Effect of Resources and Capabilities for integrating Industry 4.0 and Sustainable production to unlock Circular Economy: A South African Experience

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Abstract

The study aspires to develop a theoretical model linking Industry 4.0 and cleaner production to unlock circular economy in an emerging economy of South Africa. Drawing upon Resource based view theory; the study aims to explore the firm resources and capabilities that are necessary to integrate Industry 4.0 technologies and sustainable production to further enhance circular economy performance and secondly, to investigate the impact of each research and capabilities on circular economy performance and finally, to outline agenda for ethical business development. The review of literature led to identification of thirty-five resources and capabilities that are essential for the integration of Industry 4.0 and sustainable production that will aid in unlocking circular economy. Further, exploratory factor analysis is used to group the variables under relevant factors and thereafter path modelling is performed using PLS-SEM technique. Research findings indicate that Project resources, Green team resources, Technological resources, Production and operations capabilities, Human resources capabilities, Management capabilities, Circularity capabilities, Information technology capabilities and Relationship capabilities are required for integration of I4.0 and sustainable production and further enhance CE performance. However, the Technological resources, Production and Operations capabilities and Circularity capabilities are found to have a stronger relationship with CE performance compared to rest of the resources and capabilities. The study concludes with theoretical and practical implications and agenda for ethical business developments.

Keywords: Industry 4.0, Sustainable production, Circular economy, Ethical business development, Resources and Capabilities

1. Introduction

The Circular Economy (CE) looks beyond the current manufacturing and consumption-based business models and aims to develop a closed loop system. CE is based on three main beliefs such as design out waste, keep goods in use and revive natural systems (Ellen Mac Arthur Foundation). Globally, the availability of key resources is gradually diminishing and at the same time intensity of pollution is also increasing. Perceiving the danger that is awaiting in the near future have made organizations more cautious and they are putting their effort towards adoption of CE principles to increase circularity and further enhance longevity of resources (Zhu et al., 2011; Liu and Bai, 2014; Franklin-Johnson et al., 2016; Huysman et al., 2017; Saidani et al., 2017; Elia et al., 2017; Figge et al., 2018). Countries such as China, EU, Japan and USA have recently started using CE principles. CE globally is in the nascent stage of development and majorly organisations are focusing on recycling rather than reusing principles (Ghisellini et al., 2016; Yang et al., 2018). Few key factors must be considered while practicing and promoting CE. These key factors are current technological use, supply chain complexity, operations strategy, planning and control, regulations and consciousness among people (Lin, 2018).

Okorie et al. (2018) indicated that CE research publications are on the rise; however, research on Industry 4.0 (I4.0) technologies to drive CE is still comparatively untouched. The concept of I4.0 is based on the progression of ICT which has made it possible to adopt the process of advanced manufacturing technologies into production systems and using technologies such as IoT, big data, cloud computing for plant automation (Telukdarie et al., 2018; Nascimento et al., 2019). Recently, few studies have investigated the concealed link between I4.0 and CE (de Sousa Jabbour et al., 2018a; de Sousa Jabbour et al., 2018b; Garcia-Muiña et al., 2019; Kerin and Pham, 2019; Nascimento et al. 2019; Rajput and Singh, 2019a; Rajput and Singh 2019b). However, these studies have either identified the critical success factors; enablers and barriers in adoption of Industry 4.0 and sustainable manufacturing to unlock CE. Since the studies related to I4.0 and CE is in the early stage; therefore, current study aims to explore the resources and capabilities required to integrate I4.0 and sustainable manufacturing. The two central questions of this study are as follows:

RQ1: What are the resources and capabilities that are necessary to support integration of I4.0 and sustainable manufacturing for unlocking CE?

RQ2: What is the impact of each resource and capability on CE performance?

The current research study focuses on automotive industry as this industry is dependent on raw material and some of them are valuable metals which present strategic challenge for operations managers. Sixty percent of these valuable metals are used as an input in manufacturing of automotive parts which presents a big risk of material shortage by 2030 (Ellen Mac Arthur Foundation, 2012 report). Unless, the end of life automotive products enters the circular loop; it is not possible to develop a harmony and sustain balance between society and environment (Bag et al., 2019). I4.0 plays an instrumental role in overcoming CE challenges such as operations level risks (Bag et al., 2020b), ownership issues, remanufacturing market demands, technological development and reverse logistics uncertainties (Bressanelli et al., 2018b). However, allocation of proper resources and development of certain organization capabilities are essential to aid in integration of I4.0 and sustainable manufacturing and further promote CE which is missing in the current literature. The research team aspires to bridge the existing gap and address the call of past researchers.

The organisation of rest of the sections is as under.

The section 2 provides the review of literature followed by section 3 on research design based on exploratory approach; section four presents the data analysis and findings. The final section provides the conclusion drawn from the study and agenda for ethical business development in circular economy driven by I4.0 and sustainable production.

2. Literature Review

This section presents the review of literature and discussing key concepts and links among Industry 4.0, Sustainable production and Circular economy

2.1 Underpinning theory: resources and capabilities

The RBV theory of the firm is a good way in identifying the internal sources of competitive advantage (Wernerfelt, 1995; Barney et al., 2001). However, managers following RBV theory may not focus too widely on every resources and capabilities, and they may not even analyse properly the connections existing among various resources and capabilities and their associated connections with environment. The case of American airlines clearly indicates that managers need to gauge resources and capabilities properly with a wider context. Successful business is developed based on the ability of firm to maintain set of resources that are precious, uncommon, matchless and hard to replace. Situations may change in this highly dynamic business environment and firms must avoid focusing too narrowly on the resources and capabilities to avoid risks. In a firm there are multiple functions such as sales, operations, finance, human resources and therefore, resources and capabilities must be assessed across these functions. It must be understood that few resources may be required in some particular situations while they may not be required in other situations. However, managers must have an overview of all the available resources and capabilities and more importantly they must understand how each of these resources and capabilities interact with each other and conditions under which each of them maintains or drop importance. It is also indicated that higher level of competition augments the values of resources and capabilities (Teng and Cummings, 2002).

Resources are possessed or controlled by the firm whereas capabilities are the abilities of a firm to position resources using its business processes. Therefore, capabilities comprise of a bundle of resources that are required to execute some job and such capabilities are developed under various functions by integrating technical, physical and human elements (Ravichandran et al., 2005).

2.2 Resources and capabilities for integrating Industry 4.0 and sustainable production to unlock circular economy

Resources and capabilities are essential for integrating Industry 4.0 and sustainable production (Bressanelli et al., 2018a; de Sousa Jabbour et al., 2018b). Literature has indicated various resources and capabilities such as IT resources which are summarized in Table 1 (Refer appendix). Information technology resources in this digital era comprise of Internet of things and big data analytics (Bressanelli et al. 2018a; Bag et al., 2020b). These technologies act in a combined manner to develop the ability to run remanufacturing, recycling and reusing production lines (Bag et al., 2020a).

Literature also reveals other resources like Teamwork and the implementation team, Organisational culture, Environmental knowledge, Project management resources, Green human resources, Robotics in shop floor, Environmental awareness of workers, Reverse logistics resources and Top management commitment.

Organisation culture and top management commitment plays an important role in success sustainable projects (Muduli et al., 2013). Green human resource teams motivate employees to pursue green production related initiatives (Jabbour and de Sousa Jabbour, 2016). Green teams develop their skills and environmental knowledge based on continuous education and various training programs designed by human resource managers as per requirement of the firm. Green training helps to adopt green supply chain practices. Green training of employees must be aligned with green supplier trainings to fulfil the cleaner manufacturing requirements (Teixeira et al., 2016). Reverse logistics resources and project management resources are critical for the success of cleaner manufacturing methods (Govindan and Soleimani, 2017). Old and defective items consisting of electronic and computer parts, phones, automobile parts, machine components are returned to the suppliers generally pass through a number of steps such as disassembly, cleaning, refurbishing, remanufacturing, assembling, painting, quality checking, packaging and return to the customers (Bag et al., 2019). Reverse logistics play an important role in return management of such goods. Reverse logistics resource commitment leads to investment in reverse logistics resources which is directly correlated with reverse logistics and remanufacturing performance (Daugherty et al., 2001). It is essential that firms manage changes in the organisation in a proper manner and configure resources as per business environment to achieve the desired outputs.

Capabilities are essential to integrate the two concepts i.e. Industry 4.0 and sustainable production. Traditional management systems must be replaced with new innovative systems to fit the Industry 4.0 and sustainable production requirements. Management involvement and transformational leadership skills are capable of driving the changes in the supply chain. Most importantly the ability of firm to develop circularity capabilities like planning and control of inventory, developing flexible production lines, design for Design for environment, Design for remanufacture, Aided assembly, Intelligent storage management, Self-configured workstation layout, Product and process traceability and Assembly control system play a critical role in integration of Industry 4.0 and sustainable production projects. Industry 4.0 technologies such as cyber physical systems can drive cleaner ways of manufacturing without producing wastages and using non moving resources. Other Industry 4.0 technologies such as Internet of things can enable production in masses and meet customer demands without manufacturing excess non moving items. Cloud computing can restrict uncontrolled use of resources and additive manufacturing capabilities can help in proactive maintenance activities in the factory and save energy and resources (de Sousa Jabbour et al., 2018b). These capabilities need to be developed by firms to develop an internal competitive edge over its competitors.

Table 1. List of resources and capabilities

Sl No	**Items**	**Type**	**Source**
1	Teamwork and the implementation team	Resources	de Sousa Jabbour et al. (2018b)
2	Organisational culture	Resources	de Sousa Jabbour et al. (2018b)
3	Project management resources	Resources	de Sousa Jabbour et al. (2018b)
4	IT resources	Resources	Bag et al. (2018); Telukdarie et al. (2018)
5	Top management commitment	Resources	de Sousa Jabbour et al. (2018b)

6	Environmental knowledge	Resources	Liu and bai (2014)
7	Green human resources	Resources	Bag and Gupta (2019)
8	Environmental awareness of workers	Resources	Liu and bai (2014)
9	Reverse logistics resources	Resources	Elia et al. (2017)
10	Environmental cooperation	Capabilities	Zhu et al. (2011)
11	Robotics in shop floor	Resources	Kerin & Pham (2019)
12	Circular product design and production	Capabilities	Elia et al. (2017)
13	Intelligent storage management	Capabilities	Li et al. (2019)
14	Flexible remanufacturing systems	Capabilities	Kerin & Pham (2019)
15	Supply chain relationships	Capabilities	Sandberg and Abrahamsson (2011)
16	Aided assembly	Capabilities	Li et al. (2019)
17	Self-configured workstation layout	Capabilities	Li et al. (2019)
18	Product and process traceability	Capabilities	Li et al. (2019)
19	Assembly control system	Capabilities	Li et al. (2019)
20	Cross cycle and cross sector collaboration	Capabilities	Elia et al. (2017)
21	Management systems innovations and long term investments	Capabilities	Liu and bai (2014)
22	Inventory Control	Capabilities	Sandberg and Abrahamsson (2011)
23	Strategic alignment	Capabilities	de Sousa Jabbour et al. (2018b)
24	Management leadership	Capabilities	de Sousa Jabbour et al. (2018b)
25	Training and capacity building	Capabilities	de Sousa Jabbour et al. (2018b)
26	Managerial knowledge and presence	Capabilities	Sandberg and Abrahamsson (2011)
27	Empowerment of employees	Capabilities	de Sousa Jabbour et al. (2018b)
28	Readiness for organisational change	Capabilities	de Sousa Jabbour et al. (2018b)
29	Communication ability	Capabilities	de Sousa Jabbour et al. (2018b)
30	Cross-functional teamwork	Capabilities	Sandberg and Abrahamsson (2011)
31	Information processing capability	Capabilities	Gupta et al. (2019)
32	Learning	Capabilities	Sandberg et al. (2011)
33	End-of-life resource management	Capabilities	Elia et al. (2017)
34	Design for environment	Capabilities	Saidani et al. (2017)
35	Design for remanufacture	Capabilities	Saidani et al. (2017)

3. Research Methods

The review of literature led to identification of thirty-five resources and capabilities that are essential for the integration of Industry 4.0 and sustainable production that will aid in unlocking CE.

3.1 Data collection strategy

The data is collected from manufacturing firms based in South Africa. The list of firms is selected using simple random sampling technique from Ezee-dex online supplier database. Firms are selected from the heavy engineering, automobile component manufacturers, electronic parts manufacturers and castings manufacturers. The online structured questionnaire (refer to Appendix 1) is sent online to 1170 firms during the month of September 2019. Only 27 filled up questionnaires are received within three weeks of sending the initial request. A gentle reminder is sent during early October 2019 to those firms that have not responded till then and further the research team received 35 filled up questionnaires. In the month of December 2019 another gentle reminder is sent to the remaining firms that have not responded so far and the research team finally received 168 filled up questionnaires by end of February 2020. Besides sending friendly reminders over online portal the research team made multiple phone calls and made polite requests to the target respondents to fill up the questionnaires.

In total the research team received 230 complete filled up questionnaires. The response rate is 21.49% which is acceptable in social science research. The demographic summary is presented in table 2.

Table 2. Demographic summary

Metric		Number of respondents	Percentage
Primary Industry			
	Heavy engineering	34	14.78
	Automobile component manufacturers	96	41.73
	Electronic parts manufacturers	43	18.69
	Castings manufacturers	57	24.78
Number of Employees			
	101-300	22	9.56
	301-500	47	20.43
	501-1000	146	63.47

	More than 1000	15	6.52
Age of your Firm			
	Below 10 years	0	0
	11-20 years	19	8.26
	21 - 30 years	143	62.17
	Above 30 years	68	29.56
Age of Employees			
	20-30	44	19.13
	31-40	165	71.73
	41-50	16	6.95
	51-60	5	2.17
Corporate role			
	CEO/President/Owner/MD	2	0.86
	CFO/Treasurer/Controller	6	2.60
	CIO/Technology Director	2	0.86
	Chief Procurement Officer	3	1.30
	Senior VP/VP	8	3.47
	Head of Business Unit or Department	14	6.08
	Senior Manager	179	77.82
	Junior Manager	8	3.47
	Company Engineer	5	2.17
	Data Analyst	3	1.30
	Others		
Years' of work experience			
	Less than 5 years	3	1.30
	6-10 years	101	43.91
	11-20 years	94	40.86
	Above 20 years	32	13.91

From the table 2 it is observed that maximum responses are received from automobile component manufacturers. This sector is showing more interest towards digitalization and sustainable manufacturing.

It is also noticed that more responses are received from firms with employees in the range of 500 to 1000. This can be due to the reason that medium and larger size firms are showing more interests towards CE as they are having more resources and capabilities than smaller firms.

Thirdly, higher number of responses is received from the age group 30-40 years who are mainly in the senior managerial positions having between 10-20 years of work experience and mainly they are the ones responsible for driving CE projects. Therefore, the data obtained for this study is suitable for performing analysis as senior managers have knowledge on the environmental subject and it is unlikely that any kind of bias would be involved in the data.

3.2 Research technique

The research team have considered exploratory research approach. In the phase I of this study the research team uses quantitative i.e. Exploratory factor analysis (EFA) to reduce the long list of resources and capabilities and categorize under relevant group. The research team used SPSS version 22 software for performing EFA. In the phase II of the study the conceptual model is tested using WarpPLS software.

Various measures are adopted during the data collection stage to avoid common method bias impacting the data. Firstly, a small note is included before the actual questions start which reads that this questionnaire is for academic use only and at no point of time this data will be used for commercial usage. This note is aimed to build confidence among industry people and encourage them to share the right data with the research team.

Secondly, the research team used the much popular Harman's single factor test to check the CMB. From the SPSS output it is found that nine factor emerges and first factor accounts for 14.15% of variance which is much below the maximum limit of 50% which means that the data is free from CMB (Podsakoff et al., 2003).

Non response bias test has been performed. The responses are received in various phases after doing follow-ups. The early and late waves are compared using Homogeneity of variance test and the results indicate that no values are statistically significant which means that between the waves no significant difference exists (Armstrong and Overton, 1977).

4. Data Analysis and findings

The results of exploratory factor analysis are presented below.

4.1 Exploratory factor analysis

EFA is a popular technique used previously in supply chain management research. EFA is mainly used to uncover the underlying structure of a large number of variables (Osborne et al., 2008).

The KMO value is 0.87 (refer to table 3) which is above the recommended minimum value of 0.60 (Kaiser, 1974). The Bartlett's Test of Sphericity result also shows significant for the resources and capabilities considered in this study. Therefore, the listed resources and capabilities are suitable for applying EFA technique.

Table 3. KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.87
Bartlett's Test of Sphericity	Approx. Chi-Square	7308.50
	df	595
	Sig.	0,000

The rotated component matrix is presented in table 4. It indicates that 35 resources and capabilities are now grouped under nine factors. The factor loadings are above 0.50 which is acceptable in social science researches. All the eigen values are above 1.00.

Table 4. EFA results

Group	Resources and Capabilities	Items	Item Loading	Eigen values	Cumulative percentage
I	Production and Operations Capabilities	Flexible remanufacturing systems (14)	0.753	4.953	14.153
		Aided assembly (16)	0.924		
		Self-configured workstation layout (17)	0.929		
		Product and process traceability (18)	0.918		
		Assembly control system (19)	0.802		
II	Human Resource Capabilities	Training and capacity building (25)	0.547	4.350	26.582
		Empowerment of employees (27)	0.798		
		Readiness for organisational change (28)	0.883		
		Cross-functional teamwork (30)	0.888		

		Learning (32)	0.884		
III	Project Resources	Teamwork and the implementation team (1)	0.735	3.756	37.312
		Organisational culture (2)	0.844		
		Project management resources (3)	0.816		
		Top management commitment (5)	0.554		
IV	Management Capabilities	Management systems innovations and long-term investments (21)	0.791	2.866	45.500
		Strategic alignment (23)	0.508		
		Management leadership (24)	0.868		
		Managerial knowledge and presence (26)	0.529		
V	Green Team Resources	Environmental awareness (4)	0.747	2.561	52.818
		Green human resources (6)	0.677		
		Environmental knowledge of workers (8)	0.676		
		Reverse logistics resources (9)	0.606		
VI	Circularity Capabilities	Circular product design and production (12)	0.521	2.239	59.216
		End-of-life resource management (33)	0.644		
		Design for environment (34)	0.634		
		Design for remanufacture (35)	0.816		
VII	Technological Resources	IT resources (4)	0.542	2.015	64.973
		Knowledge of use of robotics in shop floor (11)	0.748		
VIII	Information Technology Capabilities	Communication ability (29)	0.839	1.971	70.605
		Information processing capability (31)	0.844		
IX	Relationship Capabilities	Supply chain relationships (15)	0.876	1.105	73.761

The resource groups that emerged from the EFA analysis are Project Resources; Green Team Resources; Technological Resources and capability groups that emerged from the EFA analysis are Production and Operations Capabilities; Human Resource Capabilities;

Management Capabilities; Circularity Capabilities; Information technology Capabilities and Relationship Capabilities.

4.2 Testing of conceptual model

The conceptual model is developed based on preceding discussion and analysis.

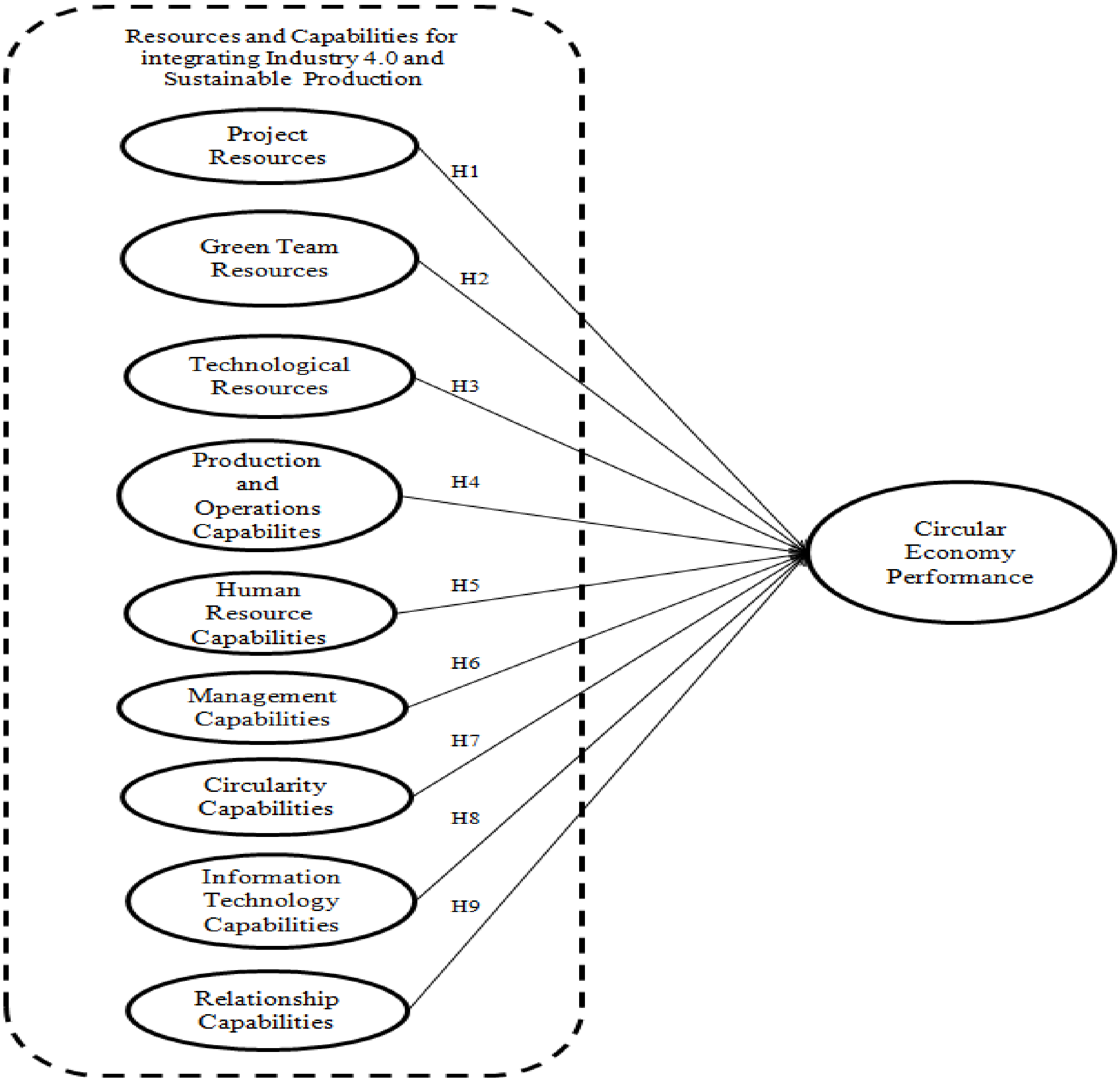

Figure 1. Conceptual Model

The discussions related to nine hypotheses are presented below:

Project resources are the resources pertaining to projects. For managing the integration of I4.0 and sustainable manufacturing related projects the key resource includes teamwork and the implementation team; organisational culture; project management resources and top management commitment (de Sousa Jabbour et al., 2018b). Without having these internal resources it is not possible to enhance CE performance.

Therefore, research team hypothesize:

H1: Project resources for integration of I4.0 and sustainable production have a positive relationship with CE performance.

The Green team resources signify the resources that need to be available to the team involved in integrating I4.0 and sustainable manufacturing. The Green team resources are environmental awareness; green human resources; environmental knowledge of workers and reverse logistics resources (Liu and bai 2014; Elia et al., 2017; Bag and Gupta 2019). These resources play a critical role in the success of CE performance.

Therefore, research team hypothesize:

H2: Green team resources for integration of I4.0 and sustainable production have a positive relationship with CE performance.

Resources such as IT resources; knowledge of use of robotics in shop floor are required to run sustainable production and unlock CE in the era of I4.0. Information technology resources involving cyber-physical systems, cloud computing, internet of things and big data management technologies are key to smart production systems. Similarly, knowledge on the operating the robots in shop floors are essential to avoid any damage and yield more productivity. Firms can use these resources to integrate I4.0 and smart production to unlock CE (Telukdarie et al., 2018; Kerin and Pham 2019).

Therefore, research team hypothesize:

H3: Technological resources for integration of I4.0 and sustainable production have a positive relationship with CE performance.

Production and operations capabilities for integration of I4.0 and sustainable production play an important role in enhancing CE performance. Capabilities like flexible remanufacturing systems; aided assembly; self-configured workstation layout; product and process traceability and assembly control system are essential to run activities such as reducing, reusing, recycling and remanufacturing. Uncertainties and risks are associated with CE models which can be overcome easily if the firm can configure the IT resources to suit the requirements. These abilities result into success of the CE based business models. (Kerin and Pham, 2019; Li et al., 2019).

Therefore, research team hypothesize:

H4: Production and operations capabilities for integration of I4.0 and sustainable production have a positive relationship with CE performance.

Human resources capabilities are the abilities of a firm to develop human resources as per the business requirements. The human resources goals are aligned with business strategies and goals. In the era of digitalisation firms having abilities like training and capacity building; empowerment of employees; readiness for organisational change; cross-functional teamwork and learning can easily adopt smart production and unlock CE. The ability to run continuous programs with the aim to upgrade manpower in this digital age can position the firm ahead of competitors. Firms that empower its employees provide more confidence to the employees to drive the digitalisation without having fear of failures. It is seen that firms that are ready for the changes embrace digital technologies for smart production to a higher degree than others. The abilities to build human resources capabilities are essential for enhancing CE performncae (Sandberg and Abrahamsson, 2011; de Sousa Jabbour et al. 2018b).

Therefore, research team hypothesize:

H5: Human resources capabilities for integration of I4.0 and sustainable production have a positive relationship with CE performance.

Literature indicates that management capabilities play a significant role in integration of I4.0 and sustainable production to open the door for CE. Management capabilities like management systems innovations and long-term investments; Strategic alignment; management leadership; and managerial knowledge and presence are the key capabilities to sustain in the CE business model (Sandberg and Abrahamsson, 2011; Liu and Bai, 2014; de Sousa Jabbour et al. 2018b).

Therefore, research team hypothesize:

H6: Management capabilities for integration of I4.0 and sustainable production have a positive relationship with CE performance.

Circularity capabilities are the abilities of a firm to perform tasks in a circular economy business model where resources stay in the system for a longer period of time. The abilities of a firm to perform circular product design and production; end-of-life resource management; design for environment and design for remanufacture can yield best output (Elia et al., 2017; Saidani et al., 2017).

Therefore, research team hypothesize:

H7: Circularity capabilities for integration of I4.0 and sustainable production have a positive relationship with CE performance.

Information technology capabilities are the ability of the firm to gather data and process the information to make quality decisions. The abilities such as communication ability; and information processing capability are key to integrate I4.0 and sustainable smart production and unlock CE (de Sousa Jabbour et al., 2018b; Gupta et al., 2019).

Therefore, research team hypothesize:

H8: Information technology capabilities for integration of I4.0 and sustainable production have a positive relationship with CE performance.

Relationship capabilities pertain to developing collaborative relationships with key stakeholders and work for a common goal. In CE business models firms achieve success if they have good business relationships with suppliers and customers (Sandberg and Abrahamsson, 2011).

Therefore, research team hypothesize:

H9: Relationship capabilities for integration of I4.0 and sustainable production have a positive relationship with CE performance.

4.3 Analysis

WarpPLS software is used to test the hypotheses. Data is cleaned and sorted before following all the five key steps in PLS–SEM analysis.

The model fit and quality indices are checked before proceeding with the path modelling.

Average path coefficient = 0.334, Average R-squared = 0.331 and Average adjusted R-squared (AARS) = 0.386 are found to be statistically significant.

The research team also checked Average block VIF = 5 and Average full collinearity VIF (AFVIF) = 4.873 which are found within acceptable limit which indicates that multicollinearity does not affect our analysis.

Tenenhaus GoF is found to be 0.30 which means a large fit of the model.

Sympson's paradox ratio (SPR) = 0.778, R-squared contribution ratio (RSCR) = 0.900, Statistical suppression ratio (SSR) = 0.709 and found within acceptable limits.

Nonlinear bivariate causality direction ratio (NLBCDR) = 0.70 which means that no endogeneity issues are present in the model.

The tested model is presented in figure 2.

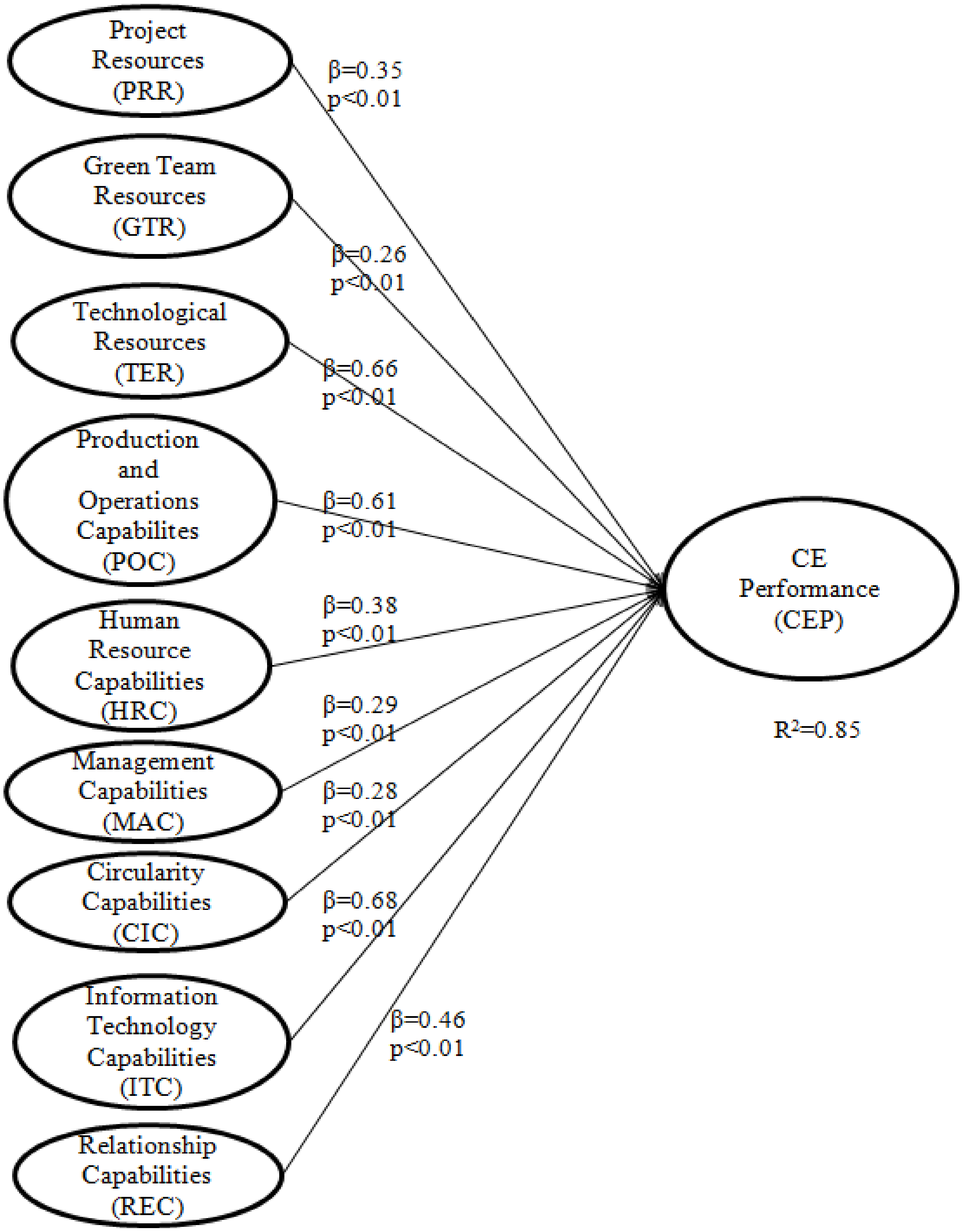

Figure 2. Tested model

5. Conclusions

The study aspires to develop a theoretical model linking Industry 4.0 and cleaner production to unlock circular economy in South Africa. Drawing upon Resource based view theory; the study aims to explore the firm resources and capabilities that are necessary to integrate Industry 4.0 technologies and sustainable manufacturing to further support circular economy performance and finally, to identify the intensity of each research and capabilities. The review of literature led to identification of thirty-five resources and capabilities that are essential for the integration of Industry 4.0 and sustainable manufacturing that will aid in unlocking circular economy. Further, exploratory factor analysis is used to group the variables under relevant factors and thereafter path modelling is performed using PLS-SEM technique. The research findings indicate that all the nine hypotheses are supported based on the data obtained from samples in South Africa. All path coefficients are found to be below 0.05 and statistically significant. Project resources, Green team resources, Technological resources, Production and operations capabilities, Human resources capabilities, Management capabilities, Circularity capabilities, Information technology capabilities, Relationship capabilities required for integration of I4.0 and sustainable production have a positive relationship with CE performance. However, the Technological resources (β=0.66), Production and Operations capabilities (β=0.61) and Circularity capabilities (β=0.68) are found to have a stronger relationship with CE performance compared to rest of the resources and capabilities. In line with the suggestion of Carmeli and Tishler, (2004) that resources and capabilities are essential for performance of industrial firms; the research team argue that resources and capabilities are essential to support integration of I4.0 and sustainable production and further enhance CE performance which is supported by prior study of Fatorachian and Kazemi, (2018) where they had established a clear link between I4.0 and smart manufacturing. Earlier, de Man and Strandhagen (2017) have opined that I4.0 can be exploited to drive sustainable business models. However, there are various challenges to I4.0 in supply chain sustainability (Luthra and Mangla, 2018) which can be overcome by understanding the relationships between resources and capabilities leading to sustainability (Paulraj, 2011). The current research findings are supported by some of the recent studies such as Cezarino et al. (2019); Chauhan et al. (2019); Daú et al., (2019); Garcia-Muiña et al. (2019); Prieto-Sandoval et al., (2019); Shivajee et al., (2019); Turner et al. (2019) which have explored the links between I4.0 and CE. However, the current study is unique as it highlights the key resources and capabilities that are essential for firms to integrate I4.0 and sustainable production and open CE opportunities.

6.1 Theoretical implications

The RBV theory suggests that resources that are precious, extraordinary, difficult to duplicate and non substitutable can bring competitive edge for the manufacturing firms. Integration of Industry 4.0 and sustainable manufacturing require a set of resources to build firm capabilities and unlock CE. The most important resources and capabilities found important in

South African context are Technological resources, Production and operations capabilities and Circularity capabilities. RBV is used in this research study to examine and understand firm's internal resources and give emphasis to critical resources in formulation strategies to achieve CE excellence. These resources are considered as key inputs to perform tasks and activities by the firm. Therefore, RBV highlighted the key resources required by firms to integrate Industry 4.0 and sustainable manufacturing by taking an "inside-out" view and stresses that firms can develop competitive advantage.

6.2 Practical implications

The key take away for managers are as under.

Focus on Technological resources, Production and Operations capabilities, Circularity capabilities, Project resources, Green team resources, Technological resources, Production and operations capabilities, Human resources capabilities, Management capabilities, Circularity capabilities, Information technology capabilities, Relationship capabilities required for integration of I4.0 and sustainable production have a positive relationship with CE performance. These are internal resources which firms develop firm's capabilities to perform critical tasks. The orchestration of these resources seems to have been underestimated in the past and led to influence the CE performance. Not all resources of the firm can help to integrate Industry 4.0 and sustainable manufacturing. The current research study therefore highlights the strategic resources and capabilities for such integration. Managers must understand the importance of each strategic resource and focus only on these resources for effective integration process and unleash CE.

6.3 Limitations

The study has been designed in a scientific manner; however, suffers from few limitations. The research topic is contemporary and literature is scarce in this area which has forced the research team to adopt exploratory study. Firms involved in heavy engineering, automobile component manufacturers, electronic parts manufacturers and castings manufacturers are only selected because Industry 4.0 and CE is relatively new in South Africa and only these sectors are practicing them. This led to low response rate. The research team cautions future researchers to interpret the findings in context to an emerging economy and further progress with exploring new areas related to this topic.

6.4 Agenda for ethical business developments

The research team provides a detailed agenda for ethical business development in this digital era; for firms practicing I4.0 and sustainable production with the aim to unlock CE.

The CE is an economic method that is being used by several manufacturers to transform the linear economy models into circular models for sustainability. In traditional linear systems the products are disposed at the end of its use. CE replaces this end-of-life concept with 'cradle to cradle' which means the product will take re-birth at the end of its life. CE business models include repair and maintenance; reuse and redistribution; refurbishment and remanufacturing; recycling; cascading and repurposing; and organic feedstock business model patterns. CE business models can eliminate the resource scarcity problems and help in creating value for the firm. Various resources and capabilities are required to drive CE business models which require high initial investment, innovations and careful monitoring to avoid any unethical practices. Many firms tend to use short-cuts and dishonest practices to do CE eye washing of customers which creates negative impact on the long run.

CE implementation takes time as the gathering of necessary resources and configuring them as per business requirement takes time and therefore firms need to be patient during this phase. CE related awareness creation among stakeholders can be helpful to eradicate unethical practices. Firms can start marketing campaigns pertaining to resource circularity and environmental thinking to promote remanufactured/recycled products and elevate customers' sustainability and ethical awareness. It is very important to bring suppliers into confidence and engage them into various research and development programs related to CE business models. Drawing up service level agreement with suppliers for any long term job will help to maintain ethics in the business transactions. It is essential to wisely use the scarce resources and avoid wastages and rejections. Penalty clause must be present in the contract to penalize suppliers for any material wastage. This will lead to a more ethical and responsible procurement practices in CE. Also focus must be given towards ethical way of profit sharing in the circular economy. CE business models will not sustain unless ethical practices are followed by all stakeholders.

Appendix I. Questionnaire

Questionnaire: I4.0, Sustainable Production and Circular Economy: An agenda for ethical business development Note: This questionnaire is for academic use only and at no point of time this data will be used for commercial usage.		
Section A.	**Our first questions are about you and your organization. Your answers will allow us to investigate whether there are differences among groups of respondents in particular roles, functions, industries, or locations.**	
	*Required	
1.	**Your Age Group***	
	20 – 30	
	31 – 40	
	41 – 50	
	51 – 60	
2.	**Your Work Experience***	
	Less than 5 years	
	6-10 years	
	11-20 years	
	Above 20 years	
3.	**What is your corporate role? ***	
	CEO/President/Owner/Managing Director	
	Chief Finance Officer	
	Chief Information Officer	
	Chief Procurement Officer	
	President/Vice President	
	Head of Business Unit or Department	
	Senior Manager	
	Junior Manager	
	Company Engineer	
	Data Analyst	
	Others	
4.	**What is your organization's primary industry? ***	
	Heavy engineering	
	Automobile component manufacturers	
	Electronic parts manufacturers	
	Castings manufacturers	
	Others	

5.	**Number of Employees in Your Company/ Institution***					
	Less than 100					
	101 - 300					
	301 - 500					
	501 - 1000					
	More than 1000					
6.	**Age of your Firm***					
	Below 10 years					
	11-20 years					
	21 - 30 years					
	Above 30 years					
SECTION B	**Significance of the resources and capabilities for integrating Industry 4.0 and environmentally-sustainable manufacturing for unlocking CE in South African Manufacturing Industry**					
I.	**Rate the following Resources and Capabilities for integrating Industry 4.0 and environmentally-sustainable manufacturing for unlocking CE on 5-point Likert scale (1- not significant, 2-somewhat significant, 3-significant, 4-very significant and 5-extremely significant) (Please tick only ONE in each row).**	**1**	**2**	**3**	**4**	**5**
1	Teamwork and the implementation team					
2	Organisational culture					
3	Project management resources					
4	IT resources					
5	Top management commitment					
6	Environmental knowledge					
7	Green human resources					
8	Environmental awareness of workers					
9	Reverse logistics resources					
10	Environmental cooperation					
11	Robotics in shop floor					
12	Circular product design and production					
13	Intelligent storage management					
14	Flexible remanufacturing systems					
15	Supply chain relationships					
16	Aided assembly					
17	Self-configured workstation layout					
18	Product and process traceability					
19	Assembly control system					
20	Cross cycle and cross sector collaboration					

21	Management systems innovations and long-term investments					
22	Inventory Control					
23	Strategic alignment					
24	Management leadership					
25	Training and capacity building					
26	Managerial knowledge and presence					
27	Empowerment of employees					
28	Readiness for organisational change					
29	Communication ability					
30	Cross-functional teamwork					
31	Information processing capability					
32	Learning					
33	End-of-life resource management					
34	Design for environment					
35	Design for remanufacture					
II.	**Rate the following CE performance at the micro level on 5-point Likert scale (1- not significant, 2-somewhat significant, 3-significant, 4-very significant and 5-extremely significant) (Please tick only ONE in each row).**	**1**	**2**	**3**	**4**	**5**
1	Reducing input and use of natural resources:					
2	Reducing emission levels					
3	Reducing valuable materials losses					
4	Increasing share of renewable and recyclable resources					
5	Increasing the value durability of products					

Thank you very much for completing this questionnaire.
If you have any comments about this questionnaire or issues involved please write them in the box given below

Table 5. Scale reliability and AVE values

Resources and Capabilities	Item No	Items	SCR	AVE
Production and Operations Capabilities (POC)	POC1	Flexible remanufacturing systems	0.895	0.634
	POC2	Aided assembly		
	POC3	Self-configured workstation layout		
	POC4	Product and process traceability		
	POC5	Assembly control system		
Human Resource Capabilities (HRC)	HRC1	Training and capacity building	0.858	0.558
	HRC2	Empowerment of employees		
	HRC3	Readiness for organisational change		
	HRC4	Cross-functional teamwork		
	HRC5	Learning		
Project Resources (PRR)	PRR1	Teamwork and the implementation team	0.738	0.515
	PRR2	Organisational culture		
	PRR3	Project management resources		
	PRR4	Top management commitment		
Management Capabilities (MAC)	MAC1	Management systems innovations and long-term investments	0.888	0.719
	MAC2	Strategic alignment		
	MAC3	Management leadership		
	MAC4	Managerial knowledge and presence		
Green Team Resources (GTR)	GTR1	Environmental knowledge	0.848	0.585
	GTR2	Green human resources		
	GTR3	Environmental awareness of workers		
	GTR4	Reverse logistics resources		
Circularity Capabilities	CIC1	Circular product design and production	0.863	0.613

(CIC)	CIC2	End-of-life resource management		
	CIC3	Design for environment		
	CIC4	Design for remanufacture		
Technological Resources (TER)	TER1	IT resources	0.929	0.867
	TER2	Knowledge of use of robotics in shop floor		
Information Technology Capabilities (ITC)	ITC1	Communication ability	0.839	0.723
	ITC2	Information processing capability		
Relationship Capabilities (REC)	REC1	Supply chain relationships	0.847	0.664
Circular Economy Performance (CEP)	CEP1	Reducing input and use of natural resources:	0.820	0.519
	CEP2	Reducing emission levels		
	CEP3	Reducing valuable materials losses		
	CEP4	Increasing share of renewable and recyclable resources		
	CEP5	Increasing the value durability of products		

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