Mapping the links between Industry 4.0, circular economy and sustainability: a systematic literature review

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Abstract

Purpose – The study aims to map the links between Industry 4.0 (I-4.0) technologies and circular economy (CE) for sustainable operations and their role to achieving the selected number of sustainable development goals (SDGs).

Design/methodology/approach – The study adopts a systematic literature review method to identify 76 primary studies that were published between January 2010 and December 2020. The authors synthesized the existing literature using Scopus database to investigate I-4.0 technologies and CE to select SDGs.

Findings – The findings of the study bridge the gap in the literature at the intersection between I-4.0 and sustainable operations in line with the regenerate, share, optimize, loop, virtualize and exchange (ReSOLVE) framework leading to CE practices. Further, the study also depicts the CE practices leading to the select SDGs ("SDG 6: Clean Water and Sanitation," "SDG 7: Affordable and Clean Energy," "SDG 9: Industry, Innovation and Infrastructure," "SDG 12: Responsible Consumption and Production" and "SDG 13: Climate Action"). The study proposes a conceptual framework based on the linkages above, which can help organizations to realign their management practices, thereby achieving specific SDGs.

Originality/value – The originality of the study is substantiated by a unique I-4.0-sustainable operations-CE-SDGs (ISOCES) framework that integrates I-4.0 and CE for sustainable development. The framework is unique, as it is based on an in-depth and systematic review of the literature that maps the links between I-4.0, CE and sustainability.

Keywords Industry 4.0, Circular economy, Sustainable development goals, Sustainable operations

Paper type Literature review

1. Introduction

Sustainability issues concerning economic, environmental and social dimensions are a major threat to organizations in the 21st century (Bag and Pretorius, 2020; Dantas *et al.*, 2021; Gupta *et al.*, 2021). It requires optimization of resources through recycling, reusing the components and products and restoration of the energy inputs for a longer duration, transforming the world's economies to be more sustainable and environment friendly (Rajput and Singh, 2019). In response, policymakers worldwide make claims about their commitment to reduce greenhouse gas emissions, global warming, address the shortage of resources and manage

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waste disposal and recycling (Dantas *et al.*, 2021; Nerini *et al.*, 2019; Zhang *et al.*, 2019). Further, governments are grappling with the need to devise rigorous environmental regulations and increase awareness about clean technologies and sustainable practices (Ambekar *et al.*, 2019). International bodies are also advocating for more stringent laws and directives that support sustainability as a prerequisite for awarding contracts as prescribed in the United Nations (UN) Agenda (Dantas *et al.*, 2021; Filippini *et al.*, 2019; Juste Ruiz, 2020; Rashed and Shah, 2020; United Nation Agenda, 2015).

In 2015, the United National General Assembly approved the "*2030 Agenda for Sustainable Development*" with a clear mandate concerning the planet, people, peace, prosperity and partnerships. The SDGs aim to eradicate poverty, protect the earth and strengthen universal peace as mentioned in 17 SDGs and 169 targets to be part of millennium development goals. These goals emphasize three sustainability dimensions: economic, social and environmental (Rodriguez-Anton *et al.*, 2019). Sustainable performance cannot be achieved holistically without digital transformations (Silvestre and Ţîrcă, 2019).

The adoption and integration of I-4.0 technologies and CE facilitates the achievement of SDGs (Hidayatno *et al.*, 2019; Saucedo-Martnez *et al.*, 2018; Dantas *et al.*, 2021; Gupta *et al.*, 2021; Rajput and Singh, 2019; Schroeder *et al.*, 2019). The importance of integrating CE practices and I-4.0 technologies has been recognized by the academic community (Govindan and Hasanagic, 2018; Pham *et al.*, 2019; Dantas *et al.*, 2021). For example, a study by de Sousa Jabbour *et al.* (2018) integrated I-4.0 and CE principles using the "ReSOLVE" framework. The ReSOLVE framework provides six action areas that enable organizations to move towards the CE (MacArthur, 2015a, b; MacArthur *et al.*, 2015), namely (1) support regenerating capacity of eco-system through reclaiming, retaining and restoring the health of ecosystems; (2) extend the life of products through creating a design for durability and upgradability; (3) removal of waste in the production and supply chain processes; (4) extract bio-chemicals from organic waste; (5) dematerialize directly or indirectly and (6) implement I-4.0 technologies [e.g. (3D) printing].

Belaud *et al.* (2019) report the benefits of combining big data and sustainability assessment for the agriculture supply chain. Verdouw *et al.* (2016) have developed reference architecture for Internet of Things (IoT)-based logistic information systems in closed loop agri-food supply chains. Rajput and Singh (2019) highlight the enablers and barriers to CE and I-4.0 in designing value chains. Chauhan *et al.* (2021) have developed a smart healthcare waste-disposal system driver of I-4.0 and CE. Therefore, emerging I-4.0 technologies can be adopted to overcome these barriers. I-4.0 is a smart technology based on a production and manufacturing system powered by information communication technology and data storage (Lasi *et al.*, 2014). However, Cwiklicki and Wojnarowska (2020) raise a concern that the connections between I-4.0 technologies and CE implementation are not well understood, creating a quandary in understanding these linkages. The motivation of this study is the increased usage of I-4.0 technologies (Schwab, 2016) and growing importance of reuse, recycling and refurbishing of input materials (CE practices) in the process of sustainable production and consumption (Khanzode *et al.*, 2021; Kirchher *et al.*, 2017). Dantas *et al.* (2021) claim that a combination of novel technologies and circular production models is critical in achieving SDGs targets.

A contribution of this study is the linking of I-4.0 technologies and CE and their application to specific SDGs through a proposed ISOCES framework. More specifically, the study aims to answer the following questions through a systematic review of literature:

(1) How will I-4.0 technologies help organizations to achieve sustainable operations?

(2) How will sustainable operations lead to CE practices?

(3) How integration of the three verticals of review, namely I-4.0-sustainable operations-CE helps in achieving select SDGs through an ISOCES framework?

The remainder of this paper is organized as follows. The theoretical background to I-4.0, CE and SDGs is presented. Next, the research methodology is outlined. Then, analysis of the links between I-4.0-SO-CE-SDGs through an ISOCES framework is discussed. Followed by contributions of the study, limitations and future research, the paper ends with a conclusion.

2. Background literature

This section presents the theoretical background essential for review. Initially, it explores the relationship between I-4.0 and CE based on the available literature. Further, it assesses the linkages between CE and SDGs.

2.1 Circular economy

CE is an economic business model based on minimizing finite consumption of limited resources by replacing the "end of life" concept and by emphasizing the design of materials, products and systems (Kirchherr *et al.*, 2017). CE aims to provide actions and practices like reuse, recycle, repair, eco-design, refurbishment, remanufacturing, recover product sharing for sustainable production and consumption (Chertow and Ehrenfeld, 2012; Ferrara *et al.*, 2014; Lombardi and Laybourn, 2012; Nasr and Thurston, 2006; Rodriguez-Anton *et al.*, 2019; Yao *et al.*, 2013). MacArthur (2015b) asserts that CE is based on three fundamental principles, namely "preserve and enhance natural capital," "optimize resource yields" and "foster systems effectiveness." The adoption of these principles can be at diverse levels, e.g. micro: relates to products and firms view; meso: corresponding to a network of companies and macro: signifies the actions undertaken by cities, regions and nations (Acerbi and Taisch, 2020; Caner and Tyler, 2015; Ghisellini *et al.*, 2016). CE is inflexibly rooted in the triple bottom line's environmental sphere that suggests a pathway to sustainable development (Athanasiadis *et al.*, 2011; Whalen *et al.*, 2018; Vinante *et al.*, 2020). CE's goal is to concentrate on businesses and economic performance, while sustainable development addresses environmental and social problems to help future generations to sustain (Kirchherr and Piscicelli, 2019). CE has received a lot of attention in recent years, with numerous reviews examining various aspects of its design and implementation. Moreover, it is also appreciated as a critical solution to the global problems because of the considerable adverse effects of the current linear economic models on our ecosystem (Kravchenko *et al.*, 2019; Rodriguez-Anton and Alonso-Almeida, 2019; Vinante *et al.*, 2020). The CE enablers have been reviewed in the domains such as textile and apparel (Jia *et al.*, 2020), procurement practices (Sonichsen and Clement, 2020), supply chains (Lahane *et al.*, 2020), product-service systems (Da Costa Fernandes *et al.*, 2020) and manufacturing (Acerbi and Taisch, 2020; Akmal and Batres, 2013).

2.2 Fourth Industrial revolution

The fourth revolution of industry started from a project of the German Government with a strategic manufacturing roadmap to promote the digitalization in 2011. The term "Industry 4.0" was publicly declared in the year 2011 at the Hannover Fair. Due to I-4.0, most manufacturing systems are supported by advance information systems (Lasi *et al.*, 2014; O'Leary, 2014). It involves smart factories and intelligent technologies to achieve better efficiency in the value chain moving from dominant machine manufacturing to digital manufacturing (Haleem and Javaid, 2019; Oztemel and Gursev, 2020; Patil *et al.*, 2020; Shrouf *et al.*, 2014; Stock and Seliger, 2016; Tiwari, 2020). I-4.0 makes use of advanced technologies to transform manufacturing systems (Formentini and Romano, 2011; Shwartz-Asher *et al.*, 2020) with digital technologies (Kang *et al.*, 2016; Pullan *et al.*, 2011). I-4.0 aims to provide real-time information on production status, energy consumption, customer orders, machines and flow of materials with the help of technologies like 3D printing, artificial intelligence (AI), Big Data, IoT and robotics that facilitate managerial decision-making (Carnabuci and Operti, 2013; de Sousa Jabbour *et al.*, 2018; Farooq, 2020; Jorro-Aragoneses *et al.*, 2019; Kyriakou *et al.*, 2017; Lin, 2014; Lu, 2017; Mareea and Belkhatirb, 2015). Previous literature lacks in agreement among researchers and practitioners about the technologies categorized under the ambit of I-4.0 (Pacchini *et al.*, 2019; Rosa *et al.*, 2020). This study refers to the most frequently cited literature to identify the most relevant technologies for I-4.0 (see Table 1). See Appendix 1 for explanation of the acronyms used in Table 1.

2.3 Linkages between Industry 4.0 and circular economy

In recent years, I-4.0 and CE continued to show rapid growth and help achieve sustainable operations through sustainable products and production/processes (see Table 1). Logistics decisions (Gunasekaran *et al.*, 2014) and integration of I-4.0 and CE help transform the linear economy into a CE-based sustainable supply chain (Geng and Doberstein, 2008; Mont, 2002). Further, the integration of supply chains through data collection and sharing helps contribute to sustainable operations management through the connection between CE and I-4.0 technologies (De Man and Strandhagen, 2017; de Sousa Jabbour *et al.*, 2018; Sauerwein *et al.*, 2019; Stock and Seliger, 2016). Table 2 indicates a detailed mapping of CE and I-4.0 with supporting references.

Existing literature highlights the strong linkage between CE and I-4.0; for example, Nascimento *et al.* (2019) suggest that I-4.0 could help reusable scrap electronic devices' circularity. Further, the impact of AI, service and policy framework establishes a strong relationship between I-4.0 and CE (Alstete and Meyer, 2020; Pradana *et al.*, 2017; Quintana-Amate *et al.*, 2015; Rajput and Singh, 2019; Vitharana *et al.*, 2012).

2.4 The role of CE and Industry 4.0 in achieving the SDGs

In 2015, the COP21 (Conference of the Parties) Paris Agreement, together with the emergence of the resolution "Transforming our World: the 2030 Agenda for Sustainable Development" (UN, 2015), put forward the essential step toward achieving sustainable, inclusive development across geographies (del Río Castro *et al.*, 2020). International affairs in the 21st century should be based on fundamental principles and the millennium development goals (Saito *et al.*, 2017; Sachs, 2012). International relationships should be built on three strong pillars of sustainable development, namely economic, social and environmental, which needs to be action oriented, indivisible, multi-disciplinary, inclusive and universally applicable (Biermann *et al.*, 2017; Cheong, 2017; Galvão *et al.*, 2018; Kanie and Biermann, 2017; Osburg and Lohrmann, 2017; del Río Castro *et al.*, 2020). The United Nations' member states have adopted SDGs to take specific actions to eradicate poverty, protect climate and ensure peace and prosperity. It comprises 17 goals, 169 targets and 231 indicators supported over five pillars (planet, people, peace, prosperity and partnerships) combined such that action in one domain helps achieve outcomes in the other (UN Development Program). According to Mohan *et al.* (2019), 11 SDGs are vital to the CE. SDGs 1, 2, 3 and 8 are socio-economic targets, while SDGs 6, 13, 14 and 15 are ecological targets. Hygienic industry and economic goals are covered by SDGs 7, 9 and 12 (Heimann, 2019). Further, Rodriguez-Anton *et al.* (2019) conducted an empirical study that reports that CE directly correlates with SDG 8, 9, 11 and 12 and has an indirect relationship with SDG 13 and 14. In contrast, Schroeder *et al.* (2019) assert that the most vital relationship between CE practices and SDGs is linked with SDG 6, 7, 8, 12 and 15; however, SDG 1, 2 and 14 do impact CE practices indirectly.

Technologies	Description	Citation sources
Internet of things	The technology enables sensors, computers and human devices to communicate wirelessly, allowing data to be accessed anywhere. It can be viewed as a highly complex and widely distributed networked system made up of many smart objects that produce and consume information	Ahuett-Garza and Kurfess (2018), Pacchini *et al.* (2019), Pang *et al.* (2015), Zhang *et al.* (2016), Jang and Yu (2017) and Schott *et al.* (2020)
Big data analytics	It deals with large quantities of structured and unstructured data from several sources for application in predictive analytics, data mining and others for which helps in effective decision-making	Gilchrist (2016), Vaidya *et al.* (2018) and Guo and Zhang (2013)
Cloud computing	It facilitates remote access by providing a quick response to data stored elsewhere and offers various services over the Internet	Zhong *et al.* (2017a, b), Pacchini *et al.* (2019), Figueroa *et al.* (2016), Divya Sahithi *et al.* (2020), Chen (2010) and Sun *et al.* (2018)
Autonomous robots	Autonomous robots are intelligent, flexible and cooperative machines that interact with each other capable of performing tasks in the world by themselves, without explicit human control	Bekey (2005) and Pacchini *et al.* (2019)
Additive manufacturing	Additive manufacturing is a disruptive innovation based on manufacturing parts of products without dedicated, sophisticated tools. It is the process of joining materials to create a 3D model from a digital design, which helps to shorten development lead times and link designers, engineers and users	Holmström *et al.* (2016), de Sousa Jabbour *et al.* (2018), Powell *et al.* (2020) and Ravichandran *et al.* (2020)
Cyber-physical systems	CPS is a technological computing system that integrates cyberspace, physical processes, sensing, controlling to communicate between machines and components in the production line. It helps collect data on production order prioritization, task optimization and identifying maintenance needs on a real-time basis that allows decision-making	Agaram (2019), Ahmadov and Helo (2018), Lee *et al.* (2015), Neethirajan *et al.* (2017), Loh *et al.* (2018), Sharpe *et al.* (2018), Moisan (2010) and Pattuelli and Miller (2015)
Augmented reality	Augmented reality is a technology that allows users to combine real and virtual worlds, interact in real-time and accurately register virtual and real objects in three dimensions. It also gives the employees real-time data to help them make better decisions and function more efficiently	Alhogail (2020), Choudhary *et al.* (2011), Vaidya *et al.* (2018), Wu *et al.* (2013) and Banda-Sayco (2020)

Table 1.
Industry 4.0 technologies

There are numerous ways to integrate I-4.0 solutions with the SDGs. For example, Bonilla *et al.* (2018) find that I 4.0 can strongly impact SDGs 7, 9, 12 and 13. Further, Modgil *et al.* (2020) suggest that I 4.0 influences SDGs 7, 8, 9, 10 and 11. Additionally, Oláh *et al.* (2020) prove that I-4.0 is a crucial technological driver for achieving the SDGs 7, 8, 12 and 13. Fatimah *et al.* (2020) argue that the use of information and communication technology (ICT) and IoT improves the efficiency and effectiveness of the waste management system covering governance, economic, social and environmental dimensions and helps achieve SDGs 3, 6, 12 and 13. Dantas *et al.* (2021)

Table 2. I-4.0 Technologies and CE practices

Circular economy practices																										Industry 4.0 Technologies														
REDS	REDU	RECO	RECY	REUS	WTE	IDS	REG	SH	L	VI	EX	CBM	REM	REE	LCM	DIS	DT	SS	REL	REEN	RET	REF	REP	REFU	REPU	IoT	CPS	CM	CC	AM	BDA	SIM	AI	ARO	ARE	RFID	BC	HPM	NAN	Supporting Reference
				√																																				Gunendran and Young (2010)
		√		√																																				Jenab and Sarfaraz (2012)
																																			√			√		Fernández-López *et al.* (2014)
				√																												√								Karray *et al.* (2014)
	√		√																							√					√									Reuter (2016)
			√	√									√																						√	√				Mircheski and Rizov (2017)
	√		√	√																										√										Singh *et al.* (2017)
																																√								Das and Das (2017)
																										√				√										Flath *et al.* (2017)
		√		√								√	√			√			√																					Lee *et al.* (2017)
																				√						√	√			√	√					√				Beier *et al.* (2018)
			√	√									√							√						√	√				√					√	√	√		Stock *et al.* (2018)
	√	√	√	√									√								√	√	√	√	√	√	√	√		√										Okorie *et al.* (2018)
							√	√	√	√	√															√	√	√		√										de Sousa Jabbour *et al.* (2018)
				√																										√										Zhang *et al.* (2018)
																																√								Alamouti and Sharafat (2018)
				√																										√										Zhao *et al.* (2018)
	√																														√									Jabbour *et al.* (2019)
	√		√	√																						√	√		√		√		√							Zhang *et al.* (2019)
			√	√																						√	√			√										Kerdlap *et al.* (2019)
	√																									√	√		√		√		√							Pham *et al.* (2019)
					√																										√									Belaud *et al.* (2019)

(continued)

Circular economy practices																										Industry 4.0 Technologies														
REDS	REDU	RECO	RECY	REUS	WTE	IDS	REG	SH	L	VI	EX	CBM	REM	REE	LCM	DIS	DT	SS	REL	REEN	RET	REF	REP	REFU	REPU	IoT	CPS	CM	CC	AM	BDA	SIM	AI	ARO	ARE	RFID	BC	HPM	NAN	Supporting Reference
					√							√		√												√	√		√	√	√	√	√	√	√		√			Rajput and Singh (2019)
			√	√																										√										Nascimento *et al.* (2019)
			√	√								√	√										√	√		√	√				√					√				Alcayaga *et al.* (2019)
	√	√	√	√																						√			√											Lin *et al.* (2019)
√	√	√	√	√	√	√																				√														Chen *et al.* (2020)
			√	√								√	√	√	√	√	√	√								√	√			√	√	√	√							Rosa *et al.* (2020)
√	√	√	√	√									√				√									√	√				√		√							Yadav *et al.* (2020)
	√		√	√									√										√			√	√		√	√	√			√	√					Abbasi and Kamal (2020)
			√										√				√		√							√	√								√					Dev *et al.* (2020)
√	√	√	√	√									√													√							√				√		√	Ramakrishna *et al.* (2020)
																√										√	√					√		√						Rocca *et al.* (2020)
																										√										√				Joannou *et al.* (2020)
																										√	√													Iglesias-Urkia *et al.* (2020)
																										√											√			Shafeeq *et al.* (2020)
			√	√								√																		√										DePalma *et al.* (2020)
			√	√								√												√		√														Kang *et al.* (2020)
			√									√							√																	√				Zhou *et al.* (2020)
	√	√	√	√									√								√	√	√	√	√	√				√			√							Bag *et al.* (2021)
												√														√	√		√	√	√				√					Dantas *et al.*(2021)

Note(s): *Circular economy practices* – REDS: redesign; REDU: reduce; RECO: recover; RECY: recycle; REUS: reuse; WTE: waste to energy; IDS: industrial Symbiosis; REG: regenerate; SH: share; L: Loop; VI: virtualize; EX: exchange; CBM: circular business models; REM: remanufacturing; REE: resource efficiency; LCM: life cycle management; DIS: disassembly; DT: digital transformation; SS: smart services; REL: reverse logistics; REEN: renewable energy; RET: rethink; REF: refuse; REP: repair; REFU: refurbish and REPU: repurpose. *I-4.0 Technologies* – IoT: Internet of Things; CPS: cyber-physical systems; CC: cloud computing; CM: cloud manufacturing; AM: additive manufacturing; BDA: big data analytics; SIM: simulation; AI: artificial intelligence; ARO: autonomous robots; ARE: augmented reality, RFID: radio frequency identification; BC: blockchain; HPM: high-performance microchips and NAN: Nanotechnology

Table 2.

establish that applying I-4.0 technologies in circular systems can support the achievement of SDGs.

3. Review methodology

This section outlines the stages adopted in the present study. The study follows the structured practices proposed by Ahmad *et al.* (2018) and Kitchenham *et al.* (2011). Figure 1 outlines the three phases and ten steps that were followed to achieve the aim of this systematic literature review.

3.1 Planning the mapping

This section of the study presents the stages 1, 2 and 3 of Figure 1. The study's primary objective is to organize and thematically analyze the literature on I-4.0 technologies, CE and selected SDGs (Ahmad *et al.*, 2018; Kitchenham *et al.*, 2011, p. 640). Therefore, the motive for conducting this review is to explore the I-4.0 technologies and CE in SDGs between 2010 and

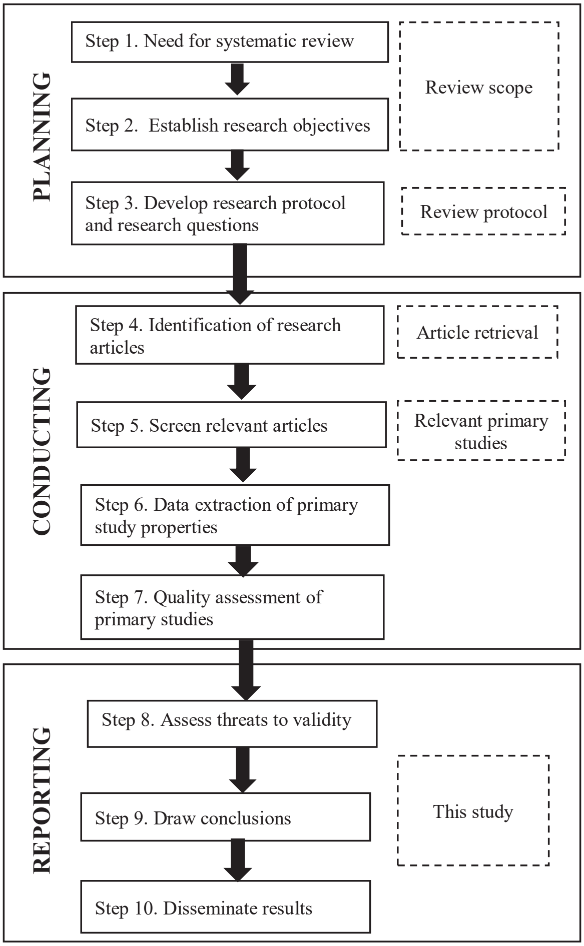

Figure 1.
Systematic literature review steps

2020 (Stage 1). The main objective of the study (Stage 2) is to (1) provide a comprehensive overview of I-4.0, CE and SDGs literature; (2) synthesize the claimed benefits of I-4.0, CE and SDGs and (3) identify opportunities for future research in the areas of I-4.0, CE and SDGs. To achieve these research objectives, the research questions stated at the end of the introduction section are answered through this study (Stage 3).

3.2 Conducting the planned mapping

This section executes the stages four, five, six and seven of the mapping procedures. In this study, a search string is developed based on the scope of the study which is confined to I-4.0, CE and SDGs. The search string presented in Table 3 is developed around the "or" and "and" operators. Scopus was used to find and shortlist 76 papers (Step 4) presented in four stages in Table 3.

The records were imported in the Microsoft excel sheet format from Scopus. The basic format includes (1) publication type, (2) title, (3) author, (4) year and (5) abstract. Further, filtration of the identified articles (Stage 5) was done on the basis of best practices of I-4.0 and CE for achieving SDGs. The article selection process is illustrated in Figure 2.

3.3 Inclusion and exclusion criteria

Articles offering empirical and non-empirical perspectives on I-4.0, CE and SDGs (e.g. systematic mapping study and systematic literature review) were selected for the review on the condition of sufficient rigor in research. The inclusion criteria used were as follows: (1) the study should be written in English; (2) the study should be published between January 2010 and December 2020; (3) the study directly answers one or more of the research questions of this study; (4) the study should clearly state its focus on I-4.0, CE and SDGs and (5) the study should describe the application of I-4.0 technologies and the approach used to study its use or implementation.

Studies were excluded if the focus was not explicitly on I-4.0, CE and SDGs or if they did not provide academic rigor or industry relevance. The exclusion criteria used were as follows:

Industry 4.0	Circular economy	UN sustainable development goals
"Industry 4.0"	"circular economy"	"UN Sustainable Development Goals"
"Internet of things"	"Circular business model"	"SDGs"
"IoT"	"Remanufacturing"	"No poverty"
"Additive manufacturing"	"Resource Recovery"	"Zero hunger"
"Smart manufacturing"	"Recycling"	"Good health and well-being"
"Cyber-Physical System"	"Reuse"	"Quality education"
"augmented reality"	"Environmental sustainability"	"Gender equality"
"3D printing"	"Sustainable supply chain"	"Clean water and sanitation"
"Knowledge based system"	"Green Logistics"	"Affordable and clean energy"
"Communication system"		"Decent work and economic growth"
"Smart Factory"		"Industry, innovation and infrastructure"
		"Reduced inequalities"
		"Sustainable cities and communities"
		"Responsible consumption and production"
		"Climate action"
		"Life below water"
		"Life on land"
		"Peace, justice and strong institutions"
		"Partnerships for the goals"

Table 3. Search string

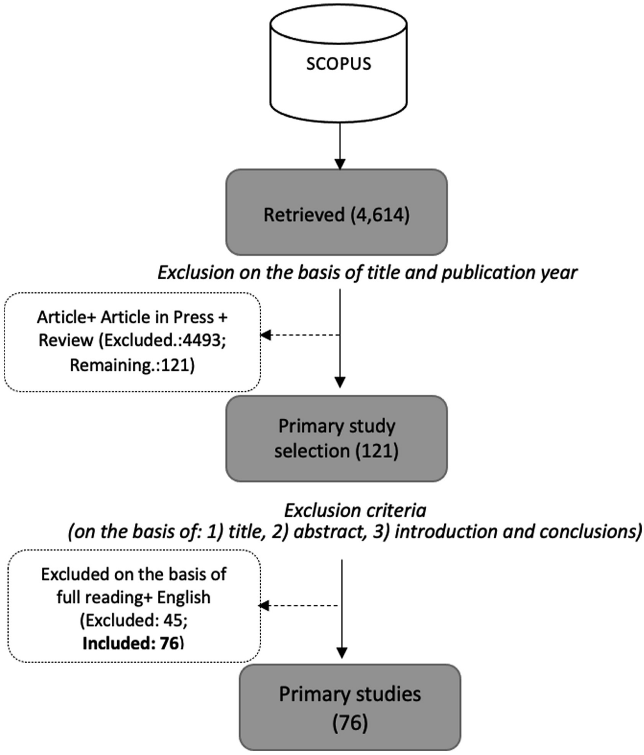

Figure 2.
Paper selection process

(1) duplicate articles, (2) not written in English, (3) studies not specifically focused on I-4.0, CE and SDGs and (4) non-peer-reviewed articles (i.e. books, book chapters and experience reports).

The search string on Scopus was used via advanced search facility. Scopus was chosen over other search engines due its wide collection and range of topics. Additionally, the choice of Scopus favors integrity in conducting research. Scopus also makes available the metrics that indicate top researchers, institutions and journals for a particular topic. The developed query was executed by two independent authors. Papers published from year 2010–2020 were considered and there was much focus on advanced technologies of I-4.0, CE and SDGs during the period as it is evident from the literature. The integrated search of three areas at first led to 4,614 articles. Further, the search was restricted only to articles, articles in press and review papers in the related domain, which resulted in 121 articles. Articles from 2021 were excluded from the shortlisted articles as the year had just started; this led to 77 articles. Each article was read, and finally, 76 articles identified as primary articles for the review [see references – primary sources by symbol *(P)].

The primary articles were analyzed based on parameters such as type of paper, methodology used, domain, publication location and relevance and rigor of the study. The primary papers were reviewed by each author and then a combined peer-review was done. In case of disagreement, input was sought from author five. Finally, the lead author, who has a broad understanding of the study, evaluated each aspect of it to ensure that the results are consistent.

Quality of the 76 primary papers was assessed against 11 criteria (Dyba and Dingsøyr, 2008). Using a binary system, each criterion was evaluated to answer the questions in Table 4.

A value of 1 indicates a "Yes" response, while a value of 0 indicates a "No" response. These 11 criteria present a measure of quality assessment for these 76 studies (see Table 5). To limit the degree of subjectivity in quality assessment, authors 1 and 2 independently reviewed the 76 articles. The outcome of these independent assessments was considered as an objective quality assessment. The results were validated by authors 3 and 4.

3.4 Results

This section presents a summary of the review carried out based on parameters such as (1) number of publications per year, (2) spread of domain and (3) publication sources (see Figure 3). The year-wise number of publications is presented in Figure 4. The trend indicates that after the announcement of SDGs in 2015, research picked up and it shows a clear rise from 2017 onward. Figure 5 indicates a considerable percentage of articles from business, management and accounting areas (29%) followed by computer science (17%) and decision sciences (16%). A total 76 research articles published in 29 journals, and year-wise publications from these journals are presented in Table A2 (see Appendix 2).

4. Analysis and findings

This section discusses the research questions and proposed framework.

4.1 Integration of technologies under I-4.0 helps organizations to achieve sustainable operations

Managing sustainable operations was conceptualized during the process of advising businesses on how to design their operations to benefit society, the economy and the environment. This involves operations starting from the concept, product design and process design, focusing on eco-friendly designs in full compliance with the three objectives of sustainable operations management (Walker *et al.*, 2014). Operations of any organization can be environmentally sustainable only when they (1) consume resources at rates that do not exceed their rate of regeneration and (2) pollute at levels that do not exceed the environment's assimilation capacity (Toffel, 2014).

Tracking the origin of sustainability in 1987, the World Commission on Environment and Development (WCED) report defines sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Previous research reported by Karlusch *et al.* (2018) and Rockström *et al.* (2009) has made an effort to tackle sustainability issues. Several scholars have looked at many aspects of I-4.0, such as real-time information sharing, modern age internet-based technology advances and their

No	Question
1	Is this a research article or is it merely "lessons learned" report based on expert opinion?
2	Is there a clear purpose of research?
3	Is the context is same with the research being carried out?
4	Was the research design adequate to address the research purpose?
5	Was the respondent selection was appropriate for conducting the research?
6	Was there a control group to compare the treatment?
7	Was data collection done in a way to address research issue?
8	Was the data analysis was rigorous enough?
9	Was the relationship among researcher and participants considered to an appropriate degree?
10	Were the findings stated clearly?
11	Whether study presents any value for research or practice?

Table 4. Quality assessment criteria

Table 5.
Quality assessment of primary papers

Code	Research	Purpose	Context	Design	Respondent selection	Control	Collection of data	Analysis	Reflexivity	Findings	Value	Overall
P1	1	1	1	1	1	0	1	1	1	1	1	1
P2	1	1	1	1	1	0	1	1	1	1	1	1
P3	1	1	1	1	1	0	1	1	1	1	1	1
P4	1	1	1	1	1	0	1	1	1	0	1	1
P5	1	1	1	1	1	0	1	1	1	1	1	1
P6	1	1	1	1	0	0	1	1	1	0	1	1
P7	1	1	1	1	1	0	1	1	1	1	1	1
P8	1	1	1	1	0	0	1	1	1	1	1	1
P9	1	1	1	1	1	0	1	0	1	1	1	1
P10	1	1	1	1	1	0	1	1	1	1	1	1
P11	1	1	1	1	0	0	1	1	1	1	1	1
P12	1	1	1	1	1	0	1	1	1	1	1	1
P13	1	1	1	1	1	0	1	1	1	1	1	1
P14	1	1	1	1	1	0	1	1	1	1	1	1
P15	1	1	1	1	1	0	1	1	1	1	1	1
P16	1	1	1	1	1	0	1	1	1	0	1	1
P17	1	1	1	1	1	0	1	1	1	0	1	1
P18	1	1	1	1	1	0	1	1	1	1	1	1
P19	1	1	1	1	1	0	1	1	1	1	1	1
P20	1	1	1	1	1	0	1	0	1	1	1	1
P21	1	1	1	1	1	0	1	1	1	1	1	1
P22	1	1	1	1	0	0	1	1	1	1	1	1
P23	1	1	1	1	1	0	1	1	1	1	1	1
P24	1	1	1	1	1	0	1	1	1	0	1	1
P25	1	1	1	1	1	0	1	1	1	1	1	1
P26	1	1	1	1	1	0	1	1	1	1	1	1
P27	1	1	1	1	1	0	1	1	1	1	1	1
P28	1	1	1	1	0	0	1	1	1	1	1	1
P29	1	1	1	1	1	0	1	1	1	1	1	1
P30	1	1	1	1	1	0	1	1	1	0	1	1
P31	1	1	1	1	1	0	1	1	1	1	1	1
P32	1	1	1	1	1	0	1	0	1	1	1	1

(continued)

Table 5.

Code	Research	Purpose	Context	Design	Respondent selection	Control	Collection of data	Analysis	Reflexivity	Findings	Value	Overall
P33	1	1	1	1	1	0	1	1	1	1	1	1
P34	1	1	1	1	1	0	1	1	1	1	1	1
P35	1	1	1	1	1	0	1	1	1	1	1	1
P36	1	1	1	1	1	0	1	1	1	1	1	1
P37	1	1	1	1	0	0	1	1	1	1	1	1
P38	1	1	1	1	1	0	1	1	1	1	1	1
P39	1	1	1	1	1	0	1	1	1	1	1	1
P40	1	1	1	1	1	0	1	1	1	1	1	1
P41	1	1	1	1	1	0	1	1	1	1	1	1
P42	1	1	1	1	1	0	1	1	1	1	1	1
P43	1	1	1	1	1	0	1	1	1	1	1	1
P44	1	1	1	1	1	0	1	1	1	1	1	1
P45	1	1	1	1	1	0	1	0	1	1	1	1
P46	1	1	1	1	1	0	1	1	1	1	1	1
P47	1	1	1	1	1	0	1	1	1	1	1	1
P48	1	1	1	1	1	0	1	1	1	1	1	1
P49	1	1	1	1	1	0	1	1	1	1	1	1
P50	1	1	1	1	1	0	1	1	1	1	1	1
P51	1	1	1	1	1	0	1	1	1	1	1	1
P52	1	1	1	1	1	0	1	1	1	1	1	1
P53	1	1	1	1	1	0	1	1	1	0	1	1
P54	1	1	1	1	1	0	1	1	1	1	1	1
P55	1	1	1	1	1	0	1	0	1	1	1	1
P56	1	1	1	1	1	0	1	1	1	1	1	1
P57	1	1	1	1	1	0	1	1	1	1	1	1
P58	1	1	1	1	1	0	1	1	1	1	1	1
P59	1	1	1	1	1	0	1	1	1	0	1	1
P60	1	1	1	1	1	0	1	1	1	0	1	1
P61	1	1	1	1	1	0	1	1	1	1	1	1
P62	1	1	1	1	1	0	1	1	1	1	1	1
P63	1	1	1	1	1	0	1	1	1	1	1	1
P64	1	1	1	1	1	0	1	1	1	1	1	1

(continued)

Table 5.

Code	Research	Purpose	Context	Design	Respondent selection	Control	Collection of data	Analysis	Reflexivity	Findings	Value	Overall
P65	1	1	1	1	1	0	1	1	1	1	1	1
P66	1	1	1	1	1	0	1	1	1	1	1	1
P67	1	1	1	1	0	0	1	1	1	1	1	1
P68	1	1	1	1	1	0	1	0	1	1	1	1
P69	1	1	1	1	1	0	1	1	1	1	1	1
P70	1	1	1	1	1	0	1	1	1	1	1	1
P71	1	1	1	1	1	0	1	1	1	0	1	1
P72	1	1	1	1	1	0	1	1	1	1	1	1
P73	1	1	1	1	1	0	1	1	1	1	1	1
P74	1	1	1	1	1	0	1	1	1	1	1	1
P75	1	1	1	1	1	0	1	1	1	1	1	1
P76	1	1	1	1	1	0	1	1	1	1	1	1

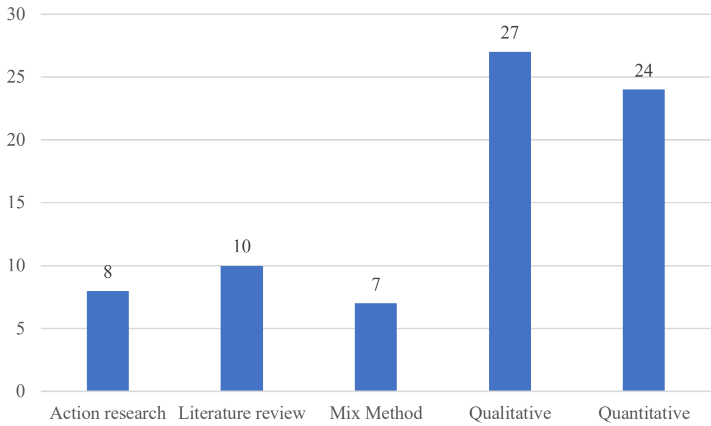

Figure 3. Mapping of research methods in primary articles

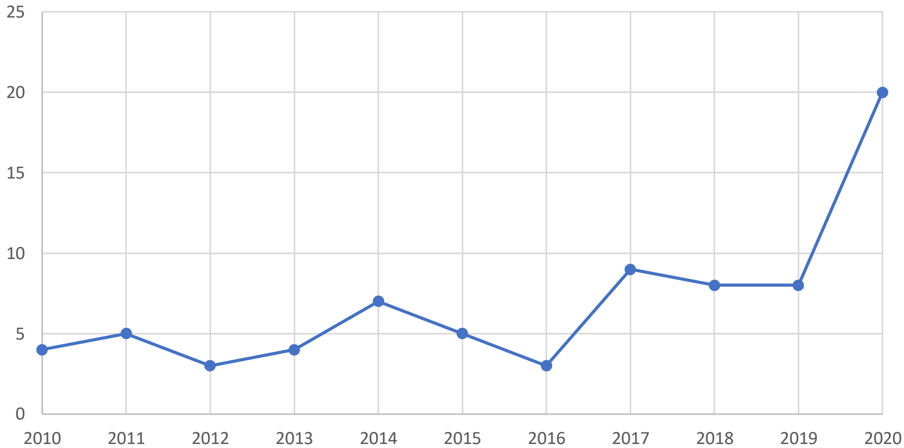

Figure 4. Publications per year

usefulness, product/service distribution speed with decreased errors at no extra expense and so on (Pacheco *et al.*, 2016; Thoben *et al.*, 2017; Zhong *et al.*, 2017a, b). Bernon *et al.* (2018) present an exploratory framework that aligns reverse logistics activities in the retail sector with CE principles. It can be viewed as a link between CE and long-term sustainability. Ellen MacArthur Foundation (MacArthur, 2015a, b; MacArthur *et al.*, 2015) has created a vision based on designing out "waste and pollution," keeping products and materials in use and regenerate natural systems. Firms' operations driving profitability and their linkage with people and the planet at large are increasingly connected to sustainability (Kleindorfer *et al.*, 2005).

The ReSOLVE framework proposed by MacArthur (2015b) includes **Re**generate – all operations with a focus on earth's biocapacity; **S**hare – sharing the total utility of resources, thereby eliminating wastage and duplication; **O**ptimize – operations involving wastage of energy and materials and shall use technologies to maximize resource usage; **L**oop – reuse/recycle/re-manufacture of the products, thereby looping them back into the economy before

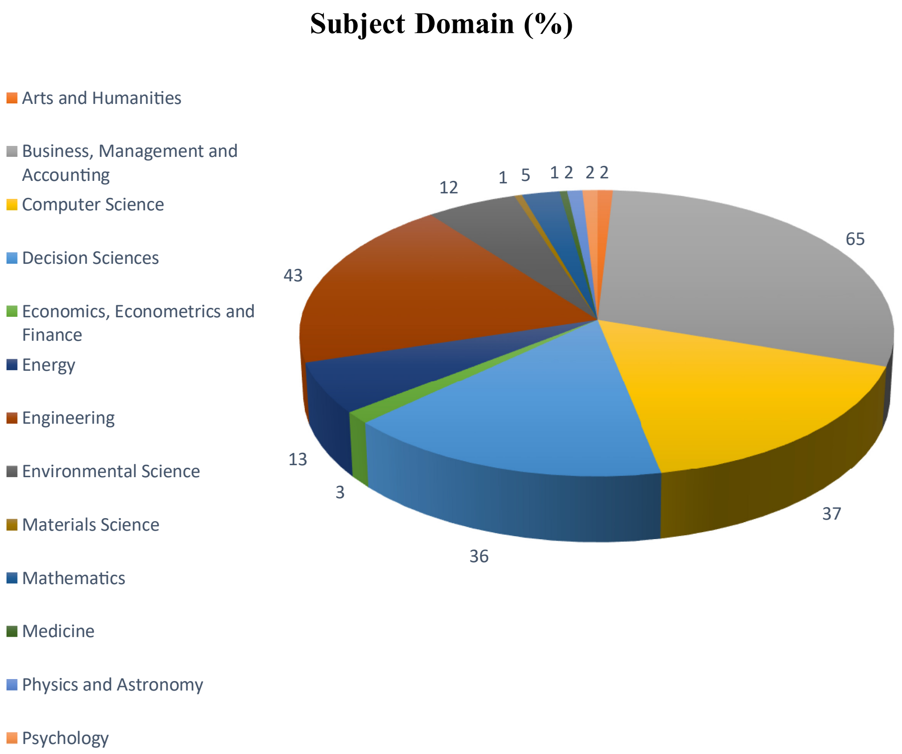

Figure 5.
Publications by subject domain

they are released for landfill; **V**irtualize – participation in virtualization of the economy using more technologies and **E**xchange – allowing operations for using or upgrading new technologies for completing the existing processes.

de Sousa Jabbour *et al.* (2018), in their study, have integrated I-4.0 and CE principles using the ReSOLVE model by MacArthur (2015b) in which all the phases are benefited by the components of I-4.0 (CPS, IoT, cloud computing and Big Data). Regenerate – IoT under I-4.0 creates real-time data of certain operations, helping production decisions resulting in sustainable operations, i.e. reducing wastages in resource usage, thereby supporting the earth's regenerating capacity of resources. Share – Technologies under I-4.0 increase manufacturing productivity via connected devices and a rapid interchange of information, resulting in a shift in economics (Rüßmann *et al.*, 2015). Optimize – I-4.0, according to Hofmann and Rüsch (2017), will aid in greatly customized production, real-time coordination and optimization of supply chains, as well as the elimination of complexity costs. This will result in the reduction of waste of resources. Loop – according to Despeisse *et al.* (2017), additive manufacturing (AM), IoT and new materials under I-4.0 are accelerating the industry's landscape in many ways. Another advantage of AM, according to Matsumoto *et al.* (2016), is the potential to apply a new material to existing surfaces to restore and remanufacture used and worn parts and components. Gao *et al.* (2015) have identified another benefit of AM that it will support remanufacturing of products independent of the value chain. Virtualize – As "digital twin" delineates mirroring product to virtual space reproduction, these data generated from several IoT sensors is transmitted to a virtual replica of the system, creating a digital twin covering the entire production process. This term originally referred to the act of mirroring a product. Simultaneously, it enables processes (manufacturing, electricity storage, etc.) to facilitate virtual space reproduction (twinning) to reap the same benefits (Stock *et al.*, 2018). Exchange – Autonomation of systems under I-4.0 are replacing the passive manufacturing systems (Stock *et al.*, 2018). The present study also depicts the mapping of the ReSOLVE framework (MacArthur, 2015a, b; MacArthur *et al.*, 2015) with the I-4.0 technologies and helps identify the interdependencies of I-4.0 and sustainable operations resulting in CE.

4.2 Integration of sustainable operations leads to CE practices

Smol *et al.* (2020) have developed a CE model framework in the water and wastewater sector, consisting of two additional aspects, "removal of pollutants" and "rethink," to introduce systematic changes in the whole value chain. This part of CE practices has achieved target 6.3 (UN, 2015), supporting the SDG 6 to ensure availability of clean water and sanitation. Further, Taskhiri *et al.* (2014), in their study, developed an optimal waste-to-energy (WTE) network model for generation of energy through waste incineration, especially in eco-industrial parks (EIPs), resulting in heat recovery from industrial processes and industrial waste. This will help improve the industries' energy efficiency linking to Target 7.3 (see, UN, 2015). According to the "European Environment Agency (EEA) (EEA, 2016, 9)," the CE as *"The concept can, in principle, be applied to all kinds of natural resources, including biotic and abiotic materials, water, and land. Eco-design, repair, reuse, refurbishment, remanufacture, product sharing, waste prevention, and waste recycling are all important in a CE."* Practices of CE will result in retrofitting industries, thereby enabling them to be more efficient in reusing, remanufacturing and reducing the waste of resources, linking to the Target 9.4 (see, UN, 2015). Additionally, Gheewala and Silalertruksa (2021) report that if more products can be produced from the same volume of raw materials and energy, then the production process would result in "cleaner production" and low levels of waste generation. CE practices of reducing wastage of virgin materials result in sustainable consumption and production linking to Target 12.2 (see, UN, 2015). Moreover, Toffel (2014) argue that sustainable operations pollute at levels that do not exceed the environment's assimilation capacity. Reduced pollution levels result in a reduced impact on the climate, reducing climate-related hazards and natural disasters, linking to Target 13.1. This study establishes that sustainable operations result in CE practices.

4.3 Linking I-4.0, sustainable operations and CE practices to specific SDGs

This study proposes a unique framework (see Figure 6) depicting a strong linkage among I-4.0, CE practices through sustainable operations and select SDGs. It is observed that the select technologies under I-4.0, namely IoT and AM, etc. support the objective of the ReSOLVE model leading to sustainability of operations leading to CE. Schroeder *et al.* (2019) find linkages between sustainability and CE, analyzing CE practices with a focus on the SDGs. Their study explores the relevance of CE practices for implementing the SDGs in the context of developing countries and links CE practices with select SDGs for establishing strong linkages between CE and SDGs. This study also depicts the CE practices resulting in select SDGs ("SDG 6: clean water and sanitation," "SDG 7: affordable and clean energy," "SDG 9: industry, innovation and infrastructure," "SDG 12: responsible consumption and production" and "SDG 13: climate action").

4.4 ISOCES framework

The study comprises a systematic literature review of selected articles indexed in Scopus for identifying the linkages between I-4.0 technologies and CE. I-4.0 and CE are the critical

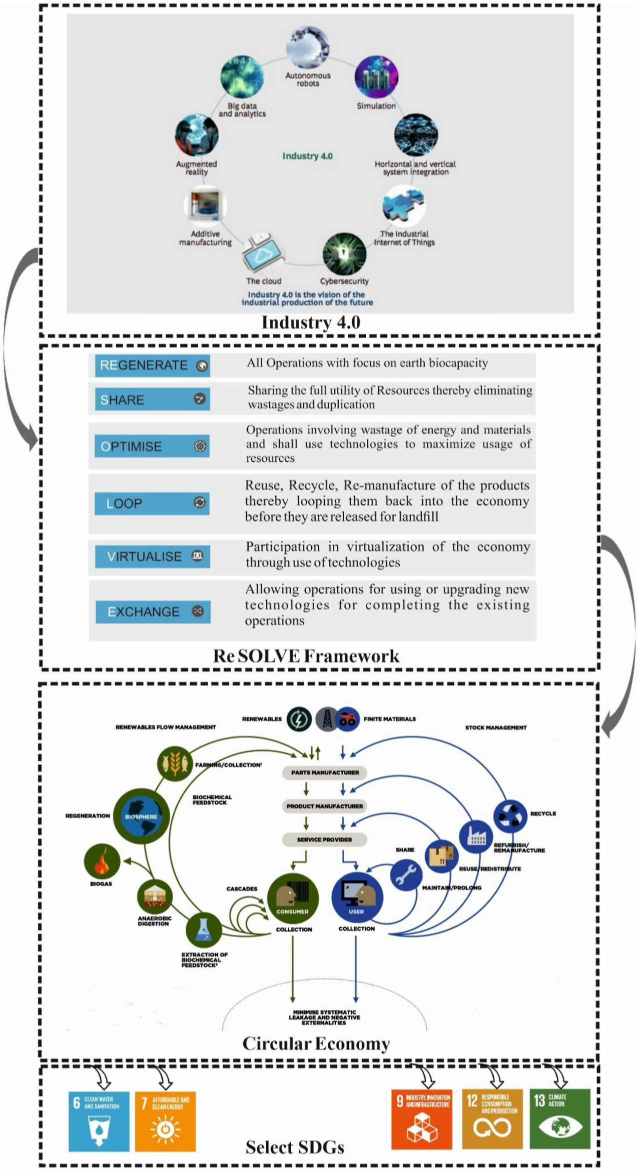

Figure 6.
ISOCES framework

dimensions in recent years driving industry and academia (Alcayaga *et al.*, 2019; Rosa *et al.*, 2020; Suárez-Eiroa *et al.*, 2019). An organization's sustainable operations are environmentally friendly when resource consumption exceeds resource regeneration and pollution does not exceed the environment's ability to absorb pollution (Toffel, 2014). I-4.0 involves a group of technologies like "IoT," "simulation,", "Internet of Service (IoS)," "cloud-based manufacturing," "big data analytics," "radio frequency identification (RFID)" focused on the digital transformation and interconnection across all production units in a given economic system

(Aulawi and Amin, 2019; Cai *et al.*, 2014; Lasi *et al.*, 2014; Lin *et al.*, 2011; Nascimento *et al.*, 2019; Pacchini *et al.*, 2019; Rezaee *et al.*, 2017; Wilson *et al.*, 2020). These technologies provide knowledge on machines, production and flow of material, integrating the information that helps in effective managerial decision-making and organizational competitiveness (Agaram, 2019; Lu, 2017; Meski *et al.*, 2020; Romano *et al.*, 2010; Tan *et al.*, 2012; Sanya and Shehab, 2014; Zablith *et al.*, 2016). The adoption of I-4.0 supports the usage of renewable energy and raw material to retain and restore the health of ecosystem and biosphere. Further, the I-4.0 adoption advocates the reuse and enhances maintainability and durability of resources which can be shared across business functions and even between organizations. The waste in the supply chain can be optimized through automation and big data analytics by adopting modern technologies. The recycling and extracting of biochemicals from organic waste can develop a closed loop system. In a closed loop system, organizations can cut-short the supply chain by reaching out to customer and virtualizing subscription-based models along with applying and exchanging the old system of manufacturing with technologies such as 3D printing. Hence, the study proposes as follows:

Proposition 1. I-4.0 technologies can facilitate in achieving the objectives of the ReSOLVE framework.

CE is a new business model that replaces the "end of life concept" with reuse and eliminates waste organizations through better material design, assisting society in moving toward sustainable development (MacArthur, 2013; McDowall *et al.*, 2017; Okorie *et al.*, 2018; Powell *et al.*, 2020). CE offers organizations innovative ways to minimize resource usage, waste management through disposal and recycling, leading to sustainable production and consumption (de Sousa Jabbour *et al.*, 2018; Dantas *et al.*, 2021). It provides economic, environmental and social benefits through a circular approach to energy and materials (Geissdoerfer *et al.*, 2017; 2018). Countries like China, Japan and some European countries have implemented incentives related regulations to promote CE practices (de Sousa Jabbour *et al.*, 2018; Ghisellini *et al.*, 2016). This study has identified linkages between the adoption of I-4.0 and sustainable operations supported by the ReSOLVE framework (de Sousa Jabbour *et al.*, 2018). The elements of the ReSOLVE framework focus on transforming our throwaway economy into one where waste is eliminated to the maximum; resources are fully circulated and nature is regenerated. In a way, the components of ReSOLVE facilitate to tackle the climate change and loss of biodiversity while fulfilling social needs. In short, the ReSOLVE framework offers opportunities to create more jobs, resilience and prosperity while reducing the greenhouse gas emissions, pollution and waste. Hence, the study proposes as follows:

Proposition 2. The elements of the ReSOLVE framework are essential to achieve circular economy in most of aspects.

Past literature highlights the significant barriers like a lack of awareness about a product's life cycle, inadequacy of advanced technologies for cleaner production and uncertainty about costs, returns on investments and implementation timelines in the overall adoption of CE in an organization and across value chains (Geng and Doberstein, 2008; de Sousa Jabbour *et al.*, 2018; Su *et al.*, 2013). The practices and models of CE have a direct impact on a few SDGs. For instance, the focus on regenerating the biosphere can ensure the availability of water and sanitation for all. Additionally, focus on renewables and renewables flow management can help in future to have access to clean, reliable and sustainable energy. The activities related to recycling and remanufacturing of CE impact the sustainable industrialization and lead to innovative ideas in that direction. Sharing and enhancing the use of products can have an impact on consumption and production patterns, which can help to address a variety of environment challenges. The integration of novel technologies, namely I-4.0 and circular business models are critical in achieving the select SDGs (Dantas *et al.*, 2021). Therefore, the study proposes as follows:

Proposition 3. The CE practices have a direct influence on select 6, 7, 9, 12 and 13 SDGs.

This study is unique as it strengthens and extends the connections between I-4.0 technologies and CE and leading to the achievement of select SDGs. It is the first study to conduct an in-depth and systematic review of the literature and mapping the links across I-4.0, CE and sustainability.

5. Contributions of the study

This study contributes to the body of knowledge on I-4.0, sustainable operations and CE mapping the linkages to specific SDGs by:

(1) Creating an original conceptualization of strong linkages between the adoption of I-4.0 technologies and sustainable operations. This study highlights the role of AM, IoT, real-time monitoring in advancing their business operations in multiple ways (Rezaee *et al.*, 2017; Verdouw *et al.*, 2018; Wu *et al.*, 2020; Zhao *et al.*, 2018). This can help management to identify and re-examine the suitable technologies under I-4.0 to implement the CE practices within their organizations.

(2) Developing a theoretical understanding of sustainable operations, resulting in CE practices. The systematic literature review has helped in the identification of strong linkage between the adoption of select technologies under I-4.0 and CE's sustainable operations and practices, depicting a vital role in adopting I-4.0 in the context to CE's sustainable operations environment (Carnabuci and Operti, 2013; DePalma *et al.*, 2020).

(3) Deriving an integrated framework for linking the practices of CE practices to select SDGs, namely "SDG 6: clean water and sanitation," "SDG 7: affordable and clean energy," "SDG 9: industry, innovation and infrastructure," "SDG 12: responsible consumption and production," and "SDG 13: climate action." It is in line with the guidelines of SDGs suggested by the UN Developmental Program (Galvão *et al.*, 2018; Verdouw *et al.*, 2018; Zhou *et al.*, 2020).

(4) It identifies that there are implications related to re-aligning an organization's management practices with the proposed framework may contribute positively to the resultant sustainable operations, thereby achieving the select SDGs.

6. Limitations and future research

As with all research, this study has limitations, which also offer directions for future research. First, the data were collected from journal articles and literature published in the Scopus database, excluding conference publications and books. Some relevant databases remained outside the study's scope; therefore, future studies may collect data from other databases like Web of Science, Proquest, EbscoHost, or individual search engines like Google Scholar to analyze more studies leading to different conceptualizations. Moreover, the data collected with some specific keywords from the Scopus database were limited to research published in the English language only. Future research may use different keywords and studies published in other languages for more comprehensive results. The framework presented in this study is purely based on existing and published literature. Therefore, there is a need for substantial empirical work through a large-scale survey or a case study for statistical validation of the proposed framework. Future studies could test the propositions to validate their linkage. Additionally, the future research may include in-depth analysis of specific aspects of and linkage between CE and the SDGs while selecting more or all SDGs to extend and build on this exploratory review.

7. Conclusion

This study aimed to bridge a gap in the literature at the intersection between I-4.0 and sustainable operations in line with the ReSOLVE framework proposed by MacArthur (2015b), leading to CE practices and select SDGs. The literature review recognized 76 published articles and conceptual models related to this study's research theme, using systematic review methodology. Several models were scrutinized in terms of their components and relationships, resulting in a concise ISOCES framework. Further, the study has identified the relationship between sustainable operations and CE practices like reducing wastages in resource usage and remanufacturing of products. Finally, the study also depicted the CE practices resulting in select SDGs ("SDG 6: clean water and sanitation," "SDG 7: affordable and clean energy," "SDG 9: industry, innovation and infrastructure," "SDG 12: responsible consumption and production," and "SDG 13: climate action"). The proposed ISOCES framework herein represents the first attempt to "an in-depth and systematic review of the literature" integrating I-4.0, CE and SDGs to map the linkages among them.

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Further reading

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Appendix 1

Table A1.
Abbreviations

I-4.0 Technologies	CE practices
• IoT: Internet of Things • CPS: Cyber-physical systems • CC: Cloud computing • CM: Cloud manufacturing • AM: Additive manufacturing • BDA: Big data analytics • SIM: Simulation • AI: Artificial intelligence • ARO: autonomous robots • ARE: augmented reality • RFID: • BC: Blockchain • HPM: High-performance microchips • NAN: Nanotechnology	• REDS: Redesign • REDU: Reduce • RECO: Recover • RECY: Recycle • REUS: Reuse • WTE: Waste to energy • IDS: Industrial symbiosis • REG: Regenerate • SH: Share • L: Loop • VI: Virtualize • EX: Exchange • CBM: Circular business models • REM: Remanufacturing • REE: Resource efficiency • LCM: Life cycle management • DIS: Disassembly • DT: Digital transformation • SS: Smart services • REL: Reverse logistics • REEN: Renewable energy • RET: Rethink • REF: Refuse • REP: Repair • REFU: Refurbish • REPU: Repurpose

Appendix 2

Journal Title	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Advances in Science, Technology and Engineering Systems										1	1	2
Advances in Technology Innovation											1	1
Business Process Management Journal							1					1
Decision Support Systems	1				1							2
Digital Signal Processing: A Review Journal											1	1
Engineering Economics											1	1
Enterprise Information Systems						1			1			2
IEEE Communications Standards Magazine									1			1
IEEE Transactions on Engineering Management											1	1
IET Networks								1				1
Industrial Management and Data Systems										1		1
Information and Management			1									1
International Journal of Applied Systemic Studies		1										1
International Journal of Business and Management Science								1				1
International Journal of Computer Information Systems and Industrial Management Applications								1				1
International Journal of Enterprise Information Systems			1									1
International Journal of Healthcare Information Systems and Informatics								1				1
International Journal of Innovation Science										1		1
International Journal of Intelligent Information Technologies	1											1
International Journal of Precision Engineering and Manufacturing								1				1
International Journal of Production Economics		1										1
International Journal of Production Research	2	2		1	1				1		1	8
International Journal of Scientific and Technology Research										1	3	4
Journal of Advanced Manufacturing Technology									1			1
Journal of Civil Engineering and Management					1							1
Journal of Cleaner Production								1	3	2	5	11
Journal of Decision Systems					1							1
Journal of Information Technology								1				1
Journal of Japan Industrial Management Association				1								1
Journal of Knowledge Management						1						1
Journal of Management in Engineering			1									1

(*continued*)

Table A2.
Publications by year

Table A2.

Journal Title	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Journal of Manufacturing Technology Management		1								1	1	3
Journal of Product Innovation Management						1						1
Knowledge-Based Systems				1	3	2	1			1		8
MIS Quarterly								1				1
Personal and Ubiquitous Computing							1		1		1	3
Strategic Management Journal				1								1
Systems											1	1
Technology in Society											1	1
TEM Journal								1				1
VINE Journal of Information and Knowledge Management Systems											2	2
Total	4	5	3	4	7	5	3	9	8	8	20	76

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