

## Research Paper on Impact of Industry 4.0 on Sustainable Production and Circular Economy with mediating effect of Industrial Dynamism

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### Abstract

Economic development becomes possible when all of the sectors of the country work efficiently. Productivity and profitability is being affected with the passage of time and introduction of the different production techniques. The emergence of technology and machinery boosts output to a new level. Nowadays the fourth generation of industrial revolution leading the manufacturing sectors to the new peak level. This revolution is being utilized by the textile sectors of Pakistan. Objective of the current study to assess the impact of the Industry 4.0 implementation in the manufacturing sector productivity and profitability. The textile sector of Pakistan is being chosen to study the impact. The study's results indicate that Industry 4.0 implementation contributes a lot in economic development of the country too. Results of the study can be generalized in the industrial sector as well as these can be used by the academicians to improve the industrial related course content for upcoming professionals and scholars.

**Key words:** Industry 4.0, Sustainable Production, Circular Economies, Economic Development, Profitability, Manufacturing Sector.

### Introduction

Everyone has a dream of future economic development where today's products are becoming the resources of the future. The inefficient use of natural resources and traditional production processes causes low profitability and no prosperous development. With the passage of time, innovation and technology are improved enormously. The implementation of artificial intelligence, machine learning, and big data analytics has resulted in numerous efficient and efficient systems. The fourth industrial revolution is an integrated system where innovations of artificial intelligence, machine learning, and other Internet of things in production, processes, and other organizational matter. The introduction of the fourth industrial revolution leads to the modern efficient production method, collaborative industrial networks, and supply chain optimization. All businesses need to consider the business impact on the environment. All of the business needs to make the processes so that environment can sustain and sustainable development goals can be achieved. (Tsvetkova, 2017). This industrial revolution is helpful not only in achieving sustainable development goals but also help businesses to achieve economic objectives, shorter lead time, accurate planning, and efficient consumption of energy. This also creates a comfortable working environment for the employees (Krzysztof Ejmont, 2020).

Some systems and solutions are emerged together to bring innovation like cyber-physical systems. But to get more advantage, all of the technology must be integrated to realize the industrial challenges and sustainable industrial environment (Krzysztof Ejmont, 2020). Industrial revolution 4 leads to three different trends which are connectivity, automation, and intelligence. Operational technology and information technology collaborate in the industrial revolution to create the cyber-physical mechanism (FB, 2020).

The textile sector has given many opportunities to the economy like this sector causes for the enjoyment of the benefits from the European Union free trade agreement to meet the demand for the raw material for the production of the textile products. Pakistan being 4<sup>th</sup> in the world

for the production of cotton and 3<sup>rd</sup> large consumer for the consumption of the material is subjected to technological advancement as the innovation and technology led to globalization and international perfect market competition. Industry 4.0 will enable the textile sector to compete in the international market and will lead to sustainable production and circular economy which in turn lead to economic development.

## **Literature review**

### **Background**

Technology is one of the rapidly growing trends in every walk of life. Industries are now moving towards automation. Industrial automation and technological innovation lead to sustainable results. The merger of technology and innovation becomes the integration for the industries. New manufacturing levels are being achieved with the help of the internet of things, smart technology, and big data which in turn leads to the implementation of the industry 4.0 revolution in the industry (CD, 2019). There is a trend for privacy, security, and transparency in the flow of information due to connectedness in the industry 4.0 revolution. Manufacturing industries are now focusing on balancing cost and production optimization.

Simultaneously with these technological breakthroughs, manufacturing industry workforces are seeing notable transformations. The need for a qualified workforce with the ability to manage and maintain these cutting-edge technologies is growing as automation and artificial intelligence (AI) replace manual and repetitive jobs. Employee upskilling and reskilling to accommodate tasks requiring greater technical knowledge, like data analysis, system integration, and process optimization, is becoming increasingly important as a result of this trend. Moreover, the emergence of smart factories has led to increased human-machine collaboration, resulting in increased productivity and innovation. The utilization of technology by humans to improve processes and innovate in real-time not only develops creativity in problem-solving and decision-making, but also increases operational efficiency.

Businesses also need to address the ethical and social consequences of this change. Data security and privacy are critical issues as more and more sectors depend on data collecting and communication. Businesses need to safeguard confidential data while upholding stakeholder trust and transparency. In addition, worries about possible job displacement are raised by the trend towards automation and digitization. To ensure that both economic growth and human capital are fostered in this new period of industrial evolution, industries must thus adopt policies that strike a balance between technological innovation and social responsibility.

The inclusion of the industrial internet of things, big data, robotics, artificial intelligence, and other technologies are being in the utilization trend of the manufacturing concern (SUI, 2020).

### **Sustainable Production**

The term "sustainable production" describes a method of product manufacturing that takes worker safety and the environment's effects into account. This production process uses green and lean production methodologies. It focuses on the whole product life cycle which starts from the production of the product and end of the life when the consumer puts it in to use (FB, 2020). In another word, we can state that sustainable manufacturing is the process of creating a high-quality product by consuming sustainable resources efficiently alongside making it safer for the employees, consumers, and community. Overall its purpose is to mitigate the environmental impacts (Carla Gonçalves Machado, 2019).

### **Circular Economy**

According to Allen McArthur circular economy is an economy designed which can self-regenerate. It means it is an economic design that uses the waste or residual material in the successive production system and reducing the waste of the production at the minimum level.

The circular economy suggests a new production system in which all the material and energy resources are best utilized in terms of the economic, environmental, and social benefits in contrast with the traditional production system where resources are used for the production and residual is discarded (Giuseppina Piscitelli, 2019). There are three principles of the circular economy which is as under (Salahudeen, 2019);

- Preservation of the natural capital and a balanced flow of the renewable energy resources
- Circulation of the material in the product life cycle while assurance of maintaining the high quality
- As in a circular economy, there is no point in the waste of material. So there is no way of the external negativities.

### **Industrial Dynamism**

According to the oxford dictionary, industrial dynamism refers to rigorous and progressive activity. It is the change that is accepted positively in the industry. Due to innovation and technologies available worldwide, there is a global competition and which is across the borders. Now every industry has to cope up with the new trends of business manufacturing. Industrial dynamism is supportive in implementation of the industry 4.0 which will lead to sustainable production and enhance the circular economy capabilities of the manufacturing concern.

#### **RQ1: Does industry 4.0 has an impact on sustainable production**

##### **H1 = industry 4.0 has an impact on sustainable production**

Sustainable production and industry 4.0 are the interrelated components of the revolution. Sustainable production operations lead the businesses towards greater achievements in terms of revenues as well as environmental impact. Unlike the traditional production systems, the introduction of the fourth industrial revolution changed the concept of the production system. (Goncalves et al, 2020). Firms are conscious about sustainable business operations more specifically in engineering and manufacturing concerns. It is becoming irresistible for an effective production system. Industry 4.0 which is also known as the smart factory is found to be the solution to address the various production-related issues like reduction in wastage and timely meeting the quality requirement of the product by the customers (Ojo et al, 2018). For the sustainable production system, it is mandatory to implement industry 4.0. In other words, it can be pronounced that industry 4.0 is the basis for the organization to achieve sustainable production. But implementing industry 4.0 is a challenge for the organization as it has to face many barriers. Because change is not always and quickly adaptable in the organization. It was studied in (G.Khanzode et al, 2021) that removing the barriers like decision-making and policy formulation will enable the organization to achieve sustainable production operations with the help of I4.0.

#### **RQ2: Does industry 4.0 has an impact on the circular economy**

##### **H2 = industry 4.0 has an impact on circular economy**

The circular economy changes the concept of the end of life of the material used in production to the restorative method. It is the concept to reuse the residual material in the production which helps the companies in managing waste and poses environmental benefit (Paolo et al, 2019). Industry 4 is the technologies that help in maintaining and achieving the circular economy in the production system of the manufacturing concerns using various techniques like cyber-physical system, big data, robotics, and other web-based technologies (Paolo Rosa C. S., 2019). Together with the implementation of the industry 4.0 and circular economy helps the organization in achieving the sustainable development goals and it was observed in a study (T.E.T.Dantas et al, 2021) that together an implementation of I4 and CE helps the organization to maintain the sustainable production and achieving the sustainable development goal for the better environment.

**RQ3: Impact of Industry 4.0 on circular economy in the presence of sustainable production**

**H3 = Industry 4 has a positive impact on circular economy in maintaining the sustainable production**

Developing countries in the current era are now focusing on technological innovation to make business operations effective and automated to uplift the economy as well as the people of the country. Govt. of the countries are now supporting the organization moving for the innovations. In a study (Surajit Bag et al, 2021) it was found that project and human resource management, other operations like process design, green design, and supply chain all are integrated and can be more fruitful by the implementation of industry 4.0 which in turn lead to sustainable production. It is also found that there is a strong relationship between Industry 4.0 and sustainable production which in turn has a positive impact on the circular economy. It means implementation of I4.0 will lead to adopting the circular economy by achieving sustainable production.

**RQ3: Impact of Industry 4.0 on sustainable production in the presence of industrial dynamism**

**H3 = Industry 4 has a positive impact on sustainable production in maintaining the industrial dynamism**

Dynamism is referred to as the rigorous activity-based change and its positive attitude. Industry dynamism is a concept that is ignored but it is now the point of research for the scholars (Knecht, 2013). Industrial dynamism is closely related to automation and change adaptability in the company. For the development of the operational sustainability of the company via industry 4.0, all of the changes must be adaptable. Industry 4.0 has a positive impact on sustainable production capabilities in the presence of dynamism (Dayasindhu, 2020) It is reported that for the implementation of I4 in the Indian industries, dynamism is required to adopt the new technologies which will become the basis for sustainable business production with the help of I4 (Dayasindhu, 2020).

**RQ4: Does the Industry Dynamism mediate between Industry 4.0 and sustainable production?**

**H4 = Industry Dynamism significantly mediates between Industry 4.0 and sustainable production.**

Pakistan is a country that has an economic base of 70% on agriculture. Due to agriculture many of the industries are running efficiently. The textile sector is also one of them. Pakistan is the 4<sup>th</sup> largest producer of cotton in the world. It is comprised of 46% of the industrial sector and provides 40% of the labor force employment opportunity in the country. There are approximately 423 textile industries in Pakistan. We have taken the textile industry for our current study as the research coverage about the Industry 4 implementation in the textile sector is still needed.

For the proper management of the companies, it is always essential to monitor and evaluate compliance with the set objectives so that operational and strategic decisions can be taken promptly. The manufacturing system is the mature function of the business so management used accounting facts and figures to assess the business performance. But when we take the social and environmental aspects, it is always challenging for the companies to measure this. As for this, we take human capital, material, and energy resources under consideration. Impact of the production process on environmental stability like carbon footprint emission in the environment. So to manage properly, both qualitative and quantitative assessment is required. Industry 4 and its component helps to make the systems smarter and can be assessed in terms of its impacts on the environment and society so as the economic impact on business (Roberto Bellas, 2019). A comprehensive literature review is conducted by using various journal articles relevant to our current study.

### **Principles of industry 4**

*Interoperability:* it is the process where machines and equipment can be exchanges that are used for the same function. This builds a trusted network across the organization.

*Decentralization:* decentralization of the process helps to achieve the business target more easily. Breakdown of the decision making at every level and system accessibility to the down level always results in operational efficiency in contrast with the centralization where all the decisions are taken by the competent authority which may cause delay and loss of the business targets.

*Virtualization:* Virtualization is created in the business processes. Equipment and machine to the machine communication system are developed with sensors and attached to the main virtual plant model and simulation. A Cyber-physical system helps create the virtualization

*Real-time capability:* to assure the organizational task, real-time capability is required but industry 4 goes advance one step. It uses technology and the failure of one machine doesn't hinder the business process. The use of real-time information and robotics helps to achieve this target.

*Modularity and internet of services:* this system of the organization must be modular. It means it is adaptable for changes either expansion of the function or reduction in the activity. All of these things can be coordinated with the internet of services via communication among all the key players (A. Santanaa, 2018)

According to a study by Surjit Bag (2021), big data analytics, project management, management leadership, green logistics and design, and human resources are essential for the adoption of industry 4. It also suggested that there is a contribution of the industry 4 revolution for sustainable development which in turn lead towards progressive capabilities of the circular economy for the organizations.

A study conducted by (Paolo Rosa, 2019) suggested that Industry 4 has a positive impact on product life cycle management. Using industrial 4 revolution technologies like the internet of things or big data analysis helps the companies to manage the product life cycle with minimum waste as residual material is reused in the production system.

(Daniel Luiz Mattos Nascimento, 2019) conducted a study to evaluate industry 4 technology' effects on the sustainability of businesses. Study findings showed that there is a contribution of industry 4 revolution technologies in business sustainability. The study recommends reusing the scrap material, web technologies, and revers technologies so that organizations can adapt to the circular economy capability.

(Carla Gonçalves Machado, 2019) Conducted research to assess the impact of industry 4 and its implementation across the organizations. Results depicted that industry 4 has a positive impact on the use of advanced technology can be helpful in execution and maintaining sustainable development and which in turn can be a good agenda to implement the industry 4 revolution. Implementation of industry 4 leads to sustainable development and policy, sustainable production system, sustainable processes, and lead to meeting the sustainable development goal to be the responsible organization in terms of economy, social, and environment.

(Ding, 2018) Researched with a target of the pharmaceutical industry. The study showed that some factors cause the business model to face challenges in moving forward which are time consumption, cost maximization, lack of expertise and lack of training, lack of collaboration, lack of coordination in all of the pharmaceutical industry. The study revealed that the implementation of the industry 4 revolution will help the industry in meeting the above challenges to make a sustainable business and production model.

In a research carried out by (Grischa Beier, 2020) revealed that industry 4 is a socio-technological concept which includes the social, technological and environmental factor. Industry 4 is not a single concept. It also explained that only one concept of industry 4 as the



single concept cannot modify the business results. It requires integrations of the various concepts, technologies for a business to be sustainable.

(Ting Zheng, 2019) focused on the manufacturing industries to assess the implication of the industry 4 technologies in manufacturing processes of the industry. The research study showed that the implication of the industry 4 technologies can help the companies in boosting the scheduling of production and control processes. Results may be even greater with the use of the internet of things, big data analytics, and cloud technology.

Research conducted by (Ana Beatriz Lopes de Sousa Jabbour, 2018) suggested that there is a crucial relationship between industrial 4 technologies and circular economy. Moreover, smart production can also be achieved with the implementation of industry 4 technologies. In a study, research results showed the evolution of linear production to a circular economy to generate profitable results. The circular economy model is implemented with the help of the internet of things and industry 4 technologies

(Kusi-Sarpong, 2019) conducted a study for the textile sector of Pakistan to assess the implication of the industry 4 technologies in the supplier management processes. Results showed that the implication of the industry 4 technologies and circular economy enabled the textile companies in managing the supplier process management. (Muhammad Imran, 2019) stated that there are five factors of industry 4 which are big data, internet of things, smart factory, cyber-physical system, and interoperability. With the help of these factory industries, 4 technology can help maintain sustainable business performance. This research was carried on the textile industry of Pakistan and the logistics industry of Pakistan.

One study revealed that the implication of industry 4 technology in the circular economy is affected by the prevalence of some challenges like lack of automation, lack of coordination among the integrated firm, when economic benefits of digital investment are not cleared (Asma-Qamaliah, 2020). (Muhammad Haseeb 1OrcID, 2019) is of the view that industry 4 is the key to sustainable business performance. An element like the internet of things, big data, and smart factory production are the main factors of sustainable business performance.

(Antonella Petrilo, 2018) says that human capital is an important resource of the companies and its effective utilization generates marvelous results. Introduction of the industry 4 technology in smart factories and effective utilization of the human capital leads to sustainable performance. Because, in smart factories, there is balanced interaction of humans and machines to perform the assigned tasks. This positively led the company ahead.

Advanced automation is the basis of the industrial 4 revolutions. It is always a challenge for a business to bring a change in the business processes so as the case with the flexible automation using industry 4 technologies. Internet of things, big data analytics, and other ICT methodologies are the enablers for industry 4.0 to make the business process sustainable and enabling the circular economy capabilities of the organizations (Cruz-Machado, 2019).

(Judit Oláh, 2020) revealed that the flow of resources like material, energy, and others, from the production of the product till finalization, has no impact on the environmental stability. But the integration of industry 4 and other automation can make the business processes sustainable by making smart production techniques and hence reduction in waste and optimum use of the resources which in turn lead to environmentally sustainable development goals.

In the current era, industries that are working for environmental stability are widely accepted in the global market. Sustainability can be achieved by reducing the waste material in business activities. The reduced consumption of the material, resources of energy, and reduction in carbon footprint are warmly accepted in the global market. These things in the business activities can be achieved with the help of industry 4. Industry 4 and its related technologies like the internet of things, big data, and cyber-physical systems are the components that enable the business to achieve the above-mentioned targets. This thing leads

to the business process sustainability and the company can achieve the circular economy capability which in turn has its economic, environmental, and socially beneficial aspects (Salahudeen, 2019).

(Auth Alejandro, 2019) are of the view that industry 4 is the new technological industrial concept that uses different ICT technologies convergence to make the business production efficient and smart. Industry 4 concept is implemented with the help of its component like the internet of things, cloud service, big data, and analytics. With the help of these elements, businesses can achieve better front-end technologies of the business which are smart production, smart supply chain, smart working, and services, etc. Findings of the study also showed that implementation of industry 4 is relatively low so it is a challenge for the business to achieve the front end technologies where smart manufacturing plays a crucial role.

### **Objectives**

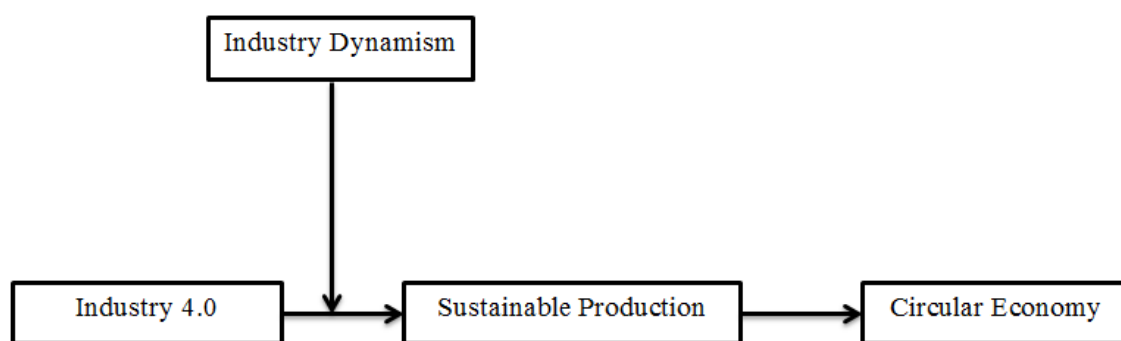
The industrial revolution introduced a lot of challenges and opportunities in the manufacturing sectors. By adopting this industry 4 revolution, not only smart and efficient production can be achieved but there would be a prosperous circular economy. But this area is still not covered for research and impact purposes in Pakistan. This study aims to study the impact of the adoption of the industry 4 revolution in the production of the textile sector and circular economy.

### **Research implication**

The finding of the research can be generalized all over the textile industry. The finding will help make the smart factory, smart production, and smart supply chain management I overall industry which in turn will lead to the economic, environmental and social impact on the country as well as industry

### **Research Methodology**

It is considered to used the exploratory research method and approach. Exploratory research is being used because of the variable we used need is still needed to be explore. The long data is collecgted and catagorised in the group for variable relationships. The EFA was conducted by the study team using SPSS version 22.0 software. Using WarpPLS software, the theoretical model was constructed and evaluated in the second phase of this project.



### **Data Collection**

The data was collected from the textile industries of Lahore and Faisalabad. Primary data is collected through a structured questionair. Afive-point Likert scale design is used for development of of the Instuments. A multiple-item, 5-point Likert-type scale (1 “Strongly Disagree”; 2 “Disagree”; 3 “Neutral”; 4 “Agree”; 5 “Strongly Agree”) was used. The target industries are selected using the snow ball sampling techniques. All catagories of the textile industries are covered in the data collection and the managerial staff is targeted for the responses to the questionnaire. Almost 237 responses were collected which becomes more

than 22% of the total and acceptable in the social science research. As the data collected from the managerial staff so it is acceptable for the research analysis.

Constructs	Items	Loadings	Alpha	C.R	AVE
Circular economy	CE1	0.62	0.916	0.927	0.564
	CE10	0.821			

### **Analysis**

Smart PLS software was used for hypothesis analysis. Data was summarized and organized as per requirement of the preliminary analysis via software. The fitness of the model and quality of the parameters will be analysed. For example, Average path coefficient = 0.175, Average R-squared = 0.256 and Average adjusted R-squared (AARS) = 0.245 were found to be statistically significant. It is also analysed that Average block VIF = 1.610 and Average full collinearity VIF (AFVIF) = 2.102 which are in acceptable boundaries. It suggests that analysis is not impacted by the multicollinearity. Tenenhaus GoF was 0.375, which indicates the model fitness. Additionally, Sympton's paradox ratio (SPR) = 1.000, R-squared contribution ratio (RSCR) = 1.000, Statistical suppression ratio (SSR) = 1.000; Nonlinear bivariate causality direction ratio (NLBCDR) = 0.727 which means that no endogeneity issues are present in the model. The tested model is presented in figure.

### **Results (Convergent validity table)**



	CE2	0.607			
	CE3	0.642			
	CE4	0.699			
	CE5	0.724			
	CE6	0.745			
	CE7	0.854			
	CE8	0.875			
	CE9	0.86			
Industry 4.0	IND(4.0)1	0.732	0.919	0.932	0.578
	IND(4.0)10	0.65			
	IND(4.0)2	0.807			
	IND(4.0)3	0.806			
	IND(4.0)4	0.761			
	IND(4.0)5	0.735			
	IND(4.0)6	0.741			
	IND(4.0)7	0.776			
	IND(4.0)8	0.822			
	IND(4.0)9	0.755			
Industry dynamism	INDY1	0.826	0.824	0.883	0.654
	INDY2	0.822			
	INDY3	0.814			
	INDY4	0.772			
Sustainable production	SP1	0.916	0.948	0.962	0.865
	SP2	0.956			
	SP3	0.944			
	SP4	0.903			

**Discernment validity table (HTMT ):**

	Circular Economy	Industry 4.0	Industry Dynamism	Sustainable Production_
Circular Economy				
Industry 4.0	0.762			
Industry Dynamism	0.696	0.485		
Sustainable Production_	0.675	0.445	0.699	

Table 3 Path Analysis

	Beta	S.D	T value	P Values	L.L	U.L	Decision
Industry 4.0 -> Sustainable Production_	0.192	0.048	4.045	0	0.105	0.279	supported
Industry Dynamism -> Sustainable Production_	0.549	0.053	10.272	0	0.427	0.642	supported
Moderating Effect 1 -> Sustainable Production_	0.063	0.038	1.647	0.1	0.013	0.16	supported
Sustainable Production_ -> Circular Economy	0.67	0.033	20.299	0	0.594	0.724	supported
Industry 4.0 -> Sustainable Production_ -> Circular Economy	0.129	0.034	3.786	0	0.401	0.534	supported

For hypothesis analysis Structural modeling was executed. Coefficients, To explain the relationships in the hypothesis, T values are computed. The bootstrapping method was used to achieve the effects of moderation and mediation.

Table 3 showed that H1 Industry 4.0 practices significantly associated with Sustainable production ( $\beta = 0.192$ ,  $t = 4.045$ , L.L= 0.105 U.L= 0.279 and P value is 0.000) therefore H1 supported, the result had shown that H2 Industry dynamism positive link with sustainable production ( $\beta = 0.549$ ,  $t = 10.272$ , L.L=0.427, U.L= 0.642 and P value=0.000), same like this H3 Moderatin effect 1 is the link to Sustainable prodiction ( $\beta = 0.063$ ,  $t = 1.647$ , L.U=0.013, U.U=0.16 with P value=0.1) therefore H3 supported, besides this H4 Sustainable production, and Circular Economy ( $\beta = 0.67$ ,  $t = 20.299$ , L.L=0.594, U.L=0.724) H4 is supported. H5 Industry 4.0, Sustainable production and Circular Economy ( $\beta = 0.129$ ,  $t = 3.786$ , L.L=0.401, U.L=0.534) H5 is supported.

### Discussion

The finding of the research indicates there is a a positive relationship of Industrial 4.0 on sustainable production thereby approving the H1. It is also indicated that there is a positive relationship of I4.0 on circular economy. Hence proving the H2. Analysis also shown that industry 4.0 has greater impact on the circular economy when there is a sustainable production. Because sustainable production is the practice which reduce the waste of material and reuse the wasted material. Analysis of the research led to the results that industrial dynamism act like a catalyst in the relationship of the Industry 4.0 and sustainable production. So in this way our all hypothesis are proved and we rejected the all null hypothesis. Moreover this finding of this research are in line with the study conducted by (Surajit Bag G. Y., 2020).

### Conclusion

The current study is conducting by the development of the model to creat the link of industry 4 with the sustainable production and circular economy with a mediating effect of the industrial dynamism. The literature reviews of the previous studies is used to complete the research as well as the validation of the model and results. The finding of the study will be contribution to the existing knowledge as the detailed and extensive research is conducted. The sustainable production goals are also in line with sustainable development goals of the united nations. The research is conducted on the basis of the previous study and it is renewed by the mediating impact of the industrial dynamism on the relation of the industry 4.0 on sustainable production and circular economy.

### Recommendation

The current study is conducted by taking only industrial dynamism as mediator on the relation of industry 4.0 on sustainable production and circular economy. Future researchers

can assess the other variable as the mediator or moderator to the relations which can be further used in the industrial production policy and planning.

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