy relies on manufacturer and end-user accountability. In a circular economy, resources last long and give maximum value before being retrieved (Bag et al., 2020a). Research and development are needed for advanced manufacturing (Bag et al., 2021). Advanced manufacturing may enhance competitiveness in organisations by adopting 10 R-based techniques, including reject, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover, to achieve cleaner production (Bag et al., 2021). Digital technologies like I4.0 can reduce 10 R manufacturing uncertainties (Pansare, Yadav, Nagare, & Jani, 2022; de Sousa Jabbour et al., 2018). I4.0 can greatly aid 10R capabilities (Pansare et al., 2022). Implementing Industry 4.0 and integrating firms vertically and horizontally to facilitate the flow of information may enhance cost management. The 10R capabilities include the act of discarding a product's functions or delivering a different function with a dissimilar product, intensifying the usage of the product, and minimising the use of natural resources. reuse (use of the discarded product with is working with similar functionality), repair (repairing defective product to their original functions), refurbish (restoring an old product in new condition), remanufacture (using the discarded product and their parts in manufacturing new products), repurpose (using discarded product in manufacturing new products keeping their function), recycle (recycling the old product for processing material to obtain similar or lower quality product) and recovering (incineration of material for energy recovery (Bag et al., 2021; Pansare et al., 2022; Rahman, Pompidou, Alix, & Laratte, 2021).

The objective of our research is to analyse the possible beneficial effects of Industry 4.0 and 10R capabilities. When assessing operational excellence, businesses that prioritise smart manufacturing focus on three crucial factors: operational flexibility, operational efficiency, and operational effectiveness. Smart production lines utilize the principles of flexible manufacturing systems to facilitate efficient changeovers and minimize downtime between input materials or returned goods (Bag et al., 2021). This allows continued product creation utilising current resources. This method could conserve time and resources and enhance equipment and personnel utilisation (Pansare et al., 2022). Cost reductions may also be considerable. Flexible systems boost resource efficiency and savings. I4.0 improves process and product efficiency (Li et al., 2020). I4.0 technologies have helped repurpose industrial waste. They also help recover energy from the remainders, rejects, and manufacturing waste. Advanced technologies may optimise company operations and minimise constrained manufacturing unit production resources (Bag et al., 2021) Data integration in I4.0 systems improves supply chain visibility (Xu et al., 2018).

Technology advances swiftly, therefore organisations must keep ahead to avoid stock obsolescence (Espindola & Wright, 2021). Industry 4.0 solutions enable savvy organisations prevent overstocking or understocking resources. Industry 4.0 technology enables accurate sales projections, enabling organisations to plan and schedule activities to fulfil client requests (Saucedo-Martínez et al., 2018). With I4.0 automation, smart manufacturing organisations may execute the 10 R manufacturing principles more efficiently in a dynamic context (Bag et al., 2021). This method may provide a company an edge over its competitors (Pansare et al., 2022). Smart manufacturing organisations may use 10R manufacturing capabilities with I4.0 automation to improve efficiency and effectiveness in an uncertain environment. Thus, it can be hypothesized as:

H2: Firms adopting I4.0 demonstrate significantly higher 10R advanced manufacturing capabilities.

### 3.3 10R capabilities and sustainable development

Production and consumption must change for the circular economy. Innovative technologies, like I4.0, may allow smart manufacturing units to reduce, reuse, recycle, repair, remanufacture, refurbish, rethink, redesign, recover, and renew. I4.0's IoT, AI, big data analytics, and automation enable sustainable smart manufacturing units (Bag et al., 2021). Production monitoring, repair prediction, and resource optimisation are possible with these systems. These technologies promote circular economy efficiency and waste reduction (Hartley et al., 2022). Companies may create sustainable closed-loop linear production lines using Industry 4.0 architecture.

These concepts assist companies and promote sustainability (Rahman et al., 2021). Promoting value chain sustainability encourages responsible consumption and production. Innovation and technology in manufacturing help build infrastructure. Implementing the 10 R principles in production using Industry 4.0 technology is a novel circular economy approach (Bag et al., 2021). Sustainable performance demands resource efficiency, environmental impact minimization, and economic and social sustainability.

Advanced technology is needed to move to a circular economy (Johansen & Rönnbäck, 2021). Building 10 R's advanced manufacturing capabilities might transform conventional operations into a circular economy (Pansare et al., 2022). Multinational firms worldwide are seeking cleaner manufacturing techniques to attain sustainability. Implementing 10R capabilities in the manufacturing line may help create a closed-loop supply chain and safeguard resources (Bag et al., 2021). Manufacturing businesses may improve the environment, economy, and society, achieving sustainable performance. These talents work together to provide a firm foundation for long-term achievement. Companies that develop these competencies get a competitive advantage and benefit society and sustainability (Pansare et al., 2022). Companies may compete and contribute to global sustainability efforts using these values, producing a more affluent and sustainable future. Financially, 10R advanced manufacturing capabilities increase operating efficiency and output (Uvarova, Atstaja, Volkova, Grasis, & Ozolina-Ozola, 2023). Businesses save money and profit with these skills. Companies may mass-customize items and react swiftly to market needs. Energy utilisation and waste are reduced in smart production. We believe 10R's advanced manufacturing capabilities improve organisations' financial and sustainable performance.

H3a: 10R advanced manufacturing capabilities positively influence FP.

H3b: 10R advanced manufacturing capabilities positively influence SP.

### 3.4 The mediating role of 10R capabilities for the impact of I4.0 on sustainable performance

This study posits that the 10R capabilities will act as a mediator for the impact of digital technology on sustainable performance (FP and SP) in the era of I4.0. Through revolutionary technologies that boost resilience, responsiveness, and competitiveness, I4.0 improves organizations' "10R" capabilities (Bag et al., 2021). The 10R capabilities are improved by I4.0, which uses cutting-edge technologies like IoT, AI, and automation to optimize resource use, reduce waste through predictive maintenance and smart manufacturing processes, and recycle and reuse materials (Pansare et al., 2022). This integration promotes closed-loop systems that boost sustainability across various industries. On the other hand, the 10R capabilities enhance sustainable development proxied by FP and SP (Hartley et al., 2022).

According to Bag et al. (2021), advanced manufacturing concepts, such as reject, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover, provide opportunities for implementing greener production methods. Uncertainties in 10R manufacturing operations can be decreased by using digital technologies (Bag et al., 2021; Pansare et al., 2022; Rahman et al., 2021). Adopting I4.0 and vertically and horizontally integrating the company to facilitate information flow can increase cost control (Narula et al., 2020). Due to the novelty of 10R production, additional research is necessary to shed light on this crucial domain. According to (Mativenga, Agwa-Ejon, & Mbohwa, 2017), cost reduction is a significant factor that drives and maintains the recycling of composite trash. Thus, the application of 10R capabilities increases producer and consumer accountability (de Mattos Nascimento, de Oliveira-Dias, Moyano-Fuentes, Maqueira Marín, & Garza-Reyes, 2024). Its application allows system to keep resources longer and maximizes their utility. So far, empirics have highlighted the direct impact of I4.0 and sustainable development, we argue that I4.0 and sustainable development relationship might be mediated by 10R capabilities (Bag et al., 2021). The empirics justify the impact of I4.0 on 10R capabilities (Bag et al., 2021) and the impact of 10R capabilities on sustainable development (Bag et al., 2021; Pansare et al., 2022; Rahman et al., 2021) , but 10R as a mediator is unexplored. In addition, the impact of I4.0 on sustainable development (FP and SP) may vary across economies; therefore, we explore the mediating role of 10R capabilities for the association between I4.0 and sustainable development in the GCC context. 10R capabilities as a mediator are applicable in the relationship between I4.0 and sustainable development as it supports effective and organized interactions among different I4.0 components and sustainable development. Principally, 10R capabilities as a mediator serves as a strategic enabler, ensuring that technological development is utilized efficiently to support ecological concern, enhance resource usage, and ensure sustainability in firms' operations that lead to FP and SP. Hence, we propose the following hypotheses:

H4a: 10R capabilities mediate the positive relationship between I4.0 and FP.

H4b: 10R capabilities mediate the positive relationship between I4.0 and SP.

### 3.5 Environmental dynamism as moderator

Nowadays, firms in emerging markets face significant environmental dynamism due to frequent customer demand changes, shorter product lifecycles, and government regulation changes (Chatterjee, Chaudhuri, Gupta, Mangla, & Kamble, 2023; Kumar & Bhatia, 2021). Organisations that are skilled in the most recent technology and attentive to the fluctuations in the market may maintain a higher level of competitiveness (Day & Kruse, 2021). The use of Industry 4.0 technology enables companies to adapt and thrive in a rapidly changing market by reorganising and improving their operations. This allows businesses to provide personalised, top-notch goods at a reduced cost to clients, while also addressing environmental issues (Kumar & Bhatia, 2021). Additionally, this may assist marketing managers in delivering comprehensive solutions for introducing new products to clients (Kumar & Bhatia, 2021). Therefore, the presence of Economic Development (ED) might incentivize companies to embrace Industry 4.0 (I4.0) technologies in order to get their desired performance results. ED may have a moderating role in the interaction between I4.0 and enterprises' sustainable development. ED influences firms' strategic decisions as they need to comply with the environment in which they are operating (Chan, Yee, Dai, & Lim, 2016).

We also suggested that ED moderates the I4.0-10R capability relationship. Environmental dynamism shapes (Hashem, 2024) . First, it influences the adoption of I4.0. Second, firms opt for a circular economy approach in emerging markets. Mere adoption of I4.0 does not ensure sustainable development and compliance with regulations regarding sustainable performance. Thus, ED also influences firms' decision to enhance 10R capabilities to stay competitive in emerging markets. Firms with strategic flexibility show proactiveness, responsiveness to change, and the ability to deal with environmental dynamism (Rialti, Marzi, Caputo, & Mayah, 2020). Firms adapt themselves according to the ED for new growth opportunities (Rialti et al., 2020). Therefore, we argue that ED moderates the relationship between I4.0 and 10R capabilities in the emerging context of GCC.

Furthermore, the study suggests that the level of ED has a moderating effect on the relationship between 10R capabilities and business performance (FP and SP). Manufacturing enterprises are inclined to adopt digital technology to establish supply chain platforms that improve the economy and SP in an unpredictable setting. However, adopting I4.0 does not guarantee efficiency (Rajput & Singh, 2019; Rosa, Sassanelli, Urbinati, Chiaroni, & Terzi, 2020). Thus, these firms have 10R capabilities, which affect performance-related outcomes. In an unstable environment, these firms will likely enhance 10R capabilities to benefit from adopting I4.0 technologies. This may give them a competitive advantage over those firms that do not have 10R capabilities to have a competitive advantage (Li et al., 2020). Further, firms operating dynamically in the environment may have a competitive edge to exacerbate SP and FP. In a nutshell, the study hypothesizes the moderating role of environment dynamism as follows: -

H5a: Environment dynamisms positively moderate the effect of I4.0 adoption on FP.

H5b: Environment dynamisms moderate the positive effect of I4.0 adoption on SP.

H6: Environment dynamisms moderate the positive effect of I4.0 adoption on 10R capabilities.

H7a: Environment dynamisms moderate the positive effect of 10R capabilities on FP.

H7b: Environment dynamisms moderate the positive effect of 10R capabilities on SP.

### 3.6 Research model

The study uses the theoretical framework and hypotheses indicated above to guide its research and conducts empirical testing based on a research framework (See Figure 1). Overall, seven main hypotheses are constructed for empirical examination. The study uses ED as a moderator and 10R capabilities as a mediator. The direct effect is tested in three hypotheses: H1 (a, b), H2, and H3 (a, b), whereas hypothesis H4 (a, b) is used to test the mediation effect. Moreover, hypotheses H5 (a, b), H6, and H7 (a, b) are used for the moderation effect. This study used economic and SP as proxies of sustainable development.

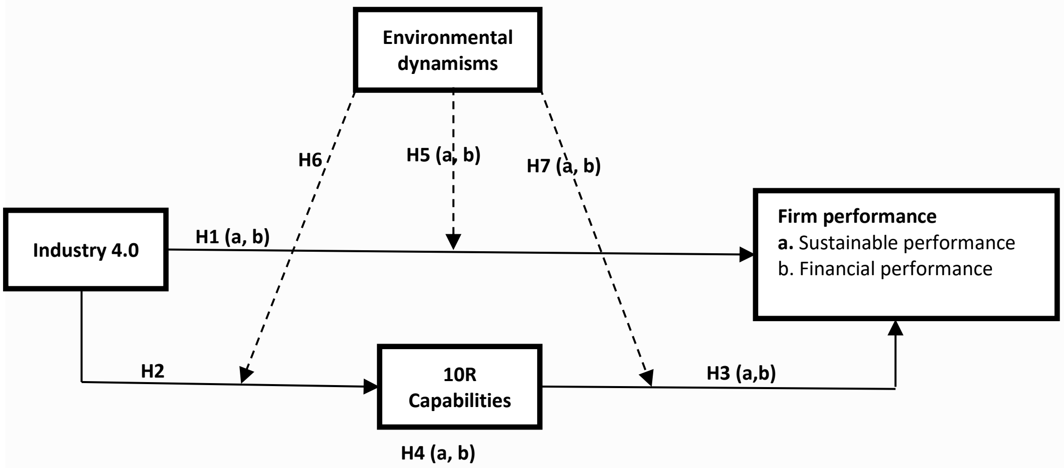


**Figure 1** - Research Framework

# 4 RESEARCH METHODS

## 4.1 Sampling and data collection

The questionnaire survey for this study was conducted at GCC. The individuals being surveyed are managers at the middle and senior levels, and the study focuses on manufacturing enterprises in the GCC region. Industrial enterprises employ digital technologies across multiple domains to achieve a competitive edge. The researcher utilized the GCC as a study framework to identify the potential sample population and acquire the contact information of businesses in the specific sampling areas.

Furthermore, manufacturing firms operating in GCC provide an appropriate research background. Indeed, I4.0 and 10R capabilities appear to be expected, particularly among large-sized enterprises in the industrial sector. In more detail, most large-scale manufacturing enterprises have used the 3Rs policies to increase their SP effectively. The region has a robust manufacturing legacy, raw resources, and energy sources; thus, GCC enterprises seek to use directness as a foundation for sustainable manufacturing. The sustainability strategy of the GCC places utmost importance on environmental stewardship, climate preservation, social accountability, and economic sustainability for both present and future generations. The approach was devised to mitigate the repercussions on the neighbouring people and the environment while generating value for our stakeholders. As a result, the GCC context and sample of manufacturing enterprises are appropriate and congruent with the research's goal. Data are gathered using an online questionnaire issued to managers working in manufacturing organizations that have begun implementing I4.0 technologies. We write the questionnaire in Arabic and then translate it into English using the process (Brislin, 1970). Multilingual researchers also pre-test the questionnaire to reduce potential sources of bias and avoid misinterpretation. The next step was to conduct pilot research with twenty volunteers to determine the questionnaire's reliability and validity. Extant literature on I4.0, 10R capabilities, financial, and SP informed the development of the questionnaire, which asked respondents to self-report using a 5-point Likert scale. The questionnaire is partitioned into two parts: the first addresses general information about respondents, such as gender, employee count, experience, and organizational structure. The data were gathered in a single wave for three months, specifically from January to March 2023. Two reminder emails and follow-up phone calls were sent to increase the response rate. Participants were offered the chance to obtain a summary of the research findings as a reward for filling out the questionnaires. All 3080 questionnaires were handed out, and 232 acceptable answers were received. The response rate of 7.53% was low but comparable to past studies due to the decreasing response rate of senior managers and several incorrect email addresses (Jin et al., 2014). This study addressed respondents from managerial posts to achieve the study's goal, as each participant was competent enough to take the survey.

Consequently, the total sample size exceeds 152 respondents, the minimum requirement of the SEM method for achieving a reliable and accurate answer (Iacobucci, 2010; Petrescu, 2013). Four alternative approaches are used to adjust for nonresponse bias. Initially, pilot research is conducted to clarify each item and minimize ambiguity. The questionnaire is then designed to distribute the independent and dependent variables throughout many sections (Jahanmir & Lages, 2016). The questionnaire guarantees anonymity by removing any identifying information of the respondents. The participants were not provided any information on the objective of the study. Harman's single-factor test was utilized to ascertain if the variation of all constructions could be explained by a single component (Podsakoff, MacKenzie, Podsakoff, & Lee, 2003).

The profit of respondents is shown in Table 1. The respondents are production managers (15.74%), R&D managers (14.35%), product managers (16.00%), marketing managers (18.98%), buying managers (19.91%), plant managers (10.19%), CEOs (4.86%), and others (15.97%). The majority of respondents, precisely 92.62%, possessed over six years of work experience, indicating their expertise in using digital technologies for product development and production and their knowledge of supply chain management. There is a 91.20% male representation. Respondents were distributed as follows based on the size of their companies: 28.70% had less than 100 workers, 49.77% had between 101 and 500 employees, 21.53% had between 501 and 1000 employees, and 13.8% had more than 2000 employees. Furthermore, the sample covered various industrial sectors, such as chemicals, petrochemicals, electronics, electrical equipment, and food and drinks—the corporate formats included private, state-owned, foreign-owned, and joint ventures.

**Table 1** - Demographics of respondents

| Variables | | Frequency | Percentage |
|---|---|---|---|
| Job Description | CEOs | 11 | 4.86 |
| | Production manager | 37 | 15.74 |
| | Purchasing manager | 46 | 19.91 |
| | R&D manager | 33 | 14.35 |
| | Marketing Manager | 44 | 18.98 |
| | Plant manager | 24 | 10.19 |
| | Other | 37 | 15.97 |
| Gender | Males | 212 | 91.20 |
| | Females | 20 | 8.80 |
| Experience | Less than 4 years | 18 | 7.38 |
| | Less than 7 years | 54 | 23.33 |
| | Less than 10 years | 105 | 45.24 |
| | 10 years and above | 56 | 24.05 |
| Organization structure | Private | 118 | 51.16 |
| | State-owned | 44 | 18.75 |
| | Foreign owned | 22 | 9.49 |
| | Joint venture | 48 | 20.60 |
| Organization size | Small-sized business: employees ≤ 100 | 67 | 28.70 |
| | Medium business: employees ≤ 500 | 115 | 49.77 |
| | Large-sized business: employees above 500 | 50 | 21.53 |

### 4.2 Measures

The measurements used in this study for the relevant constructs are adapted from tried-and-true tools from earlier works. Several operations management specialists examined and updated the measures afterward. The accuracy and clarity of the measuring items were improved by conducting a focus group discussion and pilot test involving 20 individuals. The constructs and measuring items used in this investigation are shown in Table 2. The study used a 5-point Likert scale to evaluate issues, with "1" denoting "strongly disagree" and "5" denoting "strongly agree."

### 4.3 Variables

The researcher used SmartPLS 3.2.8 to test the research framework in this study. Previous research has demonstrated that PLS is better at managing complicated big and simple models, and the normalcy condition need not be nuanced (Aziz, Afthanorhan, & Awang, 2016). Furthermore, some research suggests that the PLS-SEM technique is superior to another covariance-based strategy in estimating findings and establishing variable validity (Aziz et al., 2016). Using the PLS-SEM approach, we computed two models: the measurement model and the structural model. Both are used in the current analysis.

## 5 FINDINGS

### 5.1 Common method and nonresponse biases

The researchers in this study took measures to reduce the influence of standard techniques and nonresponse biases using statistical and procedural methodologies. The researcher recruited knowledgeable middle and upper-level managers to participate in the method remedy study (over 90% of them have more than five years of work experience). The questionnaire was designed to be concise and focused, with separate sections for each construct's measurement items. Additionally, the researcher took measures to guarantee the complete guard of the respondents' secrecy(Podsakoff et al., 2003). The methods made sure that responders could provide thoughtful and truthful answers. As a result, the researcher discovered reliable sources of information.

Following the recommendation of (Podsakoff et al., 2003), this study determined the CMB (common method bias) by employing Herman's single-factor technique. If the overall variance is less than 50%, the data does not present the CMB problem. The CMB value of 44.98% in this analysis proves that there is no CMB problem.

The findings of EFA reveal four distinct factors that account for 65.82% of the total variance and have eigenvalues above or close to 1.0. Less than 40% of the entire variable was described by the first 25 extracted components, which did not describe the majority of the variance. The exploratory factor analysis (EFA) results indicate that four identifiable factors explain 65.82% of the overall variability and possess eigenvalues equal to or around 1.0. The top 25 extracted components did not explain much variation since they accounted for less than 40% of the overall variability. Subsequently, Confirmatory Factor Analysis (CFA) was employed by assigning each construct item to a singular method factor. The fit indices displayed inadequate quality and were significantly inferior to the measurement model's (2/DF=1.588, CFI=.924, IFI=.926, TLI=.901, RMSEA=.059, and SRMR=.061). The values were as follows: CFI=.616, IFI=.620, TLI=.570, RMSEA=.137 and SRMR=.116.

The statistical analysis concluded that the presence of common process bias did not constitute a substantial concern in this inquiry. The nonresponse bias was assessed by comparing the answers provided by those who responded early with those who responded later (Armstrong & Overton, 1977). The study used a t-test to compare the early and late responses regarding revenue and the number of employees. The results show that there was little need for concern over nonresponse bias.

### 5.2 Measurement

There are three essential requirements for measuring the measurement model: content validity, convergent validity, and discriminant validity (Binz, Hair Jr, Pieper, & Baldauf, 2013).

6.2.1 Content validity

Content validity is when items designed to measure certain variables have stronger associations with their related variable than other variables within a given theoretical framework. The current study used loadings to evaluate the content validity, following the recommendations provided by previous research done by (Hair Jr, 2020). The loadings are displayed in the cross-loadings table (Table 2).

### 5.2.2 Convergent validity

Convergent validity guarantees that the variable items utilized in the present investigation precisely mirror their corresponding factor (Zhou, 2013). How strongly two measures of the same variable are positively connected is known as convergent validity (Hair Jr, Sarstedt, Hopkins, & Kuppelwieser, 2014). By examining the loadings, average variance extracted (AVE), and composite reliability (CR), we may assess the validity of the structural equation modelling (SEM) technique. In order to make an appropriate assessment of the variables, it is essential that the factor loadings of items have substantial values and have statistical significance. The minimum criterion for item factor loading is 0.50, whereas for CR and AVE, it is 0.70 and 0.50, respectively. As stated by (Hayduk & Littvay, 2012), every item with a factor loading below 0.50 should be eliminated. Retaining the best quality items will ensure the required composite reliability (CR) and average variance extracted (AVE) for this research. Furthermore, the most successful items with factor loadings greater than 0.50 will help build a solid theoretical foundation (Hayduk & Littvay, 2012). According to Nunnally (1978), all research variables should have a Cronbach's alpha of at least 0.60. Table 2 displays the researcher's findings, which indicate that the obtained CR, AVE, factor loadings, Cronbach's alpha, and R2 values surpass the standardized value. As a result, the current analysis verifies the theoretical model's convergent validity (Bagozzi & Yi, 1988).

**Table 2** - Factor loading and cross-loadings, average variance extracted (AVE), and composite reliability (CR)

| Item | Factor loading and cross-loading | | | | | AVE | CR | Cronbach's alpha | R2 |
|---|---|---|---|---|---|---|---|---|---|
| Industry 4.0 | I4.0 | 10R | ED | SP | FP | | | | |
| I4.0-1 | 0.790 | 0.356 | 0.263 | 0.152 | 0.388 | 0.591 | 0.820 | | 0.682 |
| I4.0-2 | 0.766 | 0.318 | 0.228 | 0.125 | 0.468 | | | | |
| I4.0-3 | 0.829 | 0.279 | 0.276 | 0.159 | 0.392 | | | | |
| I4.0-4 | 0.698 | 0.203 | 0.233 | 0.134 | 0.378 | | | | |
| I4.0-5 | 0.819 | 0.373 | 0.273 | 0.158 | 0.491 | | | α=0.816 | |
| I4.0-6 | 0.765 | 0.242 | 0.255 | 0.147 | 0.485 | | | | |
| I4.0-7 | 0.792 | 0.257 | 0.264 | 0.152 | 0.388 | | | | |
| I4.0-8 | 0.694 | 0.201 | 0.231 | 0.133 | 0.477 | | | | |
| I4.0-9 | 0.805 | 0.165 | 0.268 | 0.155 | 0.489 | | | | |
| I4.0-10 | 0.841 | 0.185 | 0.280 | 0.162 | 0.293 | | | | |
| 10R capabilities | | | | | | | | | |
| 10R − 1 | 0.314 | 0.834 | 0.184 | 0.088 | 0.238 | 0.560 | 0.714; | | 0.644 |
| 10R − 2 | 0.281 | 0.808 | 0.159 | 0.072 | 0.287 | | | | |
| 10R − 3 | 0.246 | 0.773 | 0.193 | 0.092 | 0.240 | | | | |
| 10R − 4 | 0.179 | 0.704 | 0.163 | 0.077 | 0.231 | | | | |
| 10R − 5 | 0.329 | 0.685 | 0.191 | 0.091 | 0.301 | | | α=0.768 | |
| 10R − 6 | 0.214 | 0.717 | 0.178 | 0.085 | 0.297 | | | | |
| 10R − 7 | 0.227 | 0.708 | 0.184 | 0.088 | 0.238 | | | | |
| 10R − 8 | 0.177 | 0.697 | 0.161 | 0.077 | 0.292 | | | | |
| 10R − 9 | 0.146 | 0.660 | 0.187 | 0.089 | 0.299 | | | | |
| 10R − 10 | 0.163 | 0.784 | 0.195 | 0.093 | 0.179 | | | | |
| Environmental dynamism | | | | | | | | | |
| ED − 1 | 0.247 | 0.189 | 0.707 | 0.093 | 0.246 | 0.517 | 0.811 | | 0.613 |
| ED − 2 | 0.220 | 0.164 | 0.614 | 0.077 | 0.297 | | | α=0.803 | |
| ED − 3 | 0.193 | 0.198 | 0.632 | 0.097 | 0.249 | | | | |
| ED − 4 | 0.141 | 0.167 | 0.743 | 0.082 | 0.240 | | | | |
| Sustainable development | | | | | | | | | |
| Sustainable performance | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | SP − 1 | 0.168 | | 0.283 | 0.390 | 0.741 | 0.308 | 0.555 | 0.750; | | 0.518 |
| | SP − 2 | 0.178 | | 0.190 | 0.393 | 0.645 | 0.246 | | | α=0.743 | |
| | SP − 3 | 0.139 | | 0.366 | 0.281 | 0.692 | 0.303 | | | | |
| | SP − 4 | 0.114 | | 0.292 | 0.295 | 0.783 | 0.311 | | | | |
| Financial performance | | | | | | | | | | | |
| | FP − 1 | 0.214 | | 0.158 | 0.091 | 0.233 | 0.715 | 0.522 | 0.781 | | 0.604 |
| | FP − 2 | 0.191 | | 0.137 | 0.075 | 0.281 | 0.766 | | | α=0.776 | |
| | FP − 3 | 0.167 | | 0.166 | 0.095 | 0.235 | 0.753 | | | | |
| | FP − 4 | 0.122 | | 0.140 | 0.080 | 0.227 | 0.746 | | | | |

Note: I4.0 –Industry 4.0 adoption; ED=environmental dynamism; FP= financial performance; SP= sustainable performance.

### 5.2.3 Discriminant validity

Discriminant validity pertains to the statistical differentiation between two indicators. Discriminant validity, as defined by (Hair Jr et al., 2014), is a measure of the degree to which one variable varies from another variable in actual terms based on empirical evidence. Variable items must possess variances that are more significant than those of other constructs. The present study examines the diagonal values above and below each other to establish discriminant validity (Fornell & Larcker, 1981). In addition, concerning discriminant validity, it is straightforward for a researcher to prove that the diagonal value should be higher than the values below it in the corresponding columns. Table 3 reports the discriminant.

**Table 3** - Discriminant validity

| Variables | I4.0 | 10R | ED | SP | FP |
|---|---|---|---|---|---|
| I4.0 | 0.816 | | | | |
| 10R | 0.206 | 0.770 | | | |
| ED | 0.161 | 0.378 | 0.825 | | |
| SP | 0.132 | 0.301 | 0.410 | 0.729 | |
| FP | 0.315 | 0.266 | 0.277 | 0.332 | 0.811 |

Industry 4.0 = I4.0, 10R = refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover, ED = environmental dynamism, SP = sustainable performance, FP = financial performance

## 5.3 Structural Model and Hypotheses Testing

In this part of the research, we tested our hypothesis. The findings are documented in Table 4. The study found a positive impact of I4.0 on (β = 0.214, $p < 0.05$, t-value = 2.131), thereby confirming hypothesis H1a. Nevertheless, the effects of I4.0 on SP are insignificant (β = 0.046, p = 0.2630, t-value = 1.483). Therefore, there is no support for hypothesis H1b. Hence, I4.0 adoption influences firms' FP in the GCC context. It empowers firms to operate efficiently and reduce manufacturing costs. In addition, it also improves product quality and allows firms to charge more to their customers, which enhances firm FP. More importantly, the relationship between I4.0 and SP is not supported.

The research performed an empirical test in H5a and H5b to assess the moderating influence of ED on the impact of I4.0 on firm performance, specifically in terms of FP and SP. For this purpose, the interaction effect between I4.0 and ED is tested on firms' performance. Both interaction terms show positive and statistically significant findings. In comparative terms, the interaction term I4.0*ED shows almost similar impact as reported for a direct association between I4.0 and FP (β = 0.201, $p < 0.05$, t-value = 2.162). The addition of ED does not improve the coefficient estimate and level of significance of the direct effect of I4.0 on FP. Thus, ED has no moderating effect on the relationship between I4.0 and SP. In contrast, the interaction term I4.0*ED is positive and statistically significant (β = 0.135, $p < 0.05$, t-value = 2.085). The interaction term shows higher coefficient estimates and significance levels than the direct effect of I4.0 on SP. This implies that ED moderates the relationship between I4.0 and SP. This is consistent with the perspective that ED capabilities mitigate the influence of technology progress on SP.

In H2 and H6, the study tested the association between I4.0 and 10R. First, I4.0 has a positive influence on 10R capabilities (β = 0.120, $p < 0.05$, t-value = 2.213). Therefore, H2 is supported. In H6, ED is used as a moderator, and the interaction term between I4.0 and ED is positive and statistically significant (β = 0.270, $p < 0.05$, t-value = 2.329). The result shows that ED moderates the association between I4.0 and 10R capabilities.

Next, we find a positive influence of 10R on FP (β = 0.166, $p < 0.05$, t-value = 2.305) and SP (β = 0.208, $p < 0.05$, t-value = 2.199). Hence, 10R capabilities significantly impact sustainable performance. Further, ED's role as a moderator is also tested for the association between 10R capabilities and sustainable development. The study finds that ED moderates the impact of 10R capabilities on FP (β = 0.166, $p < 0.05$, t-value = 2.305) and SP (β = 0.208, $p < 0.05$, t-value = 2.199). Therefore, H7a and H7b are supported.

**Table 4** - Hypotheses testing

| Hypotheses | Paths | β value | t-value | p-value | Bootstraps @ 95% | | Result |
|---|---|---|---|---|---|---|---|
| | | | | | BCI LL | BCI UL | |
| H1a | I4.0-->FP (direct effect) | 0.214** | 2.131 | 0.044 | 0.0124 | 0.652 | supported |
| H1b | I4.0-->SP (direct effect) | 0.046 | 1.483 | 0.263 | 0.000 | 0.654 | not supported |
| H5a | I4.0*ED-->FP (Moderation) | 0.201** | 2.162 | 0.034 | 0.001 | 0.428 | not supported |
| H5b | I4.0*ED-->SP (Moderation) | 0.135** | 2.085 | 0.051 | 0.154 | 0.564 | supported |
| H2 | I4.0-->10R (direct effect) | 0.120** | 2.213 | 0.049 | 0.033 | 0.384 | supported |
| H6 | I4.0*ED-->10R (Moderation) | 0.270** | 2.329 | 0.028 | 0.111 | 0.539 | supported |
| H3a | 10R-->FP (direct effect) | 0.166** | 2.305 | 0.047 | 0.056 | 0.675 | supported |
| H3b | 10R-->SP (direct effect) | 0.208** | 2.199 | 0.051 | 0.163 | 0.588 | supported |
| H7a | 10R*ED-->FP (Moderation) | 0.217*** | 4.304 | 0.000 | 0.132 | 0.499 | supported |
| H7b | 10R*ED-->SP (Moderation) | 0.328*** | 4.562 | 0.000 | 0.118 | 0.495 | supported |
| H4a | I4.0-->10R -->FP (Mediation) | 0.186*** | 3.304 | 0.000 | 0.165 | 0.596 | Partial mediation |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| H4b | I4.0-->10R -->SP (Mediation) | 0.322*** | 4.166 | 0.000 | 0.103 | 0.588 | Full mediation |

Industry 4.0 = I4.0, 10R = refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover, ED = environmental dynamism, SP = sustainable performance, FP = financial performance

Finally, 10R skills were investigated as mediators of I4.0 and sustainable development (FP and SP). The link between I4.0 and FP is mediated by 10R capabilities (β = 0.214, t-value = 3.304, p < 0.01). Similarly, 10R skills moderate the relationship between I4.0 and FP (β = 0.322, t-value = 4.166, p < 0.01). The research examined the impact of 10R capabilities on the link between I4.0 and sustainable performance (FP and SP) using variance accounted for (VAF). According to Hair et al. (2014), a VAF value of less than 20% implies no mediation, a VAF value between 20% and 80% suggests partial mediation, and a VAF value greater than 80% indicates full mediation. The strength of mediation is also analyzed. The direct effect of I4.0 on FP is 0.214, while the indirect effect via 10R capabilities is 0.186. So, the value of the net effect is 0.214+0.186= 0.400. Subtracting the overall effect from the indirect effect yields the VAF with a value of 0.186/0.400 = 0.465. So, 46.5% of the I4.0 effect on FP is explained via the 10R capabilities mediator. This condition shows partial mediation since the VAF is greater than 20% but less than 80%. Likewise, the direct effect of I4.0 on SP is 0.046, while the indirect effect via 10R capabilities is 0.322. Therefore, the net effect had a value of 0.046+0.322= 0.368. The VAF had a value of 0.322/0.368= 0.875. Consequently, VAF is greater than 20% (87.5%), showing partial mediation.

**Table 5** - Calculation of variance inflation factor (VIF)

| Independent variable | Dependent variable | Mediating variable | Direct effect | Indirect effect | Total effect | VAF (%) |
|---|---|---|---|---|---|---|
| I4.0 | FP | 10R capabilities | 0.214 | 0.186 | 0.400 | 46.5 |
| I4.0 | SP | 10R capabilities | 0.046 | 0.322 | 0.368 | 87.5 |

Industry 4.0 = I4.0, 10R capabilities = refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover, SP = sustainable performance, FP = financial performance.

In Figure 2, the study shows the mediation effect. The mediation effect is partial, as the direct impact between I4.0 and FP is statistically significant at a 5% significance level. Thus, hypothesis 7a is supported as 10R capabilities mediate the relation between I4.0 and FP. Second, the direct effect of I4.0 on SP is statistically insignificant, and the mediation path shows a significant association between I4.0 and 10R capabilities and 10R capabilities and SP. This is full mediation. Therefore, our hypothesis 7b is supported.

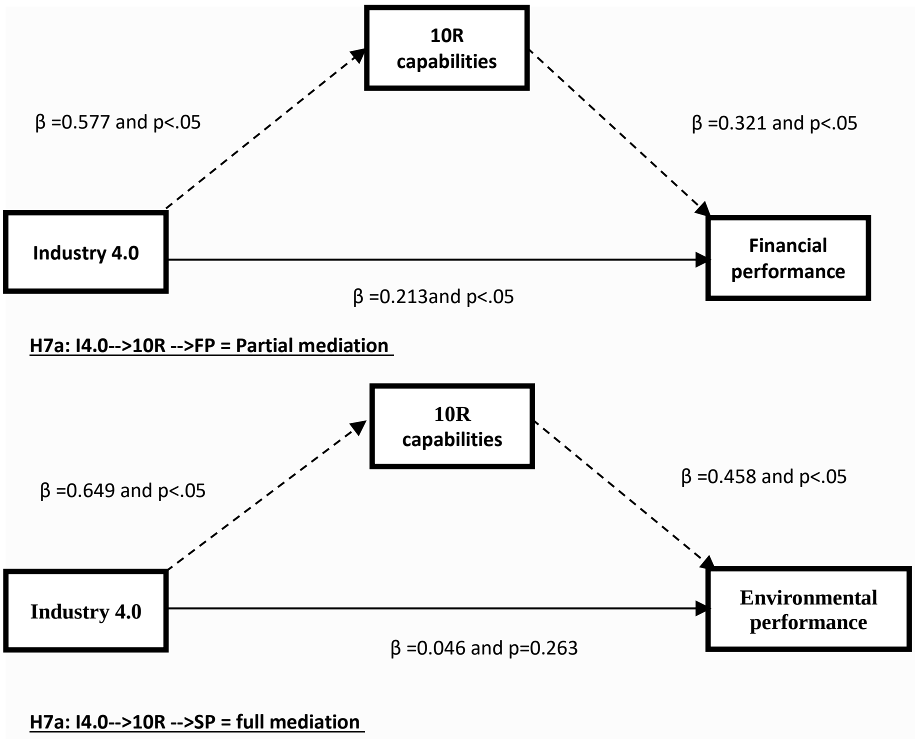


**Figure 2** - Mediation Effect

### 5.4 Predictive relevance of the model and effect size

Following earlier studies(Stone, 1974), the study computed Q2 to assess the model's predictive utility. The blindfolding method is applied in SmartPLS to compute $Q^2$ . Chin (1998) asserts that $Q^2$ should have a value greater than zero. $Q^2$values between 0.02 and 0.015 suggest a modest influence, 0.15 and 0.35 show a medium effect, and any value greater than 0.35 indicates a higher predictive significance, as stated in (Casas, Del Rey, & Ortega-Ruiz, 2013). This study shows a medium predictive relevance impact on FP ($Q^2$ = 0.372) and 10R capabilities ($Q^2$ = 0.226). Similarly, the predictive relevance for SP is also medium ($Q^2$ = 0.199). So, according to this study, exogenous variables considerably illuminate endogenous variables.

## 6 DISCUSSION AND CONCLUSION

### 6.1 Discussion of the findings

The study investigates the influence of I4.0 on firms' FP and SP in the GCC context. Our findings show that I4.0 significantly impacts firm FP (H1a accepted). The adoption of I4.0 has numerous advantages, including increased productivity and efficiency, business flexibility, and customer happiness(Dalenogare et al., 2018; Li et al., 2020). I4.0 technologies enable firms to obtain the knowledge required to make the best business decisions. They may optimize their operations and produce more products and services in less time and with fewer resources. As a result of I4.0-related technologies, multiple aspects of the production line may become more efficient, including decreased machine downtime and the potential to produce more items more quickly. These outcomes enhance the firm's FP. In contrast, I4.0 does not affect SP (H1b is not accepted). Our findings are inconsistent with those reported by (Narula et al., 2021). This may be due to a lack of managerial concern in the region, and the firms use profitability as a primary performance metric. In addition, the stakeholders' pressure is insufficient to influence organizational decisions. In the Western context, the stakeholder's and customers' awareness is a powerful mechanism that binds management to take the initiative to improve SP (Dalenogare et al., 2018).

We observed the impact of ED as a moderator in the relationship between I4.0 and firm performance (FP and SP) in H5a and H5b. For this purpose, the interaction effect between I4.0 and ED is tested on firms' performance. The results show that ED does not moderate the impact of I4.0 on FP. In contrast, the interaction term indicates that ED moderates the relationship between I4.0 and SP. Further, ED moderates the relationship between I4.0 and 10R capabilities, supporting H6. Lastly, ED also moderates the impact of 10R capabilities on FP and SP, supporting H7a and H7b. The findings support the role of ED as a moderator. Thus, ED not only impacts firms' strategic choices (I4.0) and capabilities enhancement (10R), but it also helps firms to generate benefits. The effective application of I4.0 depends on the conduciveness of the external environment. Firms may be able to achieve sustainable development in the presence of conducive ED if they have I4.0 and 10R capabilities in emerging markets like GCC. ED significantly influences firms' and consumers' strategies, behaviors, and choices. Firms must adapt their plans and operations to market trends, regulatory changes, and technology advances. Industry 4.0 can help agile business models and flexible production processes adapt to rapid change. ED can increase risk exposures if strategies are not aligned with market dynamism. Thus, ED offers a competitive edge to firms that adopt I4.0 as a strategic choice and enhance their 10R capabilities in emerging contexts. In brief, ED influences corporate and consumer strategies and behaviors, changing business practices, market dynamics, and firms' expectations towards sustainable development (FP and SP).

As I4.0 directly impacts FP, and its effect on SP is mediated by 10R capabilities, the results support the Practice Based View (PBV). ED has a strong moderation effect and is perceived as an essential component of improving SP. The findings show that I4.0 does not directly impact SP, but management still needs to consider I4.0 because 10R capabilities fully mediate the relation. One may also make the case that for I4.0 to play a significant role in sustainable development, businesses must implement 10R capabilities. According to Díaz-Chao, Ficapal-Cusí, and Torrent-Sellens (2021), 10R capabilities have two advantages. For starters, it acts as a mediator in the relationship between I4.0 and FP, and secondly, it strongly mediates the influence of I4.0 on SP. This study has intriguing conclusions because I4.0 measures sustainable development, and 10R capabilities mediate the relation (Díaz-Chao, Ficapal-Cusí, & Torrent-Sellens, 2021). These findings adhere to the natural RBV hypothesis. ED and 10R capabilities are the firms' dynamic capabilities, and their moderation and mediation roles also support the DCV(Díaz-Chao et al., 2021). Our findings support the DCV and the PBV, as these perspectives effectively describe the association between corporate resources and sustainable development.

### 6.2 Theoretical implications

The theoretical contribution necessitates a particular form of study conclusion that can give novel insights into a phenomenon deemed necessary for increasing the value of a corporation(Hanelt, Bohnsack, Marz, & Antunes Marante, 2021). This study offers a novel viewpoint on the impact of I4.0 on sustainable performance via the mediating role of 10R capabilities. Our research explores the relationship between I4.0 and sustainable performance, specifically focusing on the mediating role of 10R capabilities. This study contributes to theoretical advancements and practical implications for organizational decision-making and policy development in digital transformation and sustainability transitions. This study looked at the SP and FP areas of sustainable development and how they relate to adopting Industry 4.0 innovations.

Additionally, the study investigated the role of ED and resource availability as factors influencing this relationship. As a result, the current research contributes significantly to the field of operational management fields. According to the researcher, the current study is the first to combine I4.0, ED, 10R capabilities, and Sustainable development (FP and SP) into a single research model. Using the DCV, this study adds to the current literature by investigating the moderating effect of exogenous factors. The current study advances sustainable performance research by evaluating how manufacturing firms govern their I4.0 and green capabilities to achieve sustainable performance. In brief, the current study contributes to the DCV and the PBV by exploring how organizations can enhance their sustainable performance in a GCC context.

### 6.3 Managerial implications

The present study also holds several management ramifications. The present research model intends to explain the role of I4.0 adoption in determining sustainable development. Managers can consider the outcomes of the current study in their decision-making as the relationship is proven in the GCC context. Managers should ensure that their I4.0 initiatives are in line with sustainability goals. Our research assists in understanding the potential benefits of utilizing digital technologies to enhance sustainable and financial performance. By incorporating sustainability considerations into their I4.0 strategies, managers can generate value for their businesses and society. However, the relationship between I4.0 and SP is indirect, and the managers should recognize the role of ED and 10R capabilities in determining sustainable development. The adoption of ED and 10R capabilities provides economic and ecological benefits. The significance of 10R capabilities is heightened as it serves as a mediator between I4.0 and sustainable development. The current study's results and context demonstrate that each construct is relevant. The managers must be aware of the usefulness of I4.0 Technology.

### 6.4 Research implication

Our findings have several policy implications. Further research on I4.0 and sustainable development should prioritize longitudinal studies, cross-sectorial analysis, and multi-level analysis toward achieving sustainable development goals in the era I 4.0. In addition, the relationship between I4.0 and sustainable development is indirect. Firms should prioritize ED as it plays a crucial role in shaping their policies and influencing the relationship between I4.0 and sustainable development. Furthermore, 10R capabilities can be considered a suitable mechanism due to its significant mediation effect in the GCC context. In addition, the authorities must pay close attention to the current study's findings and develop regulations that effectively utilize I4.0 technologies. The results of our research have significant financial and sustainable implications, offering potential timely solutions to address the pressing sustainable concerns in the region.

### 6.5 Limitations and future research

Our research has several limitations. Our research is confined to an emerging context of the GCC region; it may not be generalized to other emerging economies like BRICKS or developed economies. The primary constraint is the inherent reductionism in establishing a cause-and-effect relationship between I4.0 and sustainable development (FP and SP). Future research can use other internal (green intellectual capital, innovation) and external (customer agility, market competitiveness) factors to explore the relationship. Further, the relationship between I4.0 and 10R capability may be casual, which is one of the main limitations of the research. Future research can address the missing linkage between the variables. As the study considers the managerial perspective, the perspectives of other stakeholders (employees, CEO, customers) may add to the significance of current research. Lastly, the study used a closed-ended questionnaire; an open-ended questionnaire can be developed to explore the managerial view regarding the effect of I4.0 on sustainable development.

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Appendix: Research questionnaire

| Industry 4.0 | | Adopted from |
|---|---|---|
| **Item** | **Construct** | |
| "Please indicate the degree to which you agree to the following statements concerning your company's I4.0 adoption over the past three years (1=strongly disagree, 5=strongly agree)" | | |
| I4.0-1 | Digital-automation without sensors | (Bag et al., 2021) |
| I4.0-2 | Digital-automation with process control sensors | |
| I4.0-3 | Remote-monitoring and control of production through systems like Manufacturing Execution Systems and Supervisory Control and Data Execution | |
| I4.0-4 | Digital automation with sensors for product and operating condition identification, flexible lines | |
| I4.0-5 | Integrated-Engineering System for Product Development and Product Manufacturing | |
| I4.0-6 | Additive-Manufacturing, Rapid Prototyping, or 3D Printing | |
| I4.0-7 | Simultaneous/analysis of Virtual Models (finite elements, computational fluid dynamics, etc.) for design and commissioning | |
| I4.0-8 | The acquisition, manipulation, and examination of substantial volumes of information (big data) | |
| I4.0-9 | Utilization of cloud services linked to the product | |
| I4.0-10 | Incorporation of digital services into products (Internet-of-Things or product services system) | |
| | 10R capabilities | Adopted from |
| Refuse (10R-1) | My organization focuses on rendering things obsolete by eliminating their functionalities or replacing them with new products that perform the same function. | (Bag et al., 2021; Kirchherr, Reike, & Hekkert, 2017) |
| Rethink (10R-2) | My organization is committed to boosting product intensity. | |
| Reduce (10R-3) | My organization is committed to lowering resource consumption and enhancing manufacturing efficiency. | |
| Reuse (10R-4) | My company encourages the reuse of rejected products that are still in good shape and perform their intended function by another consumer. | |
| Repair (10R-5) | My company repairs and maintains damaged products to be used for their intended purpose. | |
| Refurbish (10R-6) | My company renovates and modernizes old products. | |
| Remanufacture (10R-7) | My company incorporates wasted product components into a new product that performs the same function. | |
| Repurpose (10R-8) | My organization repurposes abandoned items or parts to produce a novel product that serves a distinct function. | |
| Recycle (10R-9) | My firm engages in the process of recycling materials to get materials of equivalent or lower quality. | |
| Recover (10R-10) | My company recycles materials to get the same or lower quality. | |
| Environmental Dynamism | | Adopted from |
| "Please indicate the degree to which you agree to the following statements concerning your company's Environmental dynamism over the past three years (1=strongly disagree, 5=strongly agree)." | | |

| | | |
|---|---|---|
| ED-1 | Significant alterations in the methods of manufacturing and/or provision of services | (Wamba et al., 2020) |
| ED-2 | Significant shifts in consumer demography | |
| ED-3 | Regular and significant fluctuations in governmental regulations | |
| ED-4 | Short product life cycle | |
| | Sustainable Development | Adopted from |
| Sustainable performance | | |
| "Please indicate the degree to which you agree to the following statements concerning your company's sustainable performance over the past three years (1=strongly disagree, 5=strongly agree)." | | |
| SP-1 | A decrease in air emissions. | (Kirchherr et al., 2017) |
| SP-2 | A decrease in  waste water | |
| SP-3 | A decrease in solid wastes. | |
| SP-4 | Improvement in the firm's sustainable situation | |
| Financial Performance | | Adopted from |
| "Please indicate the degree to which you agree to the following statements concerning your company's Financial Performance over the past three years (1=strongly disagree, 5=strongly agree)" | | |
| $FP - 1$ | Increase in return on sales. | (Bag, Gupta, & Luo, 2020; Kirchherr et al., 2017) |
| $FP - 2$ | Increase in profit | |
| $FP - 3$ | Increase in return on investment. | |
| $FP - 4$ | Increase in market share. | |