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Sustainable strategic investment decision-making practices in UK companies: The influence of governance mechanisms on synergy between industry 4.0 and circular economy

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ABSTRACT

Prior studies articulate the growing synergy between Industry 4.0 (I4.0) technologies and CE techniques. However, the literature lacks empirical evidence regarding boardrooms' commitment to implementing these technological domains through sustainable strategic investment decision-making practices (SSIDMP). This paper uses computer-aided textual analysis to explore the current trend of SSIDMP in UK companies. Our debate draws on data from UK companies, FTSEE ALL Share, over the period (2012−2021). We develop proxies for I4.0 technologies and CE techniques to examine the synergy between I4.0 technologies and CE techniques and the influence of this synergy on companies' financial performance. The findings reveal the vital role the organizational ambidexterity plays in the synergy between I4.0 technologies and CE techniques through exploring and exploiting technological techniques and mechanisms to cope with changing business environment. Our empirical study explores the impact of governance mechanisms on the relationships between SSIDMP, I4.0 technologies, CE techniques, and companies' financial performance. Findings support that synergy between these two domains is the key determinant of sustainable value creation and sustainable organizational performance. The synergy between I4.0 technologies and CE techniques significantly impact SSIDMP and companies' financial performance, though the level of the synergy varies according to industry sectors. Furthermore, our analysis shows that governance mechanisms (ESG, board compositions, risk management, internal audit) strengthen the relationships between these two domains and companies' performance.

1. Introduction

The concepts underpinning CE support a practical approach toward the utilization of finite natural resources sustainably (de Sousa Jabbour et al., 2018a). Integrating I4.0 technologies and CE techniques has received significant attention from scholars and practitioners. Industry 4.0 (I4.0) and CE are the two major trends in the current business model transformation (Dev et al., 2020; Rosa et al., 2020; Belhadi et al., 2022). The fourth industrial revolution, known as Industry 4.0, and its applications in the manufacturing sector ushered in a new era for business entities. It not only promises enhancement in operational efficiency but also focuses on designing and reengineering sustainable operations practices. Reports establish the growing interest in integrating the sustainability dimension in I4.0 paradigms, extending the support to CE implementation (Sharma et al., 2020; Rosa et al., 2020).

Recently, studies demand effective synergies between I4.0 and CE techniques with systematic assessment support (Belhadi et al., 2022). Using a dynamic capabilities perspective, they develop a self-assessment model to evaluate the systematic level of I4.0 technologies and CE techniques within organizations. From a sustainability perspective, I4.0 technologies could bring incremental impacts to a linear economy toward CE. I4.0 technologies have significant potential to support decision-making processes and business model transformation toward CE. Exchanging real-time lifecycle information supports the business model transformation toward CE and fosters a sustainable culture via benchmarking and collaboration (see Rosa et al., 2020; Dev et al., 2020;

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Kamble et al., 2020; Belhadi et al., 2022). Based on a systematic literature review, Sahu et al. (2022) stated that little attention has been directed to research integrating these two domains. The findings of their study reveal that I4.0 technologies, including digitalization, real-time monitoring, and decision-making capabilities, played a significant role in CE technique implementation. Synergies and interrelationships created from internal and external organizational resources build up companies' innovation capabilities (Radicic and Alkaraan, 2022). Based on a comprehensive literature review, Agrawal et al. (2021a) point out that effective integrated implementation of these two domains improves the design of products and services, focusing on reducing the wastage of material and energy. CE techniques enable consumers to return products after use and reuse the product with more value.

Brand image, regulatory compliance, investment efficiency, and competitive advantage through product/process innovations are significant factors associated with sustainable strategic investment decision-making practices (SSIDMP) (Alkaraan, 2022). Global warming has many environmental impacts, such as land degradation, degradation of deserts, and food insecurities. Many international initiatives have been launched to reduce climate change through SSIDMP, including fossil fuel divestment and reinvestment in renewable energy systems, mainly in the United States and the United Kingdom (Hestres and Hopke, 2020). Dedicated stakeholders drive this movement of divestment and reinvestment as a commitment to SDGs. This includes investment in renewable energy and cleaner production manufacturing processes. I4.0 technologies leverage CE techniques and enable companies to contribute to SDGs, including sustainable societies. Boardrooms' commitments regarding environmental, social, and governance (ESG) issues can be viewed as critical factors influencing the strategic investment decisions of individual and institutional investors. Boardrooms' responsibilities regarding strategic choices are articulated as fundamental principles underpinning directors' duties (section 172, UK Companies Act 2006). SSIDMP, grounded with integrated mechanisms of I4.0 technologies and CE techniques enables companies to achieve resource efficiency by reducing energy and resource usage. Effective integration of I4.0 technologies and CE techniques would allow companies to provide Triple Bottom Line (TBL) environmental, social and economic benefits (Agrawal et al., 2021b; de Sousa Jabbour et al., 2019) through strategic choices embedded in SSIDMP at boardrooms as a materialization of their commitments to SDGs including sustainable societies. Successful integration of I4.0 technologies and CE techniques enables companies to redesign value creation structure, achieve desired outcomes of their SSIDMP and accelerate the processes toward sustainable business models and SDGs. In recent years, the business architecture of value creation has been subjected to a significant transformation due to the rapid progress of digital technologies and huge volumes of data that new intelligent devices and their applications toward CE. I4.0 technologies and CE techniques significantly impact SSIDMP, including scanning and screening investment opportunities, product, and process innovation, strengthening organizational resource control mechanisms, and improving investment efficiency.

The recent call for new studies urges researchers to study the synergy between I4.0 technologies and CE techniques and their influence on organizational performance in different contexts and settings (Vial, 2019; Kunkel and Matthess, 2020; Verhoef et al., 2021; Alkaraan et al., 2022). However, to our knowledge, the literature lacks research evidence based on empirical analysis and narrative disclosure measurement regarding the synergy between I4.0 technologies and CE techniques and their impacts on organizational performance. Further, it is crucial to explore the influence of governance mechanisms and boardrooms' commitment to implementing these two domains in their SSIDMP. Accordingly, this paper endeavors to address the following two questions:

RQ1. Does synergy between I4.0 technologies and CE techniques leverage companies' financial performance?

RQ2. Do corporate governance mechanisms strengthen the synergy between I4.0 technologies and CE techniques?

The study uses a novel approach and computer-aided textual analysis to examine the synergy between I4.0 technologies and CE techniques and narrative disclosure of SSIDMP in UK companies. The specific attention of this study is to study the influence of governance mechanisms on the synergy between I4.0 technologies and CE techniques. We use a computer-aided textual analysis to answer the research questions underpinning this study. This evolving paradigm helps examine large-volume texts to identify and analyze the linguistic features of documents. We conduct an empirical analysis to examine the trend of synergy between I4.0 technologies and CE techniques over time (2021−2021) and across the industry sector. Besides, to show the trend of relationships between these new disclosure types and benefits associated with SSIDMP. Further, we have supported our debate and results of data analysis using extracts from companies' annual reports of different sectors.

The UK provides a unique context to this study for many reasons. First, in 2013, a long-term action plan for the manufacturing industry in the UK called the 'Future of Manufacturing' was implemented. Second, to sustain itself, the manufacturing industry will need to develop novel processes, innovations, and methods to meet demanding sustainability targets and create new economic growth. Government strategies primarily drive guidelines for integrating I4.0 technologies with CE techniques, including minimizing material inputs, waste management, reduced water usage, energy efficiency, low-carbon technologies, supply chains with spare capacity, material that is not land-filled but engaged in productive loops, and less material consuming products and are close to consumers (see Foresight, 2013).

Our conceptual framework and results offer important managerial and theoretical implications. First, we develop a new measure of I4.0 technologies and CE techniques disclosure, a pioneering attempt in the manufacturing literature to the best of our knowledge. Second, we provide new empirical evidence regarding the synergy between I4.0 technologies and CE techniques and the influence of this synergy on SSIDMP and companies' financial performance. Third, we examine how governance mechanisms influence these relationships. We find they moderate the relationships between I4.0 technologies, CE techniques, SSIDMP, and companies' financial performance. Our findings offer insights into organizational ambidexterity's vital role in the synergy between I4.0 technologies and CE techniques. An ambidextrous organization requires mobilization, integration, and coordination of organizational resources to maintain exploitation and exploration to achieve successful outcomes of SSIDMP. The findings of this study have important managerial implications regarding the influence of the synergy between these two domains on value creation and realization and their potential economic, ecological, and social consequences for SDGs.

The remainder of the paper is structured as follows. Section 2 reviews the literature and highlights the underlying study rationale, including hypotheses development. Section 3 outlines the research methodology. Section 4 presents the findings of this study. Section 5 concludes the paper with limitations and future scope.

2. Literature and hypotheses development

2.1. SSIDMP: synergy between I4.0 technologies and CE techniques

A new era of strategic investment decisions in UK companies is emerging, characterized by the synergy between I4.0 technologies and CE techniques. It unlocks new strategies and influences strategic thinking in boardrooms' commitment and including oversight and support and a full-integrated organizational structure, sales, logistics, marketing, production, development, design, supply management, finance, human resources, and legal functions (see de Sousa Jabbour et al., 2018a, 2018b; Jabbour et al., 2019; Mardani et al., 2020; Maciel

et al., 2022; Alkaraan, 2022). The synergy between I4.0 technologies and CE techniques significantly impacts SSIDMP and achieving desirable outcomes regarding value creation and sustainable performance (Alkaraan, 2022).

Moreover, companies are led by effective boards, whose roles are to promote the company's long-term sustainable success, generate value for shareholders, and contribute to society (Alkaraan, 2020). Strategic investment decisions reflect the art of the science of leading, steering, and controlling organizational resources (Alkaraan, 2016). These decisions require substantial investments with a significant long-term impact on organizational performance (Alkaraan and Northcott, 2007; Alkaraan and Northcott, 2013). Typical examples of strategic investment decisions are business technologies, substantial shifts in production and processes capability, mergers and acquisitions, the introduction of significant new product lines, and installing new advanced manufacturing systems (Alkaraan and Northcott, 2006; Northcott and Alkaraan, 2007).

Past studies reveal the complexity of strategic investment decisions within private and public paradigms. SSIDMP is debatably one of the CEOs, strategies, and strategic and critical steps to arriving right choices. However, no appraisal techniques or KPIs are adequate or precise yet. Conventional appraisal techniques and conceptual frameworks offer partial explanations of how CEOs deal with such SSIDMP. The literature suggests how relevant theories might be aggregated to make sense of these types of decisions within organizational contexts (see. Alkaraan, 2016; Alkaraan, 2017; Alkaraan and Floyd, 2020). Further, strategic investment decisions demand reliable, accessible, accurate, consistent, timely, and contextual information (Adel and Alkaraan, 2019). Boardrooms should engage with the sustainable business model, long-term value creation, sustainable performance, and long-term stakeholders. Boardrooms are responsible for their business return on investment, including financial effectiveness, cost-effectiveness, assets, operations, marketing strategies, and long-term business viability and success.

I4.0 technologies have significant potential to unlock environmentally sustainable manufacturing and are expected to play a critical role in social and organizational change and support SSIDMP toward SDGs (see. Li, 2018; Jabbour et al., 2019; Alkaraan, 2021; Llopis-Albert et al., 2021). Boardrooms will attest to the importance of profitability and return on investment, including financial effectiveness, cost-effectiveness, assets, operations, and marketing strategies, toward long-term success. Digitization, digitalization, digital transformation, and the fourth industrial revolution are widely used interchangeable terminologies of I4.0 technologies. Nevertheless, the ongoing confusion about these technologies remains a barrier to a standardized theoretical framework regarding academic investigations of I4.0 technologies applications and implications (see Vial, 2019; Osterrieder et al., 2019; Culot et al., 2020). Digitalization can go beyond using new technologies, and implementing new technologies can lead to business model transformation. The digital era has caused a technology-enabled change (see Balci, 2021; Costa Climent and Haftor, 2021). I4.0 technologies enable the transformation of industrial processes. Typical examples of these technologies include the Internet of Things (a computational approach that enables collecting and exchanging data from electronic devices), cloud computing, big data, and artificial intelligence (Frank et al., 2019; Benitez et al., 2020; Meindl et al., 2021). Digitization enables companies to optimise their processes, including cost reduction. It refers to converting analog to digital, while digitalization processes refer to the implementation stage of digitized data and digital technologies to impact organizational and operational processes, how companies interact with each other, and their tasks are performed (Ritter and Pedersen, 2020).

Besides, I4.0 technologies enhance decision-making processes, inform SSIDMP, enable manufacturing systems for scanning and screening, generating, storage, and analysis, and sharing real-time data through analytical techniques and computer algorithms. Undoubtedly, these technologies derive timely, relevant, and meaningful insight for improving SSIDMP and achieving desirable value-creation outcomes and sustainable performance. I4.0 technologies refer to the successful integration of information technologies and production processes. Successful integration of I4.0 technologies enables companies to improve system efficiency through horizontal and vertical integration of manufacturing processes. This is through intertangles of real-time data between various actors in value chains and value creation. I4.0 technologies are more flexible, agile, and intelligent, enabling boardrooms to meet challenges associated with the highly competitive environment of the adynamic global markers (Zhong et al., 2017). I4.0 technologies have attracted researchers, practitioners, standard setters, regulators, and policymakers (Hinings et al., 2018). I4.0 technologies applications enable companies to enhance organizational capabilities (Khrais and Ohidwan, 2020) and drive product innovation and open innovation processes toward digital intelligent manufacturing platforms with various industrial-oriented applications (Kamble et al., 2018). Researchers examined the usefulness of business model transformation for value creation, generating revenue, reducing costs (Rosa et al., 2020), and how I4.0 technologies improve companies' financial performance (Alkaraan et al., 2022).

Recently, researchers (Kamble et al., 2020) argued that I4.0 technologies enable a successful transition to CE. I4.0 technologies have great potential to improve productivity, reduce ecological impacts, achieve cleaner production and mitigate business risks. Previous studies call for more comprehensive research to advance the knowledge of how I4.0 technologies impact different facets and aspects of our lives, which have been largely ignored or received very little attention in the literature. Some of the notable works are the influence of I4.0 technologies on CE (de Sousa Jabbour et al., 2018a, 2018b), corporate social responsibility (Vial, 2019), environment (Kunkel and Matthess, 2020), companies' performance (Verhoef et al., 2021). I4.0 technologies enable companies to adapt and implement processes and innovative strategies to improve their performance (see Fuchs, 2018; Akhtar et al., 2019; Alkaraan et al., 2022; Hussainey et al., 2022).

Moreover, the productive synergy between I4.0 technologies and CE techniques relies on contextual factors and the role played by eleven critical success factors that boardrooms should consider carefully when simultaneously implementing I4.0 technologies and CE techniques, including environmentally-sustainable manufacturing organizational structures and processes (de Sousa Jabbour et al., 2018a). de Sousa Jabbour et al. (2018a) develop twelve research propositions to stimulate further debate on integrating I4.0 mechanisms and environmentally sustainable manufacturing. Integration of I4.0 technologies and CE techniques enable operational excellence associated with SSIDMP toward SDGs. Their study highlights a roadmap to enhance the application of CE mechanisms through I4.0 mechanisms and shows how different I4.0 technologies could underpin CE strategies toward sustainable operational decision-making. However, only a few studies focus on the relations between I4.0, and they call for further research on the integration between I4.0 and CE using different lenses of management theories. Based on the above debate, we postulate the following hypotheses:

H1. There is a positive relationship between I4.0 technologies and CE techniques.

H2. I4.0 technologies and CE techniques significantly mediate the relationship between SSIDMP and companies' financial performance.

2.2. The influence of governance mechanisms on the synergy between I4.0 and CE

The SDGs are created to create a better sustainable future for all countries regarding social, ecological, and economic needs, as articulated by the UN in 2015 (Awan et al., 2018). Strategic thinking and changes are key drivers of green innovation strategies in value creation and enhancing sustainable organizational performance (Awan, 2019) through cleaner products and technologies associated with product and

process innovation mechanisms. Compliance with laws and regulations and meeting stakeholders' expectations is the fundamental responsibility of boardrooms (Alkaraan, 2020). Companies collapse, weaknesses of internal control mechanisms, and ineffective risk management and risk mitigation strategies. All these issues raised a warning in boardrooms regarding the outcomes of their strategic investment decision practices and their commitment to building trust and legitimacy. Recently, the investment markets have changed significantly in many countries, including the UK. Investors' awareness has increased in recent years regarding green investments and governance mechanisms in boardrooms, including environmental, social, and governance indicators regarding corporate social responsibility. These issues can be correlated with the factors significantly impacting investors' strategic investment decision-making.

Besides, investors have increasingly considered governance mechanisms, including corporate social responsibility, while designing strategic investment decisions. Due to the lack of regulation, no compulsory models exist yet regarding sustainability reporting. The "comply or explain" inherent in the corporate governance code enables boardrooms to manage disclosure issues by explaining non-compliance reasons. The Financial Reporting Council (FRC) develops corporate governance, risk management, and stewardship codes in the UK. The UK corporate governance code (2018) comprises principles rooted in UK corporate law frameworks. The UK corporate governance code encourages boardrooms to report how they implement their business strategies and consider long-term sustainability issues associated with their SSIDMP. The code (FRC, 2014) regarding risk management strategies and internal audit and control mechanisms aims to prompt boardrooms regarding their responsibility to existing and emerging business risks. Boardrooms are responsible for maintaining effective strategic control mechanisms, including risk management and risk mitigation strategies.

Companies reporting practices of financial and non-financial disclosures must maintain completeness, relevance, and reliability and allow effective communication mechanisms with stakeholders. However, uncertainty remains significant concerning the complexity and ambiguity of the content and context underpinning the reliability of sustainability reporting (Muslu et al., 2019; Garcia-Torea et al., 2020; Al-Shaer et al., 2022). Based on signaling and agency perspectives, previous studies show that disclosure correlates with financial performance (Elamer et al., 2019; Hassanein et al., 2019; Albitar et al., 2020; Albitar et al., 2021). Findings of more recent studies (Alkaraan et al., 2022; Hussainey et al., 2022) reveal that disclosures of business-model transformation are correlated with companies' financial performance. Hence, we postulate the following hypothesis.

H3. Governance mechanisms have significant mediating effects on the relationship between I4.0 technologies, CE techniques, SSIDMP, and companies' financial performance.

3. Research design and empirical setting

3.1. Theoretical framework

In this study, we have particular attention to four disclosure pillars of determinants to enable us to offer a comprehensive assessment of narrative disclosure measurement of current SSIDMP in UK companies: (a) I4.0 technologies; (b) CE techniques; (c) internal and control mechanisms (board characteristics; ESG; audit and control mechanisms; and SDGs), and (d) companies' financial performance. The conceptual underpinning of this study, as depicted in Fig. 1, is based on theoretical triangulation rooted in resource-based theory, triple bottom line (TBL) theory, and stakeholder theory to understand better and advance our knowledge of critical strategic pre-decision control mechanisms associated with SSIDMP.

The fundamental assumption underlying the resource-based theory is that the control/position of resources is valuable, rare, difficult to imitate, and cannot be substituted. Accordingly, boardrooms should seize opportunities in their companies to recognize sources of competitive advantages through leveraging and maximizing the use of limited resources. Competitive advantages allow boardrooms to generate sales, increase profit margins and retain more customers than their competitors.

The triple bottom line theory proposed by Elkington (1998) focuses on sustainability as the primary objective and incorporates three performance dimensions: economic, social, and environmental, enabling sustainable results. Based on TBL, the most critical objective of firms is to sustain profitability for the long term. The social sustainability dimension includes the social affairs of the relevant societies, human rights, and health services, whereas environmental sustainability includes paying attention to environmental changes and obeying ecological regulations. Most studies examined the green and sustainable manufacturing sector have a great potential to influence the triple bottom line; economic, social, and environmental aspects (see Mardani et al., 2020).

The stakeholder theory suggests that firms seek to gain shareholders' satisfaction and other groups, including customers, suppliers, creditors, regulators, NGOs, and social groups to create a balance between shareholders and stakeholders to mitigate conflicts of interest between these two groups. These issues resulted in the need for comprehensive disclosures of financial and non-financial information regarding strategies and mechanisms adopted by boards for leading and steering organizational resources (Helfaya et al., 2019).

3.2. Sample and data collection

We use the computational linguistic technique to examine the disclosure content of the current trend of SSIDMP in UK companies using a sample of UK-listed companies (FTSE All-Share-non-financial firms) for the period (2012–2021). Following prior research, financial companies are excluded from this study due to the differences in disclosure regulations (Hassanein et al., 2019). Also, companies with missing data are excluded. We examine the influence of governance mechanisms on the synergy between I4.0 technologies and CE techniques, SSIDMP, and Companies' financial performance. Our initial sample on the 2379 firm-year observations of the FTSE-All-Share-UK Companies.

3.3. Selection of disclosure terminologies and empirical model

To answer this study's research questions, we use textual analysis to identify the disclosure of I4.0 technologies and CE techniques in narrative sections of UK companies' annual reports (2012–2021). Computer-aided textual analysis is an evolving paradigm that helps examine large-volume texts to identify and analyze the linguistic features of documents (Loughran and McDonald, 2011). We followed the literature regarding constructing a word pool. To measure I4.0 technologies, CE techniques, and SSIDMP disclosure practices, we have used search processes comprising three stages.

i. We developed the first draft of 14.0 technologies and CE techniques terminologies using the framework adopted by Alkaraan et al., 2022. This stage helps to produce preliminary proxies. We examined the primary representatives of I.4 technologies and CE techniques terminologies against ten selected annual reports (2020) of major UK companies from sectors such as aviation, pharmaceutical, research-based biopharma, groceries, general merchandise retailer, technology, oil and gas, tobacco, and

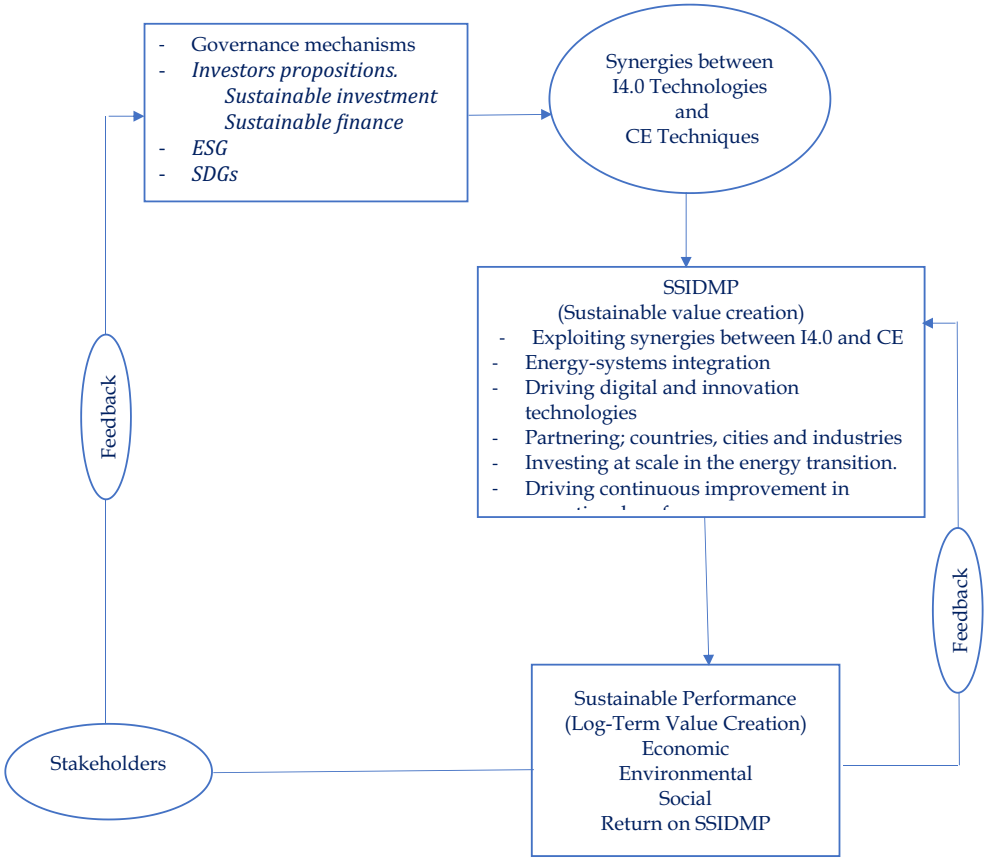


Fig. 1. Conceptual framework; SSIDMP: the influence of governance mechanisms on synergies between I4.0 technologies, CE techniques, and companies' performance.

mining (RR,[1] GSK,[2] AZ,[3] T,[4] OG,[5] BP,[6] RT,[7] U,[8] AA,[9] BAT[10]).

ii. We added synonyms and amended the preliminary I.4 technologies and CE techniques proxies. In this stage, we recognized synonyms and added them to the primary proxies. Further, the reviewing terminologies ensured the reliability of our proxies. At this stage, inconsistencies were resolved. Appendix 1 presents the final versions of our proxies.

iii. We use content analysis using computerized textual analysis software called Corporate Financial Information Environment (CFIE) Final Report Structure Extractor (FRSE) to score the total disclosure on I.40 technologies and CE techniques. The disclosure level is measured simply by counting I.4 technologies and CE techniques terminologies related to (i) sentences or (ii) words before transforming this number into a natural logarithm. CFIE-FRSE tool is a desktop application that detects the structure of annual reports and extracts the reports' contents at the section level. CFIE-FRSE help explores texts using natural language processing (NLP) (El-Hajet al., 2020).

The study uses regression models to answer the two research questions and test the three hypotheses underpinning this study. The definition of variables is depicted in Table 1. We have proposed the multivariate regression model below to examine SSIDMP and the influence of governance mechanisms on the synergy between I4.0 technologies and CE techniques. All our regression models include year and industry-fixed effects. Industry dummies are based on the standard industrial classification (SIC- two-digit).

We use descriptive statistics to examine the trend of SSIDMP and illustrate the synergy between I4.0 technologies and CE techniques over the sample underpinning this study (2021–2021) and across the industry sector. Besides, to show the relationship between disclosure types and benefits associated with SSIDMP. Further, we have supported our debate and results of data analysis using extracts from companies' annual reports from different industries. To test our hypotheses regarding CE technologies' impact on SSIDMP, we run the following models using ordinary least squares (OLS). To reduce the standard error and avoid the effect of omitted variable bias, we re-run our regressions using a fixed-effect panel model.

$$CI = \alpha 0 + \beta 1 I4.0 + \Sigma \beta i\ CONTROLSitni = 1 + \varepsilon it$$

4. Empirical results

Table 2 shows summary statistics of dependent, independent, and control variables.

Summary statistics based on the industry sector are shown in Table 3 (Appendix 2 depicts the correlation matrix).

The regression analysis results confirm our hypotheses, as illustrated in Tables 4 and 5.

As shown in Table 6, structural equation modelling (SEM) results

[1] Rolls-Royce is aerospace and defence company, designs, manufactures and distributes power systems for aviation and other industries.
[2] GlaxoSmithKline plc is a British multinational pharmaceutical company
[3] AstraZeneca UK - Research-Based Bio Pharmaceutical Company
[4] Tesco PLC is a British multinational groceries and general merchandise retailer
[5] Ocado Group is a business which licenses grocery technology
[6] BP plc is a British oil and gas company
[7] Rio Tinto is metals and mining company.
[8] Unilever plc is a British multinational consumer goods company
[9] Anglo American Platinum Mining company
[10] British American Tobacco plc

Table 1
Variable definitions.

Variables	Symbols	Definitions
Circular Economy Techniques	CE	It contains the level of CE techniques disclosure using a self-constructed index. Appendix 1 contains a sample of the keywords used.
Industry 4.0 Technologies	I4.0	It contains the level of I4.0 technologies disclosure using a self-constructed index. Appendix 1 contains a sample of the keywords used.
Company size	FSIZE	Natural log of total assets of the company.
Total sales	Sales	Natural log of total sales of the company.
Market capitalization	Markcap	Natural log of the market capitalization of the company.
Leverage	LEV	Percentage of total debt to total assets
Capital expenditure	Capex	Natural log of Capital expenditure of the company.
Profitability	ROA	Percentage of net income to total assets as an indicator for financial performance.
Non-current assets	PPE	Natural log of Property, plant, and equipment.
Intangible assets	IA	Natural log of intangible assets.
Research and development	RD	Research and development expenditure.
Board size	BSIZE	Number of directors on board.
Board independence	BINDE	Percentage of independent directors on the board of a company.
Audit independence	AINDE	Percentage of independent directors on the audit committee.
Corporate governance	GOV	Combining the variables (Board size, board independence, audit committee independence) through a principal component analysis (PCA).
SSIDMP	SSIDMP	Sustainable strategic investment decision-making practice
BENEFIT	Benefit	It contains the level of organizational performance disclosure using a self-constructed index. Appendix 1 contains a sample of the keywords used.
Industry	INDUSTRY	Dummies, representing ten industries, based on the Industry Classification Benchmark to control for industry effects.
Year	YEAR	Year dummy to control for year effects.

Table 2
Summary statistics of the dependent, independent, and control variables.

Variable	Obs	Mean	Std.Dev.	Min	Max
CEI	2379	1644	686	17	6159
I40	2379	986	978	0	5708
FSIZE	5334	17	19	4	22
SALES	5332	11	12	−8	15
MARKCAP	5248	11	12	−1	16
LEVERAGE	5325	24	23	0	66
CAPEX	4561	8	10	0	13
ROA	5144	8	15	−10	169
PPE	3825	10	12	0	15
IA	2100	10	12	2	14
RD	2080	14	55	0	581
BSIZE	3074	9	3	1	22
BINDE	3074	63	18	0	100
AINDE	3053	98	6	20	100

Notes: The definitions of all variables are presented in Table 1.

reveal the influence of governance mechanisms effects on the relationship between I4.0 technologies, CE techniques, SSIDMP, and companies' financial performance.

4.1. RQ1: Synergy between I4.0 technologies and CE and financial performance

SSIDMP in UK companies toward CE is illustrated according to the sector (SIC-UK code) as depicted in Figs. 2 and 3.

Table 3
Summary statistics based on the industry sector.

	CE Techniques	I4.0 Technologies	Benefit
Communication Services	176,081.1	176,114.2	176,090.200
Consumer Discretionary	144,746.7	85,856	144,769.183
Consumer Staples	180,344.88	140,119.61	180,376.681
Energy	215,712.68	146,325.66	215,728.203
Health Care	185,940.83	126,406.97	185,999.263
Industrials	161,034.65	95,335.813	161,060.994
Information Technology	148,189.69	67,877.1	148,216.464
Materials	186,670.78	137,481.52	186,699.985
Real Estate	138,989.89	71,133.072	139,006.664
Utilities	185,328.63	96,316.882	185,299.078
	CE Techniques	I4.0 Technologies	Benefit
2012	48,680.5	18,128	48,686.000
2013	131,357.43	80,410.013	131,374.657
2014	137,333.08	85,501.75	137,352.962
2015	143,864.4	85,409.684	143,888.418
2016	150,629.7	89,739.058	150,654.807
2017	159,250.66	97,448.523	159,274.617
2018	170,577.36	103,668.2	170,606.822
2019	187,357.45	110,058.25	187,386.059
2020	212,114.85	122,604.52	212,139.394
2021	206,827.48	125,611.32	206,844.043

Table 4
I4.0 technologies and CE techniques.

Variables	Dependent variable: Circular economy (CEI)		
(Model)	(1) Pooled OLS regression	(2) Robust regression	(3) Fixed-effects regression
I4.0	0.150***	0.842***	0.150**
	(0.0369)	(0.14)	(0.073)
FSIZE	0.00249**	0.0455*	0.0249*
	(0.0221)	(0.0421)	(0.0235)
SALES	0.0605	0.0022	0.0605
	(0.0098)	(0.00175)	(0.000874)
MARKCAP	0.0229	0.0153	0.0229
	(0.00066)	(0.00139)	(0.000517)
LEVERAGE	0.00708*	0.0709	0.00708***
	(0.00361)	(0.0073)	(0.00234)
CAPEX	−0.0415	−0.0807	−0.0415*
	(0.0308)	(0.0933)	(0.0231)
ROA	2114***	808.5	2114***
	−631.7	(527.1)	(584.5)
PPE	2.509***	2.509***	2.601***
	(0.474)	(0.486)	(0.413)
IA	0.107***	0.021***	0.144***
	(0.0111)	(0.0111)	(0.0178)
RD	0.0310**	0.0210	0.0767*
	(0.0207)	(0.0227)	(0.0272)
BSIZE	0.0149	0.0512	0.203
	(0.202)	(0.156)	(0.132)
BINDE	0.0523**	0.0595**	0.0765**
	(0.000244)	(0.000244)	(0.000322)
AINDE	0.0870***	0.424***	0.029***
	(0.111)	(0.0895)	(0.0781)
Observations	2100	2100	2100
Adj. R-squared	0.709	0.649	0.709

Note: Table 1 outlines variable definitions. ***, ** and * indicate statistical significance at 1 %, 5 % and 10 % levels, respectively. Robust standard errors are shown in parentheses.

The findings of this study reveal positive relationships between I4.0 technologies and CE techniques in UK companies according to Standards Industrial Classification SIC-UK code), as shown in Fig. 4.

SSIDMP in UK companies has accelerated over the last decade (2012–2021), as depicted in Fig. 5.

Further, the synergy between I4.0 technologies and CE techniques significantly mediates SSIDMP, as illustrated in Fig. 6.

Table 5
Governance mechanisms effects the relationship between I4.0 technologies, CE techniques, SSIDMP, and companies' financial performance.

	Dependent variable: CE Techniques		
(Model)	(1) Pooled OLS regression	(2) Robust regression	(3) Fixed-effects regression
I40	719.7***	802.0***	549.9***
	(97.43)	(126.1)	(69.16)
SSIDMP	5868***	2137**	11,121***
	(803.4)	(981.8)	(682.3)
ROA	363.5***	181.5	649.5***
	(0.0178)	(0.0136)	(0.0110)
I40#GOV	822.4***	814.2***	601.6***
	(0.0122)	(0.0118)	(0.0152)
SSIDMP#GOV	5.961***	2.261***	11.795***
	(0.0142)	(0.0139)	(0.0163)
ROA#GOV	401.5***	210.9***	682.6***
	(0.474)	(0.486)	(0.413)
Constant	1.816*	1.212*	1.021*
	(1.0706)	(1.720)	(1.516)
Observations	1860	1860	1860
R-squared	0.287	0.220	0.203

Note: Table 1 outlines variable definitions. ***, ** and * indicate statistical significance at 1 %, 5 % and 10 % levels, respectively. Robust standard errors are shown in parentheses.

Table 6
Governance mechanisms effects the relationship between I4.0 technologies, CE techniques, SSIDMP, and companies' financial performance.

	(1)	(2)
	CE Techniques	CE Techniques
I4.0	14.39***	16.04***
	(194.86)	(252.2)
SSIDMP	11.73***	42.72***
	(1606.8)	(1963.6)
ROA	7.27**	3.63***
	(0.0356)	(0.0272)
GOV		15.68***
		(0.0236)
Constant	1439.4	1604
	(4740)	(432,602)
Observations	1542	1542

Note: Table 1 outlines variable definitions. ***, ** and * indicate statistical significance at 1 %, 5 % and 10 % levels, respectively. Robust standard errors are shown in parentheses.

de Sousa Jabbour et al. (2018a) stated that productive synergy between I4,0 technologies and CE techniques relies on understanding the roles played by critical success factors, which boardrooms should consider carefully when simultaneously implementing these two paradigms. They address top management responsibilities regarding scanning, screening, and forecasting organizational opportunities for integrating I4.0 technologies and environmentally sustainable manufacturing into existing production systems. The critical proposition underlying their conceptual framework is that I4.0 technologies can unlock the full potential of CE techniques implementation.

Boardrooms of UK companies are aware of the value of integrating these two paradigms on value creation and sustainable performance. Extracts from companies' annual reports show that I4.0 technologies strengthen sustainability. For example, blockchain technology can be used as an effective mechanism to provide revenant, accurate and timely information regarding critical ingredients of sustainable supply chains; how and where the product is manufactured. I4.0 technologies leverage CE techniques such as carbon footprint, water management, and renewable energy recycled contents.

"By investing in genetics, genomics, big data, and AI, we are accelerating the pace at which we develop transformational medicines and prioritizing those molecules with a higher probability of success." GSK, AR, 2020, p14.

"6,200,000 pounds of copper scrap recycled at our Kennecott copper mine in the US" RT, AR, 2020, p.51.

Partnering is a significant issue for successful SSIDMP and maintaining effective synergy between I4.0 technologies and CE techniques that enable product and process innovation and contribute toward a sustainable world.

"Together with other companies, we collectively pledged a total of US$100 million in funding to Circulate Capital, an investment firm that incubates and finances waste management solutions and infrastructure. It is a unique investment model designed to create lasting systems change to address the ocean plastic crisis. This year Circulate Capital announced inaugural investments in two companies in India and Indonesia that recycle local plastic waste into useful products. Across all our plastic targets, we need to continue our advocacy, partnerships, and policy approach to drive system-wide change and shift the economy from a finite and linear – take, make, dispose of – model to a circular approach that protects the environment and protects our resources" U, AR 2020, p.59.

"To improve the visibility and traceability of our commodity supply chains, we use satellite imagery, geolocation data, blockchain, and AI. We're part of Global Forest Watch, a group of companies developing radar technology to detect deforestation more quickly and accurately. In 2020, we began working with US geospatial analytics specialist Orbital Insight to get data around the 'first mile' in our supply chains". U, AR, 2020, p.27.

"At some of our former assets, we are exploring options to repurpose the site for renewable energy, such as our pilot photovoltaic cell facility at Marignac, France, a former ferroalloy plant. We sometimes partner with universities and other companies to find opportunities to repurpose and reprocess waste and improve water and waste treatment. For example, in the Saguenay – Lac-Saint-Jean region of Quebec, Canada, we worked with local blueberry growers to create a safe and effective fertilizer from waste from our aluminum operations". RT, AR, 2020, p.81.

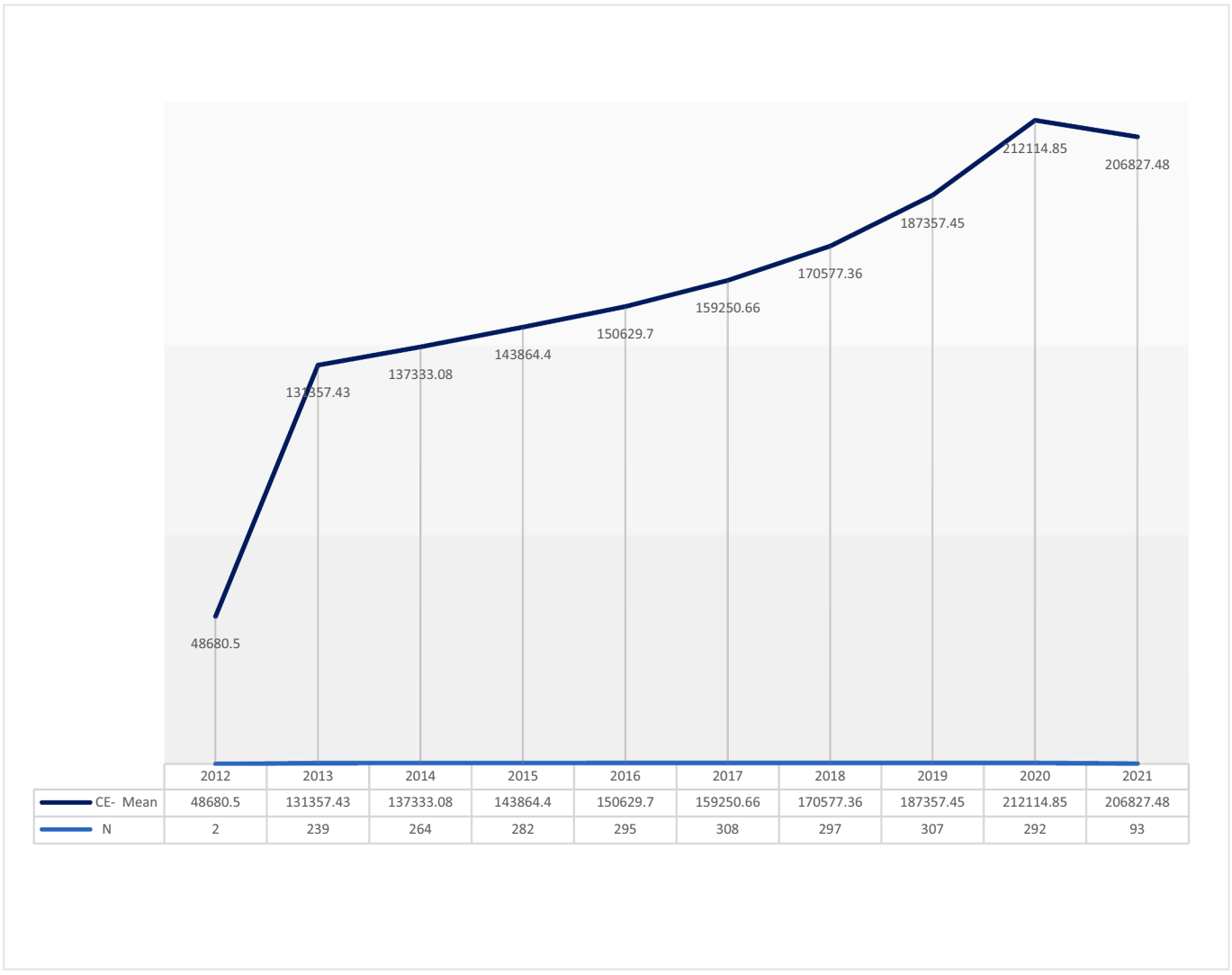
"We contribute to Rio Tinto's sustainable growth by unlocking value from our high-grade orebodies and developing new materials. By giving a second life to mining waste with by-products, we are expanding our frontiers for the increasing demand for critical minerals. We apply innovative technology and processes to deliver products that will contribute to a decarbonizing and sustainable modern world". RT, AR, 2020, p.3

"By embedding circular economy principles into packaging and product formulations, we're shifting from using fossil-fuel derived feedstocks to renewable or recycled carbon sources for cleaning chemicals." U, AR, 2020, p.55.

"The Group's strategy for further growth and increasing profitability depends largely on digital transformation and innovation on digital transformation and innovation. Digital transformation and innovation are key drivers of the Group's Ethos, including new and modern product categories, increased interaction with customers, data-driven decision-making, and cost optimization efforts driven by automated and modernized processes" BAT, AR, 2020, p292.

"The disruption of COVID-19 also gave us the opportunity to accelerate and expand our use of digital solutions – such as offering customers the opportunity to buy our products through a mobile app and conducting end-to-end digital transactions using blockchain technology". RT, AR, 2020, p.19.

"However, we are focusing on processes to boost our operational efficiency and investing in waste reduction projects to help us reach



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
CE- Mean	48680.5	131357.43	137333.08	143864.4	150629.7	159250.66	170577.36	187357.45	212114.85	206827.48
N	2	239	264	282	295	308	297	307	292	93

Fig. 2. SSIDMP towrds CE (2012–2021).

our target to reduce waste generation by 10% by 2025". AZ, AR, 2020, p.75.

"Anglo American Platinum is working to realise this future as an led by its purpose and driven by its values. We are combining integrity, circularity, and smart innovation with the utmost consideration for our people, their families, local communities, our customers, and the world to better connect our precious resources to the people who need and value them". AA, AR, 2020. P.38.

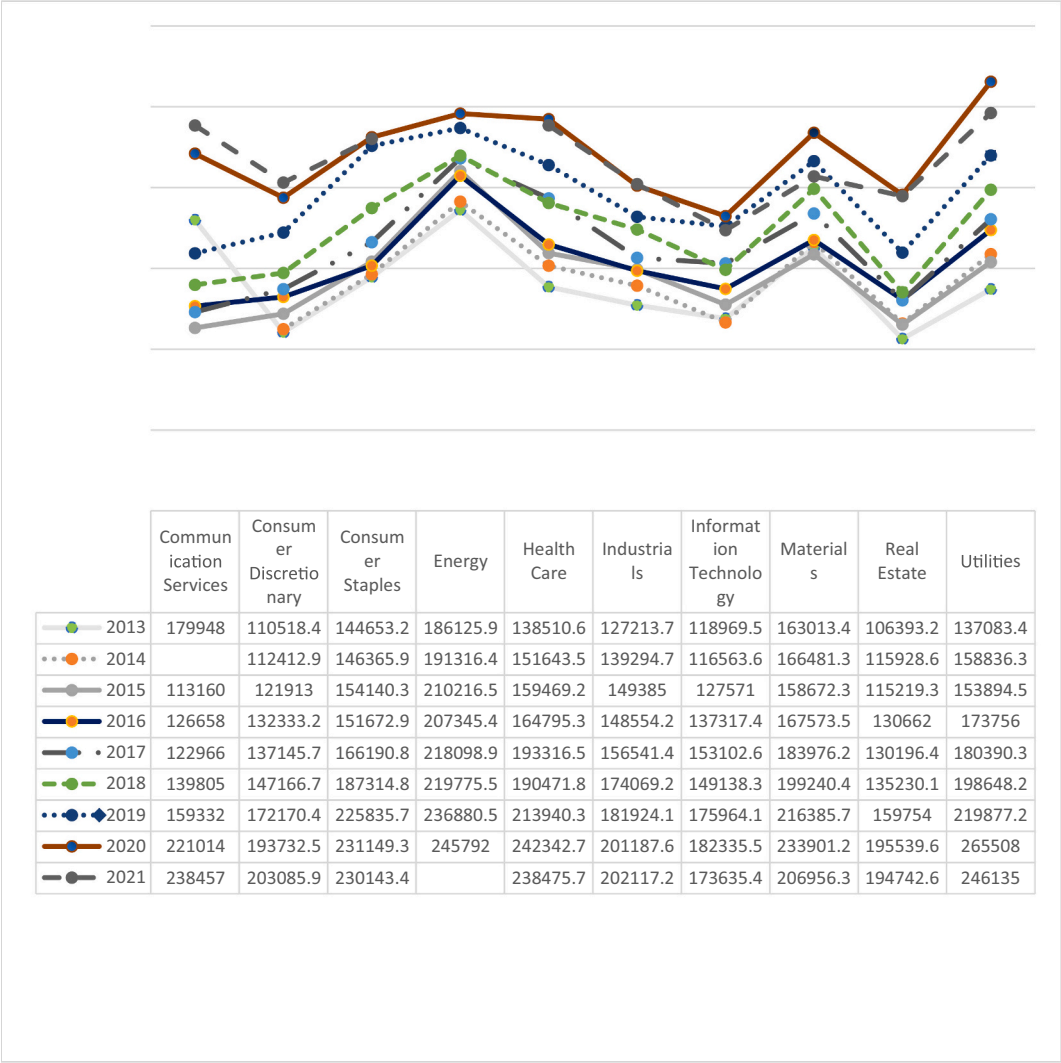
"funding our resilient dividend as the first priority, deleveraging the balance sheet, investment in low carbon and convenience and mobility to advance our energy transition strategy, investment in resilient hydrocarbons to generate sustainable cash flow" BP, AR 2020, p 307.

4.2. RQ2: The influence of governance mechanisms on SSIDMP toward CE and SDGs

Successful SSIDMP requires the successful integration of I4.0 technologies and CE techniques. Successful integration of I4.0 technologies and CE techniques leverages organizational performance. Our results reveal that synergy between these two domains significantly effects the relationship between SSIDMP and companies' financial performance. The integration can be viewed as a successful prerequisite toward more efficient and effective sustainable manufacturing processes through a combination of product and process innovation rooted in stakeholder-oriented value creation restructuration. Stakeholder lenses describe how boardrooms view the interests of business constituencies. Stakeholders affect organizational decision-making or are affected by their outcomes. This includes international institutional regulations, suppliers, customers, and other stakeholders (see Awan et al., 2021). It is essential to highlight that successful SSIDMPs are subject to boardrooms 'leadership, commitment, and national culture. SSIDMP rooted in synergy between I4.0 technologies and CE techniques, enables companies to contribute to achieve sustainable performance and contribute to a better sustainable future and show evidence of boardrooms' commitment to SDGs;

"We aim to contribute to a more sustainable future – through reducing our global carbon footprint, addressing the UN Sustainable Development Goals, forming smart, technology – and value-chain – focused partnerships and producing materials essential to a low-carbon economy". RT, AR, 2020, p.65.

"In 2021, we launched StaRT, the first sustainability label for aluminium, which will be delivered to customers using blockchain technology. This 'nutrition label' for aluminium will provide key information about where and how the aluminium was produced, covering ten criteria: carbon footprint, water management,



	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
2013	179948	110518.4	144653.2	186125.9	138510.6	127213.7	118969.5	163013.4	106393.2	137083.4
2014		112412.9	146365.9	191316.4	151643.5	139294.7	116563.6	166481.3	115928.6	158836.3
2015	113160	121913	154140.3	210216.5	159469.2	149385	127571	158672.3	115219.3	153894.5
2016	126658	132333.2	151672.9	207345.4	164795.3	148554.2	137317.4	167573.5	130662	173756
2017	122966	137145.7	166190.8	218098.9	193316.5	156541.4	153102.6	183976.2	130196.4	180390.3
2018	139805	147166.7	187314.8	219775.5	190471.8	174069.2	149138.3	199240.4	135230.1	198648.2
2019	159332	172170.4	225835.7	236880.5	213940.3	181924.1	175964.1	216385.7	159754	219877.2
2020	221014	193732.5	231149.3	245792	242342.7	201187.6	182335.5	233901.2	195539.6	265508
2021	238457	203085.9	230143.4		238475.7	202117.2	173635.4	206956.3	194742.6	246135

Fig. 3. SSIDMP towrds CE (2012–2021)
Industry sector (SIC-UK code).

renewable energy, recycled content, waste management, safety performance, contribution to communities, supplier due diligence, governance systems, and diversity. The blockchain technology will enable traceability, helping customers and consumers make informed choices about the products they buy." RT, AR, 2020, p.47

Committing $4.5 million to support research projects at the Tsinghua-Rio Tinto Joint Research Centre for Resources, Energy, and Sustainable Development over the next five years. Signing a Memorandum of Understanding with Nippon Steel Corporation to jointly explore, develop and demonstrate technologies to transition to a low-carbon emission steel value chain". RT, AR, 2020, p.59

"In 2020, we started the transition to renewable energy in the Pilbara, in Western Australia, with the approval of the $98 million, 34MW solar plant at Gudai-Darri and 45MW battery system at Tom Price. Today, 75% of electricity used in our managed operations is from renewable sources. Of the $1 billion we committed to climate-related projects over five years, in 2020, we approved spend of more than $140 million". RT, AR, 2020, p.79.

The results show that the current SSIDMPs in UK companies can be viewed as a new era of strategic investment decisions that support ecological, social, and economic contributions. Further, internal and external governance mechanisms (board compositions including board size, diversity; non-executive audit committee, ESG, and SDGs) strengthen the relationship between I4.0 technologies and CE techniques, as well as the relationship between these two domains, SSIDMP, and financial performance. Stewardship is the responsible allocation, management, and oversight of capital to create long-term value for clients and beneficiaries, leading to sustainable benefits for the economy, the environment, and society. The UK Stewardship Code, 2020 (Financial Reporting Council) allows organizations to meet the expectations aligned with their business model and strategy (The UK Stewardship Code, 2020, FRC). The board is responsible for the effective development and delivery of a company's strategic objectives, the ability to seize new opportunities, and to ensure its longer-term survival depending upon its identification, understanding of, and response to the risks it faces (FRC, 2014) as illustrated by the following extracts from annual reports;

"We're investing €1 billion over ten years in researching and developing new technologies to reduce the carbon footprint, plastic waste, and water use and increase the biodegradable and sustainable ingredients associated with our products. For example, we'll be replacing the crude oil and other fossil fuels used to make some of our chemicals with renewable and recycled carbon" U, AR, 2020, p.23.

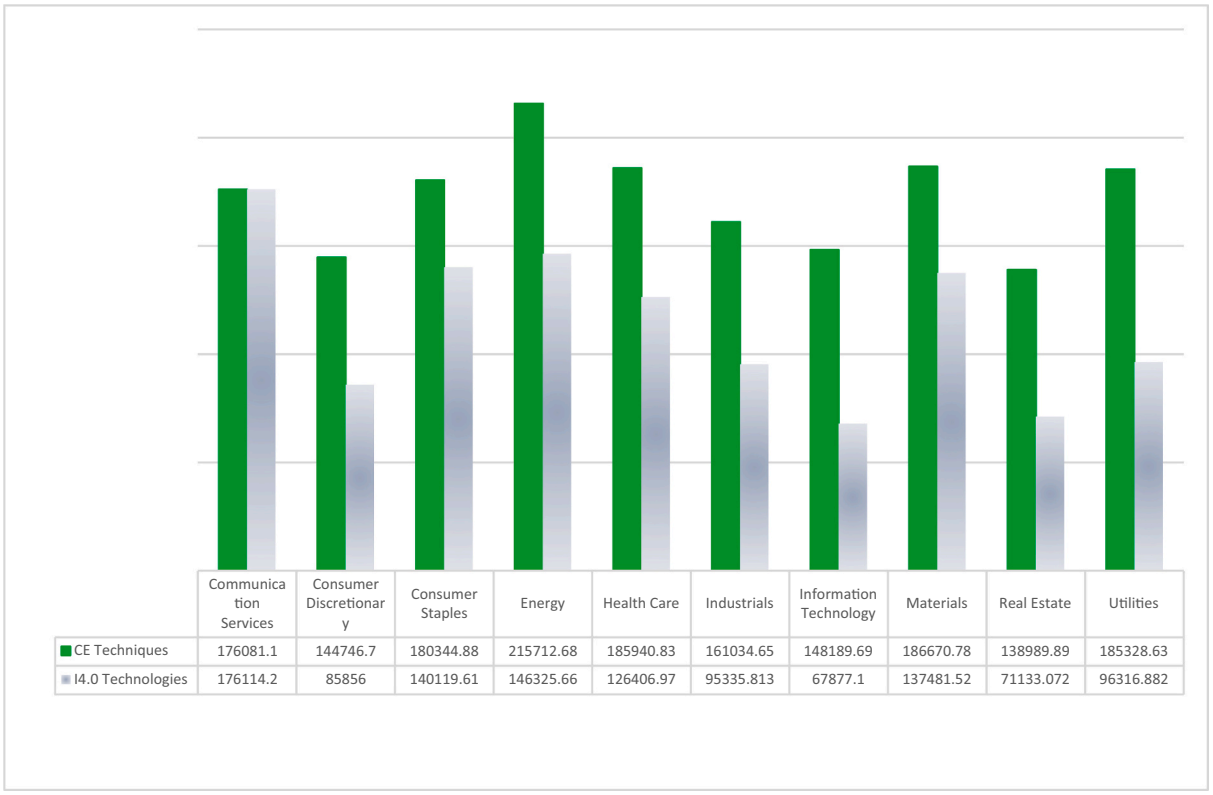


Fig. 4. Synergy between I4.0 technologies and CE techniques - Industry sector (SIC-UK code).

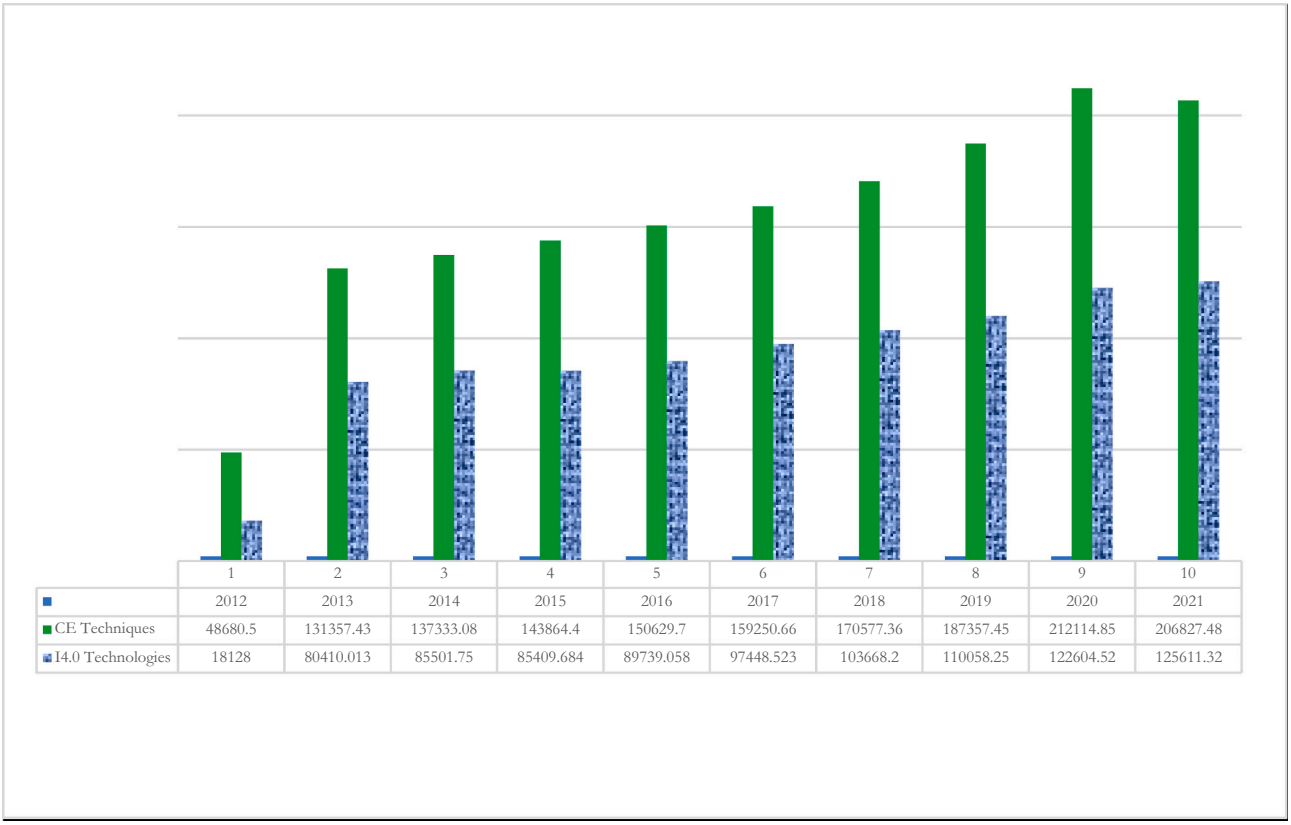


Fig. 5. Synergy between I4.0 technologies and CE techniques (2012–2021).

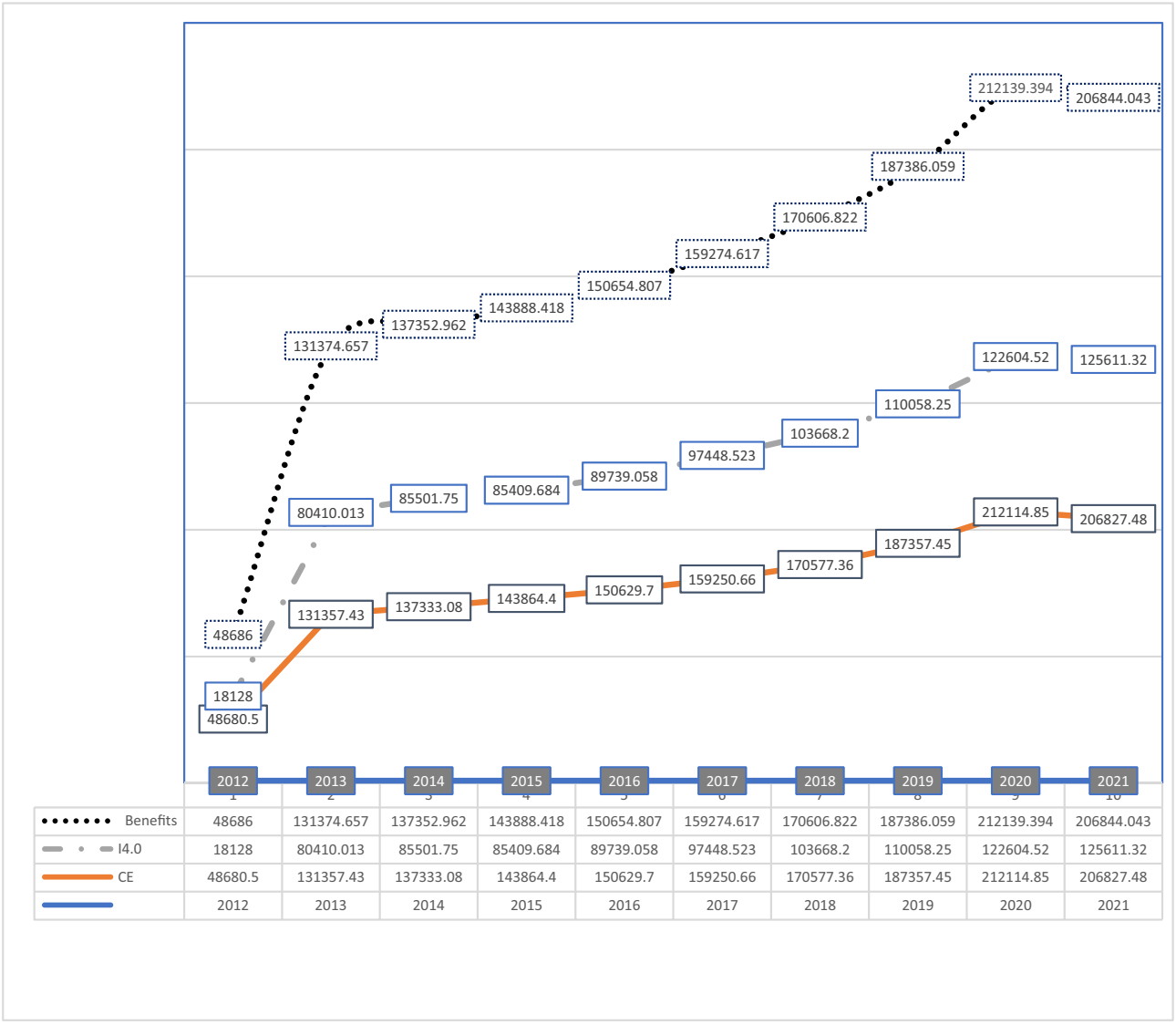


Fig. 6. SSIDMP towrds CE and synergy between I4.0 with CE.

"We continue to invest heavily in energy efficiency across all our operations. Key initiatives include: LED lighting upgrades across the entire Group estate; installation of aerofoil technology across all our UK stores, saving 15% energy use in fridge operation; investment in high-efficiency ventilation fans; Trialled Lightfoot® telematics which improves driver efficiency; Initial findings indicate 7% improvement in miles per gallon fuel consumption; continue to optimize distribution and home delivery operations to reduce road miles and secure efficiencies". T, AR, 2021, p100.

"This year, we set new Scope 3 emissions reduction goals, focused mostly on our contribution to the development and deployment of low-carbon technologies, as well as new goals and targets related to emissions from shipping our products: we will work with customers on steel decarbonization pathways and invest in technologies that could deliver at least a 30 percent reduction in steelmaking carbon intensity from 2030. We will work with our partners to develop breakthrough technologies with the potential to deliver carbon neutral steelmaking pathways by 2050"—RT, CEO, AR, 2020, p.14.

Boardrooms should respond promptly to risks when they arise and ensure that shareholders and other stakeholders are well informed regarding SSIDMP. Boardrooms are responsible for the organization's culture and essential in considering and addressing risk within and with external stakeholders. Boardrooms are accountable for the effectiveness of SSIDMP inherent in business model transformation, including changes in strategy, major new strategic projects, and other significant commitments to stakeholders. The risk management and internal control systems encompass the policies, culture, organization, behaviors, processes, procedures, and other aspects of a company that, taken together: facilitate its effective and efficient operation by enabling it to assess current and emerging risks, respond appropriately to risks and significant control failures and to safeguard its assets.

Moreover, I4.0 technologies help reduce the likelihood and impact of judgment in SSIDM, including human error and control processes. Boardrooms are responsible for ensuring compliance with applicable laws and regulations and with internal policies concerning the conduct of their business. I4.0 technologies enable the boardroom to maintain an effective risk management strategy, including risk assessment, management or mitigation of risks, effective control systems, information and communication systems, and monitoring and reviewing their effectiveness. Risk management strategy should be embedded in the organizational processes and respond quickly to business model risks that arise from the internal corporate environment or the changes in their business environment. Effective risk management strategy should

be an integral part of day-to-day business operations processes. I4.0 technologies enable boardrooms to maintain adequate risk management strategy and focus on the current position, challenges that could threaten their business model, the supply chain issues, and future company performance, as articulated in the following extracts from companies' annual reports. With the development of production specialization and internationalization, companies focus more on their knowledge (Wang et al., 2021). Further, I4.0 technologies are critical drivers of business model transformation, which includes product and processes innovation rooted in data-driven decision-making and cost optimization, as revealed by extracts from annual reports;

> "*The disruption of COVID-19 also allowed us to accelerate and expand our use of digital solutions – such as offering customers the opportunity to buy our products through a mobile app and conducting end-to-end digital transactions using blockchain technology". RT, AR, 2020, p.19.*

> "With our IT foundation now firmly in place and operating at high levels of efficiency, we have a growing program portfolio to support this business transformation, which takes advantage of data and analytics, artificial intelligence, digital and the Internet of Things. "And this year, 52% of our total energy use in manufacturing was generated from renewable resources"—U, AR, 2020, p.28.

> "Digital transformation and innovation are key drivers of the Group's Ethos, which includes new and modern categories of the product, increased interaction with customers, data-driven decision-making, and cost optimization efforts driven by automated and modernized processes." BAT, AR, 2020, p292.

5. Conclusion

The findings of this study reveal that SSIDMP is the emerging contemporary approach to strategic investment decision-making in the recent decade for achieving sustainable performance, brand image, efficiency, market share, and reducing environmental concerns. This study offers a new paradigm to investigate SSIDMP in UK companies through developing recent scores regarding narrative disclosure measurement of synergies between I4.0 technologies and CE techniques and the influence of these two domains on SSIDMP and companies' financial performance. The study explores the impact of governance mechanisms on the synergy between I4.0 technologies and CE techniques. The findings reveal positive relationships between I4.0 technologies and CE techniques. Further, the synergy between I4.0 technologies and CE techniques significantly influences SSIDMP and companies' financial performance. The synergy between I4.0 technologies and CE techniques leverages organizational performance. Internal and external governance mechanisms (ESG, SDGs, board compositions; board-size, board-independent, board-diversity; non-executive audit committee) strengthen and leverage the relationships between I4.0 technologies, CE techniques, SSIDMP, and companies' financial performance.

The results show that SSIDMP can be viewed by boardrooms of UK companies as comprehensive regenerating systems that enable narrowing organizational inputs, material, and energy loops through renewable energy usage and eliminating waste through superior materials, products, and processes. The synergy between I4.0 technologies and CE techniques allows boardrooms to decouple economic growth from finite resource constraints. The findings of this study support the view of de Sousa Jabbour et al. (2018a, 2018b) and (Jabbour et al., 2019) regarding their comprehensive framework and technology plan for boardrooms to exhibit commitment and responsibilities toward unlocking the CE through strategic changes, strategic thinking, and the new era of business model transformation. Findings of narrative disclosure measurement and extracts from companies' annual reports (2020) show that synergies between these two domains leverage SSIDMP and financial performance. Further, the synergies between I4.0 and CE techniques allow boardrooms to achieve the desired outcomes through a new strategy regarding value creation, minimizing costs, and rebuilding trust and legitimacy. Undoubtedly, effective integration of these two domains enables organizations to implement SSIDMP, enhancing companies' financial performance and achieving SDGs. Value creation and realization of SSIDMP can be successfully achieved through synergy between I4.0 technologies and CE techniques, which require inevitable cooperation with external partners, including R&D, open innovation, and strategic alliances regarding product and processes innovation (see Wang et al., 2021).

5.1. Theoretical contributions

This study is grounded on multidisciplinary concepts to advance the data-driven approach for sustainability assessment and understand the influence of synergy between I4.0 technologies and CE techniques, new platforms of a new era of business model transformation, on SSIDMP and financial performance in UK companies. It combines paradigms to understand the key contextual factors around SSIDMP disclosure in companies' annual reports. The study focuses on four disclosure pillars of determinants to enable us to offer a comprehensive assessment of narrative disclosure measurement of current SSIDMP in UK companies: I4.0 technologies; CE techniques; internal and control mechanisms, and companies' financial performance, as depicted in Fig. 1. The findings offer insightful contributions to the current deliberations on the synergy between I4.0 technologies and CE techniques and SDGs, articulated by de Sousa Jabbour et al. (2018a, 2018b) and Jabbour et al. (2019). This contributes to the current debates on rethinking the extension of stakeholder theory to include sustainable governance mechanisms. The extracts of annual reports regarding boardroom practices are rooted in reasoned action behavioral perspectives to offer insights that account for internal and external stakeholders. Our conceptual framework and empirical findings confirm the view of Venkatesh et al. (2021) that collective dynamics are potent drivers of the current trends of SSIDMP, thereby setting an imperative for the convergence of social sustainability and governance mechanisms by recognizing stakeholders' views and standards-setting attributes. The findings support the arguments of Alkaraan et al. (2022) that synergy between I4.0 technologies and CE techniques and internal and external mechanisms can be viewed as strategic pre-decision strategic control mechanisms associated with SSIDMP, a new era of business model transformation in UK companies combined with technological ecological, social, and economic determinants toward value creation and sustainable business performance.

5.2. Practical - managerial and policy implications

The results of this study have practical implications for boardrooms regarding the strength of the relationship between I4.0 technologies, CE techniques, SSIDMP, and companies' financial performance. I4.0 technologies leverage CE and enable companies to achieve potential objectives such as increasing production efficiency, productivity, and quality, supplementing operational flexibility, contributing to safety issues and operational sustainability, and amalgamating the production system with critical stakeholders (Meindl et al., 2021). Further, our results reveal the vital role the organizational ambidexterity plays in the synergy between I4.0 technologies and CE techniques through exploring and exploiting technological techniques and mechanisms to cope with changing business environment. Organizational ambidexterity mirrors companies' capabilities and how efficient current management is in using exploration and exploitation technological techniques and mechanisms to cope with changing business environment and succeed in innovation trajectories of value creation and realization. The Board of directors is of significant importance for facilitating the content and the context for ambidexterity. The ambidextrous organization requires mobilization, integration, and coordination of organizational resources to maintain exploitation and exploration to achieve successful outcomes of SSIDMP. Furthermore, the results of this study offer insights into

managing the current trend of SSIDM and its potential implications on SDGs. This is a key input to the boardrooms' decision-making. However, maintaining a high level of synergy between I4.0 technologies and CE techniques requires ensuring a high level of synergies among stakeholders to consolidate governance mechanisms associated with SSIDMP. For investors and other financial institutions with preferences linked to CSR/SDGs patterns, corporate disclosure on SSIDMP is particularly important for their strategic investment decision-making. Successful SSIDMP is rooted in comprehensive engagement with stakeholders. Regulatory bodies and policymakers need to evaluate the outcomes of SSIDMP against SDGs indicators to increase awareness, knowledge, practices, and necessary adjustment that can be operationalized to ensure a global society that can afford sustainable living.

5.3. Social implications

The debates underpinning the findings of this study are relevant to SDGs and offer insights to decision-makers, investors, regulatory bodies, and other stakeholders regarding desirable outcomes of SSIDMP, including ESG impacts. The findings provide empirical evidence to amalgamate I4.0 technologies with CE techniques in SSIDMP to achieve sustainable performance. However, successful implementation of SSIDMP and achieving sustainable performance require comprehensive processes to encourage stakeholders' engagement through the early stage of SSIDMP, scanning and screening strategic investment opportunities. These comprehensive processes will provide an impetus to SSIDMP driven by stakeholders' interests and expectations, enabling a better environmental innovation solution supporting SDGs (Awan et al., 2021).

5.4. Limitations and future research

The study limits our sample size to companies operating in the UK, and future research can explore the results in other countries or different settings and contexts. Further studies may adopt survey-based questionaries or semi-structured interviews to examine stakeholders' perspectives on SSIDMP using different theoretical lenses. This study combines other research streams to advance our knowledge of I4.0 and CE disclosures and our understandings of SSIDMP underpinning the new era of business model transformation. The research deliberations call for research to examine boardrooms' commitment toward the circular economy in different contexts using dynamic capabilities lenses and theoretical frameworks to investigate relationships among directors, managerial human capital, capabilities, and strategic changes toward CE and SDGs.

Further studies may adopt a case study methodology rooted in the case study approach to examine how effective integration of I4.0 technologies and CE techniques enables boardrooms to capture new emerging risks and opportunities. The questions remain open for debates on how the synergy between these two domains allows boardrooms to accurate analysis of cost-benefit aspects of different control mechanisms embedded in risk management strategies. Besides, it is interesting to explore how the successful integration of these two paradigms enables boardrooms to monitor the effectiveness of risk mitigation strategies and adjust strategic pre-decision control mechanisms associated with SSIDMP. Such integration enables boardrooms to proactively introduce operational level changes and explore how the synergy between I4.0 technology and CE techniques offers improved, balanced and understandable mechanisms that would allow companies to provide relevant stakeholders with the necessary information. Finally, future studies may examine the influence of the two domains on a company's dynamic capabilities and value creation determinants.

Declaration of competing interest

The authors confirm that they do not have any conflicts of interest to declare.

Data availability

Data will be made available on request.

Acknowledgments

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Appendix 1

CE Techniques Proxy	
Circular economy	Lower carbon footprint products
Circularity	Low carbon raw materials
Circulate capital	Low-carbon desalination
Circulate approach	Limiting the increase in our waste generation
Cleaner production	Manufacturing resource reduction
Cleaner product	Material recycling
Circular economy strategy	Minimise water use
Closed-loop recycling	New ways to source
Creating products from waste	New products from the waste itself
Decarbonise	Natural resource efficiency projects
Developing new materials	Natural resource reduction
Energy recovery	Percentage of waste recycled
Electric cars	Percentage of plastic packaging to be reusable, Percentage of plastic packaging to be recyclable
Efficient waste infrastructure	Renewable sources
End-of-life solutions	Producing materials essential to a low-carbon economy
Alternative consumption	Pollution emissions
Alternative fuel	Pollution prevention
Avoiding landfill disposal	Product innovation
Alternative heating solutions	Renewable
Adopt circular economy principles	Renewable sources for power
Cut the amount of plastic we use Eliminating pollution	Renewable sources for heat

(continued on next page)

(*continued*)

Eliminating waste	Reducing water use
Energy recovery	Reducing material use
Energy efficiency	Reduction in potable and raw water consumption
Energy transition	Reducing pollution
Energy storage system	*Re*-using materials
Green economy	Re-using products
Green product	Reduce energy consumption
Green future	Reduce waste production
Greener future	Recycled plastic
Illuminating plastics	Recycled carbon
Investment in water treatment	Restore land-use
Investment in waste treatment	Reduce road miles
Investing in waste reduction projects	Reducing plastic packaging emissions
Improving waste infrastructure	Reducing manufacturing emissions Reducing transport emissions
Introduce new modes of production	Reducing food waste
Introduce new modes of production consumption	Reduce carbon emissions
Hydropower	Reduce spills
Hydrothermal	Reduce dependency
lowers CO_2 emissions	Reduce environment footprint
Metal recycling	Reduce greenhouse gas emissions
Regenerating natural systems	Reprocess waste
Renewable energy	Resources efficiency
Renewable materials	Responsible consumption of resources
Renewable sources	Recycled metal
Narrowing material	Recycling system/s
Reprocess	Shared production
Recycle /Recycled	Shared assembly
Reutilize	Shared mobility
Repurpose	Solar electricity
Remanufacture	Solar capacity
Repair	Sustainable future
Reuse/ reused	Sustainable purchasing
Refining	Sustainable water
Reinvent /reinventing	Sustainable product
Renew	Transition to a circular economy Recycled materials
Regenerate	Wind turbines
Recycling	Waste prevention
Remanufacture	Waste minimizing
	Waste management
	Waste prevention
	water efficiency
	Water reduction and reuse projects
	Water stewardship compliance
	Water management
	Waste management solutions
	Waste treatment
	Waste heat recovery systems
	Using resources efficiently
	Unlock circularity
I4.0 Proxy	
Investment in advanced technologies	Intelligent algorithms
Investment in advanced technology	Automation
Internet of Things	Artificial intelligence
3D printing	Digital transformation
Cloud-based technologies	An integrated data platform
Novel computing technologies	Process automation
Machine learning	Digital communication interfaces
Greater automation and smart analytics	Digital transformation
Emerging technology	Digital modelling
Emerging technologies	Digital applications
Cutting-edge technologies	Digitalization strategies
Advanced technology	Digital technologies *and* analytics
Advanced technologies	Digital capabilities
Technology	Hybrid technology
Technological advancement	*Disruptive technology*
Technological innovation	Machine learning
New technologies	Integrated data platform
The next generation of tools	Robotics
Next generation technologies	Robots
Next generation technology	Robotic
Next technologies	Digitalisation
Next technology	Data analytics
Innovation	Automating activities.
Innovation processes	**Driverless vehicles**
Blockchain	**Drones**
	Data as an asset

(*continued on next page*)

(*continued*)

Benefits	
More flexible resource allocation	To save business money
Agile decision making	Most value to our customers
Enhance decision making	Long-term growth
Support decision making	Better connected
Improve decision making	Provide greater automation
Simplifying systems	Smart analytics
Simplify and improve processes	Support manufacturing process
Automating activities	Support operational process
More transformative and digital capabilities	Support supply chain
Digital capabilities	Support sales capabilities
Digitalisation of trade	Augmented decision support
Digital modelling to make operations safer and more efficient	Demand-driven supply chain
To keep people safe	Additive manufacturing
High levels of efficiency	Product improvement and innovation
Intelligent operations	Product improvement
Flexible production	Product innovation
Revenue growth and profitability	Rising customer satisfaction and loyalty
Accelerate product development	Increasing customer satisfaction
Cost efficiency	Attractiveness with respect to tax
Quality	Tax incentives
Enhance product safety evaluation	Trade incentives
Enhance the long-term efficiency	Improve data governance
Enhancing the long-term efficiency Improvement of the business	Improve data analytics capability
New opportunities for revenue growth	Reduce operating costs
Optimise our business processes	Reduce documentation
Optimise working capital	Reduce turnaround times
Optimizing	Blockchain transaction
Optimisation	Support the evolving needs of the business
Optimise	Enhance communication
Operational decisions can be made Independently of humans	Enhance risk mitigation capabilities
New digital service model	Risk mitigation capabilities
Greater leadership accountability	Enhance scientific innovation
Long-term competitiveness	Increase collaboration
Efficiency	Safeguarding and communicating data.
Simplify processes	Safeguarding data.
Enhance our productivity	Communicating data.
More productive through digital solutions	Confidentiality and integrity
Digital solutions	To serve our customers better
	To stay competitive
	Enhanced service levels
	Reduction in inventories
	Improved transport flows and costs
	Improve overall customer experience

Appendix 2. Correlation analysis

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) CE	1.000													
(2) I4.0	0.458	1.000												
	(0.000)													
(3) FSIZE	0.459	0.238	1.000											
	(0.000)	(0.000)												
(4) SALES	0.413	0.280	0.358	1.000										
	(0.000)	(0.000)	(0.000)											
(5) MARKCAP	0.264	0.099	0.358	0.656	1.000									
	(0.000)	(0.000)	(0.000)	(0.000)										
(6) LEVERAGE	0.371	0.151	0.843	0.543	0.612	1.000								
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)									
(7) CAPEX	0.307	0.124	0.204	0.828	0.826	0.509	1.000							
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)								
(8) ROA	−0.138	−0.085	−0.058	−0.044	0.001	−0.054	−0.020	1.000						
	(0.000)	(0.000)	(0.000)	(0.001)	(0.950)	(0.000)	(0.188)							
(9) PPE	0.369	0.141	0.184	0.843	0.758	0.512	0.937	−0.031	1.000					
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.058)						
(10) IA	0.453	0.165	0.228	0.267	0.623	0.421	0.344	0.053	0.331	1.000				
	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.182)	(0.000)					
(11) RD	0.054	0.057	0.024	0.040	0.040	0.031	0.037	0.039	0.041	0.077	1.000			
	(0.033)	(0.026)	(0.187)	(0.026)	(0.027)	(0.083)	(0.049)	(0.034)	(0.035)	(0.066)				
(12) BSIZE	0.307	0.292	0.304	0.232	0.505	0.345	0.185	−0.012	0.172	0.310	0.039	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.689)	(0.000)	(0.000)	(0.260)			
(13) BINDE	0.469	0.206	0.328	0.281	0.270	0.334	0.193	−0.062	0.189	0.303	0.048	0.322	1.000	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.008)	(0.000)		
(14) AINDE	0.259	0.082	0.079	0.084	0.064	0.093	0.081	0.007	0.148	0.237	0.091	0.154	−0.207	1.000
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.707)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	

Notes: The definitions of all variables are presented in Table 1.

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