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From dark data to insight: The role of knowledge management in promoting digital decarbonisation

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Background: Sustainable transformation is a key component of organisational sustainability, particularly as the exponential growth of data drives the need for energy-intensive data centres. This study focussed on knowledge management (KM), specifically dark data management, as a practice to reduce the demand on data centres that ultimately contributes to carbon emissions.

Objectives: Data-driven technologies have exponentially increased data generation, much of which remains unused as dark data. Dark data contribute to the growing environmental impact of digital activities, as the storage and processing of unused data require substantial energy resources.

Method: The study applied a survey strategy to analyse 539 responses through factor analysis, using the Statistical Package for the Social Sciences (SPSS) software tool to investigate dark data KM strategies and practices towards supporting digital decarbonisation and enhancing organisational sustainability. Qualitative data were analysed using thematic analysis and integrated with the extracted factors.

Results: The study identified 13 key considerations to derive a socio-technical work system using KM strategies and practices in support of digital decarbonisation and sustainability: business process, data governance and stewardship, data management, data security, decision-making, interdisciplinary collaboration, knowledge and information management, measurement, organisational culture, organisational goals, organisational learning, technology and organisational structure.

Conclusion: Rather than considering typical Green Information Technology (IT) strategies, this study focussed on KM, specifically dark data management, as a practice to reduce the demand for data centres that ultimately contribute to carbon emissions.

Contribution: The study offers insights into applying KM capability as an additional approach to achieving Green IT goals for organisations focussing on Green IT strategies.

Keywords: knowledge management; dark data; organisational sustainability; digital decarbonisation; Green IT strategies.

Introduction

Digitalisation, a leading global megatrend, is reshaping the corporate landscape through its rapid pace and complexity (Vivas et al. 2024). Furthermore, digitalisation and its associated technologies are driving significant transformations in the organisational environment as businesses work towards achieving the United Nations Sustainable Development Goals (SDGs) (Yilmaz 2023). Digital technologies unlock new opportunities for adding value by transforming business models and streamlining workflows while influencing socioeconomic and environmental dimensions (Chatterjee, Rana & Dwivedi 2024).

These rapid technological advancements and innovations in storage, hardware and software are propelled by digital transformation and have significantly accelerated data growth (Vermesan & Friess 2022). This data expansion has enabled organisations to collect and utilise information more effectively, converting decision-making from intuition-based to data- and evidence-based approaches (Brynjolfsson & McElheran 2016; Smuts & Smith 2021). The adoption of data-centric strategies has transformed business models, fostered product innovation (Lies 2019), enhanced organisational performance (Chaudhuri et al. 2024) and improved customer experiences (Saura, Ribeiro-Soriano & Palacios-Marqués 2021). The rise of these advanced data management strategies, alongside artificial intelligence (AI) integration for predictive analysis, highlights the importance of data automation, marketing intelligence and business intelligence (Liu & Lai 2022). Artificial intelligence-driven big data analysis spans all data generation, acquisition, storage and evaluation phases, generating value at each stage through insights, recommendations and decision support (Grander, Da Silva & Santibañez Gonzalez 2021). The effective use of big data can potentially transform economies, driving new growth and becoming integral to business models, processes and information systems (Surbakti et al. 2020).

To explore the interplay between knowledge management (KM) and digital decarbonatisation, Jackson and Hodgkinson (2023) developed the Data Carbon Ladder, a digital data carbon measurement tool designed to help organisations assess their carbon footprint across the stages of the data-to-information-to-knowledge journey (Knowledge Pyramid) (Jackson & Hodgkinson 2023). Zhong et al. (2024) addressed the challenge of using KM as a digital decarbonisation strategy by constructing a Knowledge Management System (KMS). Georgiou et al. (2024) considered the environmental impact of the data industry associated with digital knowledge practices, while Inderwildi et al. (2020) discuss how cyber–physical systems (CPS) create synergistic effects that enhance the efficiency of energy provision and industrial production, thereby optimising economic feasibility and reducing environmental impact. The authors also examined the role of intelligent CPS in improving systemic resilience and energy security, culminating in policy recommendations (Georgiou et al. 2024; Inderwildi et al. 2020; Zhong et al. 2024). However, these research articles integrated KM practices into the broader sustainability goals of specific organisations (manufacturing and supply chain) and involved setting long-term objectives to reduce carbon emissions by managing knowledge. In this article, KM as a digital decarbonisation practice denotes more specific, actionable steps or tools within the KM framework that directly contribute to digital decarbonisation by leveraging AI and data analytics to inform sustainable decision-making processes.

However, the growing demand for data collection and storage in an increasingly digitalised world has led to a rise in the need for data centre services (Shehabi et al. 2018). Technologies such as AI, smart and connected energy systems, distributed manufacturing and autonomous vehicles are expected to increase this demand further (Masanet et al., 2020). Because data centres are energy-intensive, accounting for up to 3% of global electricity consumption, these trends raise significant concerns (Law 2022). Firstly, data centres are largely powered by carbon-intensive energy sources such as natural gas and coal (Law 2022). Secondly, their massive electricity consumption produces substantial carbon emissions (Cao et al. 2022). To align with the SDGs (SDG 7 and SDG 13), which aim to reduce carbon emissions through clean energy, organisations must adopt Green Information Technology (IT) strategies in the context of data generation and storage (Yang et al. 2024). These strategies include e-waste management, energy-efficient data centres, green procurement, dark data management and sustainable software development (Schembera & Durán 2020; Sharanya, Vijayalakshmi & Radha 2024; Siebra et al. 2013; Yadav et al. 2023,). By implementing Green IT strategies, organisations can take key steps towards digital decarbonisation, reducing their carbon footprint while driving sustainable innovation in the digital age (Jackson & Hodgkinson 2023; Liao et al. 2024).

This article focusses on digital decarbonisation, specifically applicable KM strategies and practices to address digital decarbonisation. It builds on an investigation by Jackson and Hodgkinson (2023) into responsible management practices based on extensive work in organisational learning and the KM field, as well as a review of environmental competencies by Dzhengiz and Niesten (2020), which refers to managerial skills aimed at enhancing environmental sustainability. This article seeks to explore the role of KM in promoting digital decarbonisation by considering the research question: 'What dark data management KM practices should be implemented to support digital decarbonisation and enhance organisational sustainability?'. By exploring the intersection of digital decarbonisation and KM, this study aims to offer actionable KM strategies to enhance organisational practices and decision-making towards sustainability.

The article is structured as follows: 'Background of the study' section introduces key concepts related to digital decarbonisation and KM focussing on the roles of data and dark data in organisational sustainability. Section 'Materials and methods' provides a description of the research design, and Section 'Results' contains an analysis of the data presented in the findings section. Section 'Discussion' reflects on the discussion, Section 'Knowledge management strategies and practices in promoting digital decarbonisation and sustainability' relates to the research contribution by highlighting the key insights derived from the findings, and Section 'Conclusion' reflects on the conclusion of the article.

Background of the study

Sustainable transformation has emerged as a key component of organisational sustainability, particularly because exponential data growth drives the need for energy-intensive data centres (Lörsch et al. 2024). As organisations generate vast amounts of data, effective management becomes vital (Thomas & Chopra 2020; Zhong et al. 2024). Knowledge Management can serve as a strategic tool to address this challenge by optimising how organisations manage data (Jackson & Hodgkinson 2023).

Organisational sustainability

Organisational sustainability is a multidimensional approach that addresses long-term business challenges, including climate change, industrial waste, economies of scale and social well-being, among others (Kumari & Singh 2023). Organisational sustainability involves having the necessary leadership, resources, global perspective and adaptive strategies to address these unique challenges (Rahman 2022).

The adaptive strategies of an organisation to endure over time incorporate balancing economic, environmental and societal aspects for long-term success (Singha 2024). The economic component measures the financial performance of an organisation by considering not only profit but also the economic value created for all stakeholders. It includes factors such as revenue generation, cost management and long-term financial sustainability. The objective is balancing profitability with social and environmental responsibilities, ensuring that economic success does not come at the expense of ethical and sustainable practices (Dao, Langella & Carbo 2011). The environmental aspect assesses an organisation's environmental impact, including resource consumption, waste generation, emissions and ecological preservation. It encourages companies to minimise their ecological footprint, adopt sustainable practices and promote biodiversity. The aim is to ensure that business operations do not harm the planet, but rather contribute to environmental sustainability (Dao et al. 2011). The societal aspect evaluates the impact of an organisation's activities on its stakeholders, including employees, customers, suppliers and the community. It focusses on issues such as employee practices, human rights, community engagement and overall social equity to ensure positive social outcomes and enhance the quality of life for all affected parties (Dao et al. 2011).

These three aspects foster a holistic approach to business that values not only financial success but also social equity and environmental stewardship, necessitating innovative and socially responsible leadership (Chopra et al. 2021; Peerally et al. 2022). As leaders recognise essential knowledge and grasp its systemic nature and KM practices, organisations can embed sustainability principles successfully into their practices (Klingenberg & Rothberg 2020).

Knowledge management practices

Knowledge is a recognised fundamental source of organisational competitive advantage and value creation (Liu et al. 2019). Knowledge exists in two forms: explicit and implicit. Explicit knowledge refers to formally recorded, easily articulated and accessible information, such as manuals, reports and databases. This knowledge type can be shared and transferred efficiently within and between organisations (Li & Zhao 2023). Implicit knowledge is derived from individuals' experiences and is often not formally documented. It encompasses the skills, insights and contextual understanding individuals acquire over time, making it more challenging to express or codify (Davies 2015). A specific subset of implicit knowledge, tacit knowledge, refers to individuals' personal, intuitive and context-specific knowledge. Tacit knowledge is often gained through personal experience and is difficult to transfer through written or spoken communication (Li & Zhao 2023). Through well-documented data, reports and best practices, explicit knowledge can facilitate the sharing of sustainable processes and technologies, thus enabling organisations to adopt digital decarbonisation strategies more efficiently. Implicit and tacit knowledge is rooted in individual experiences and contextual understanding able to drive innovative, context-specific solutions for carbon reduction, thereby fostering a culture of sustainability that might be difficult to codify yet essential for impactful environmental practices (Wolf & Erfurth 2019; Wu, Lo & Ng 2019; Yang et al. 2024).

Knowledge Management is defined as the process of 'continually managing knowledge of all kinds and requires a companywide strategy which comprises policy, implementation, monitoring and evaluation' (Demarest 1997:374). A core concept of KM implementation in organisations is the Knowledge Pyramid, which outlines the transformation of raw data into valuable, actionable knowledge (Ackoff 1989; Frické 2019). Data form the base of the pyramid, consisting of unprocessed facts and figures. When these facts are organised and contextualised, they become information. As information is further analysed, synthesised and applied, it is elevated to knowledge, which supports decision-making and action (Ackoff 1989; Jennex 2009). Six KM processes facilitate the transformation from data to knowledge, ensuring its effective use and value to organisations (Costa & Monteiro 2016). Together, these KM processes, that is knowledge acquisition, storage, codification, sharing, application and creation, enable organisations to transform raw data into practical, actionable knowledge (Costa & Monteiro 2016; Jennex 2017). This ongoing cycle drives innovation, fosters growth and provides a sustainable competitive advantage (Costa & Monteiro 2016).

Organisational value of data and digital decarbonisation

Based on digital decarbonisation requirements, using advanced digital technologies must account for environmental challenges and recognise the potential of the KM discipline to reduce the overall carbon footprint through more effective KM practices (Santarius et al. 2023). This premise aligns with KM practice, whereby KM processes help transform data into information and then into knowledge (refer to the Knowledge Pyramid in the previous section). This approach highlights KM as a praxis for managing data, particularly dark data (unused or forgotten data that consumes storage resources without adding value), ultimately aiming to reduce carbon emissions from data centres and, consequentially, contributing to sustainability (Jackson & Hodgkinson 2023; Zhong et al. 2024).

Dark data, that is underutilised data, often contain valuable insights that, if effectively managed and integrated into KM practices, can provide opportunities for reducing carbon emissions and promoting sustainability (George et al. 2023). By adopting comprehensive KM strategies that address dark data, organisations can enhance their overall data governance, ensuring that all available data are leveraged to support sustainability initiatives and create organisational value (Ajis & Baharin 2019; Gimpel 2021). Organisations can make informed decisions that promote sustainability and contribute to digital decarbonisation efforts by applying KM as a practical approach to addressing the objectives of moving from data to green insights (Jackson & Hodgkinson 2023). By leveraging KM frameworks, organisations can optimise their operations to minimise waste and reduce energy consumption (George et al. 2023; Gimpel 2021). By creating a culture that encourages knowledge-sharing and collaboration, organisations can harness the collective intelligence of their workforce to generate new ideas and solutions that contribute to decarbonisation (Ajis & Baharin 2019). By utilising data to evaluate the environmental impact of their products and services, organisations can design and implement more sustainable design choices and practices, incorporating the development of green technologies towards creating organisational value (Vrchota et al. 2020).

The organisational value of data within the digital decarbonisation context is substantial (Huang & Lin 2023; Mohamed et al. 2024; Ye 2021). By leveraging effective KM practices to transform data into actionable insights, organisations can enhance resource management, foster innovation and manage dark data effectively (George et al. 2023; Roden et al. 2017). Furthermore, by aligning KM practices with broader environmental policies and frameworks, organisations can establish clear guidelines that integrate sustainability into their core operations (Smuts & Van der Merwe 2022). As a result, KM becomes a key component of the organisation's operational ethos instead of an isolated function, consequently fostering a culture of accountability and continuous improvement and, ultimately, enhancing resilience and adaptability in a rapidly changing environment (Godwin & Amah 2013; Miidom, Okoroafor & Mabel 2022).

Further to highlighting the key considerations for moving from data to green insights, Table 1 presents a summary of dark data management, sustainability and vital digital decarbonisation considerations within the KM context. The first column describes the key considerations, followed by citations highlighting the particular consideration.

Materials and methods

This study sought to examine the role of KM in promoting digital decarbonisation and applied a pragmatism philosophy (Goldkuhl 2012; Mcbride, Misnikov & Draheim 2022). Pragmatism emphasises understanding and improving reality by examining behaviours and applying knowledge to produce practical, real-world solutions (Goldkuhl 2012). A survey research strategy, defined as 'the collection of information from a sample of individuals through their responses to questions', was utilised (Check & Schutt 2011:160; Ponto 2015). The study was exploratory to gain a deeper understanding of the research problem and identify areas for further investigation (Mcbride et al. 2022). Hence, convenience sampling was applied as it enabled efficient data collection to explore trends and identify potential areas of interest aligned with the research objective and question (Oates, Griffiths & Mclean 2022).

Based on the factors extracted (Table 1) and consistent with the survey research strategy, a questionnaire with three

TABLE 1: Knowledge management, dark data management, sustainability and digital decarbonisation (KMSU) key considerations summary.

Key considerations summary from the literature	References
Implementing measures to reduce the energy consumption of servers and computers and clear goals and metrics to track the progress of energy-efficient IT operations	Uddin and Rahman (2012), Shao et al. (2022), Gandhi et al. (2023), Corbett (2010)
Conducting employee workshops and training sessions to create visibility of Green IT sustainability objectives and to collect experience-based insights from employees	Vrchota et al. (2020), Shahzad et al. (2020), Brooks, Wang and Sarker (2012), Corbett (2010)
Effectively identifying, capturing and tagging single-use knowledge for possible future usage	Jackson and Hodgkinson (2022), Jackson and Hodgkinson (2023)
Procuring and using IT hardware designed for sustainability, including the use of environmentally friendly materials and energy-efficient devices	Yadav et al. (2023), Sharanya et al. (2024), Schembera and Durán (2020), Bathre and Das (2020), Khosravi et al. (2024)
Implementing e-waste management policies, including responsibly disposing of, recycling and reusing outdated IT equipment	Yadav et al. (2023), Sharanya et al. (2024), Schembera and Durán (2020)
Applying software development practices that emphasise energy efficiency, ensuring that applications minimise processing power and energy usage	Katal, Dahiya and Choudhury (2023), Adhiatma, Fachrunnisa and Tjahjono (2021), Siebra et al. (2013)
Having an awareness of the potential risks and challenges associated with managing dark data and implementing strategies to identify and manage dark data within data storage systems by uncovering valuable insights	Ajis and Baharin (2019), George et al. (2023), Schembera and Durán (2020), Gimpel (2021)
Avoiding and/or discarding single-use knowledge after its immediate use reduces opportunities for reusing valuable insights	Jackson and Hodgkinson (2022), Jackson and Hodgkinson (2023), Mersico et al. (2024), Yates (2016)
Taking a structured approach to converting information into actionable knowledge and valuable insights, particularly when dealing with dark data, towards organisational wisdom and strategic decision-making	Ajis and Baharin (2019), Khan, Usman and Moinuddin (2024), Beer (2020), Costa and Monteiro (2016)
Establishing a centralised database for tracking carbon emissions from all digital operations, allowing monitoring and reduction of digital carbon footprint	Yang et al. (2024), Yadav et al. (2023)
Utilising a KM system, including tools and protocols for analysing energy consumption data across all IT systems, supporting energy efficiency improvement	Liao et al. (2024), Yadav et al. (2023), Yang et al. (2024) Abbas and Khan (2023)
Providing employee guidelines on sustainable software development, including how to write energy-efficient code and minimise computational waste	Siebra et al. (2013), Shahzad et al. (2020), Sharanya et al. (2024)
Adopting virtualisation and cloud computing to reduce the physical footprint and energy consumption of IT operations	Achar (2022), Katal et al. (2023), Sharanya et al. (2024), Oztemel and Gursev (2020)
Sharing, documenting, and exchanging tacit knowledge (knowledge gained through experience) among employees to improve dark data management	Hung et al. (2024), Asbari et al. (2020), Davies (2015), Zhong et al. (2024)
Combining documented knowledge to create comprehensive strategies for managing dark data and empowering employees to apply these strategies into their everyday practices to enhance the management of dark data	Gimpel (2021), Lugmayr et al. (2017), Yang et al. (2024), Jackson and Hodgkinson (2023)

Note: Please see the full reference list of this article, Smuts, H. & Van der Merwe, A., 2025, 'From dark data to insight: The role of knowledge management in promoting digital decarbonisation', *South African Journal of Information Management* 27(1), a1967. https://doi.org/10.4102/sajim.v27i1.1967, for more information.

IT, information technology; KM, knowledge management.

sections was developed, aligned with the research question for this study. The questionnaire included a demographic section, a content section using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree), and a general section with an open-ended question. The open-ended question was intended to capture any additional KM strategies or practices the respondents wished to share regarding the research topic. The questionnaire was hosted on *SurveyMonkey* (https://www.surveymonkey.com/), and a URL was generated and shared via *LinkedIn* networks, including KM practitioner groups. After reading a description of the background and purpose of the study, the respondents provided informed consent before accessing the questionnaire. Quantitative and qualitative data were collected over a 3-month period from August to September 2024. The quantitative data were statistically analysed utilising Statistical Package for the Social Sciences (SPSS, IBM Corporation, Armonk, New York, US) v29.0.0.0, including reliability tests through Cronbach's alpha, one-way analysis of variance (ANOVA) and factor analysis. Thematic analysis was applied to analyse the qualitative data, creating themes and a frequency count (Oates et al. 2022).

Ethical considerations

Ethics in research ensures that studies are conducted responsibly, respecting participants' rights, dignity and well-being (Oates et al. 2022). It requires obtaining informed consent, maintaining confidentiality and adhering to honesty, integrity and fairness principles throughout the research process. As part of the ethics process, this study was approved by the Institutional Ethics Committee. Ethical approval to conduct this study was obtained from the University of Pretoria and Faculty Committee for Research and Integrity (EBIT/23/2022).

Results

This article presents the study results in three sections: the demographic profile, the statistical analysis and the thematic analysis. The respondents' demographic profiles include their location (continent), operating and decision-making roles, and the industry sectors represented. Of the 606 responses received, 11 respondents did not provide consent and 23 gave consent but did not begin the questionnaire. After screening for incomplete data, 33 responses were excluded, with 539 remaining for analysis. Table 2 and Table 3 display the respondents' continental locations and industry sectors.

Table 2 represents the distribution of the respondents across seven continents. North America has the largest representation at 31.9% (172), followed by Europe at 21.5% (116) and Asia at 19.9% (107). Africa (10.8%) and Australia (9.8%) have moderate representation, while South America (5.8%) and Antarctica (0.4%) have the smallest shares.

Table 3 depicts the industries, with the highest contribution from IT at 21.9% (118), followed by banking and financial services at 13.5% (73), construction and building at 10.0% (54), education at 9.8% (53) and healthcare at 9.6% (52). The remaining industries, such as agriculture, automotive, engineering, telecommunication, hospitality, aerospace and aviation, and niche sectors such as legal services, the military, mining, and waste and recycling, each represent a smaller share of the overall profile.

Table 4 and Table 5 presents the respondents' functional roles consisting of their operating roles and decision profiles.

Table 4 highlights three operating roles, with KM practitioner the most prominent at 41.7% (225), followed by data analyst or data scientist and organisational learning practitioner,

TABLE 2: Location of respondents.

Continent	Count	%
Africa	58	10.8
Antarctica	2	0.4
Asia	107	19.9
Australia	53	9.8
Europe	116	21.5
North America	172	31.9
South America	31	5.8
Total	**539**	**100.0**

TABLE 3: Representation of industry sectors (in percentage).

Industry	Count	%
Aerospace and aviation	10	1.9
Agriculture	19	3.5
Automotive	19	3.5
Banking and financial services	73	13.5
Construction and building	54	10.0
Education	53	9.8
Engineering	16	3.0
Healthcare	52	9.6
Hospitality	12	2.2
Information technology	118	21.9
Legal services	6	1.1
Military	4	0.7
Mining and minerals	4	0.7
Telecommunication	17	3.2
Waste and recycling	6	1.1
Other	76	14.1
Total	**539**	**100.0**

TABLE 4: Operating roles of respondents.

Operating role	Count	%
Data analyst or data scientist	107	19.9
Knowledge management practitioner	225	41.7
Organisational learning practitioner	107	19.9
Other	100	18.6

Note: *Operating role* refers to a position responsible for the day-to-day execution of business activities, ensuring smooth operations and alignment with strategic goals.

TABLE 5: Decision profiles of respondents.

Decision profile	Count	%
Decision-implementation	158	29.3
Decision-making	345	64.0
Other	36	6.7
Total	**539**	**100.0**

Note: *Decision-making profile* defines an individual's approach, authority, and responsibility for making decisions that impact business outcomes and operations.

both at 19.9% (107). Where respondents selected the Other category, operating roles such as C-level roles and consulting roles were specified. Table 5 depicts the decision profiles of the respondents, with decision-making having the highest representation at 64.0% (345). Decision-implementation accounts for 29.3% (158), while the respondents specified consultant and general staff in the Other category.

In terms of the statistical analysis, Cronbach's alpha reliability for the factors is 0.973, suggesting that the 18 Knowledge Management Sustainability (KMSU) factors have excellent internal reliability (Izah, Sylva & Hait 2023; Tibeica et al. 2024). This result implies that the factors are closely correlated. Factor analysis was used to identify a relatively small number of factor groupings that can be used to represent relationships among sets of many interrelated variables (Field 2024; Purwono et al. 2023). This technique was applied to the questionnaire data to explore the groupings that might exist among the KMSU factors promoting digital decarbonisation. The Varimax rotation method was used to produce factor loading that minimises the number of variables with high loadings, either positive or negative, for each factor (Akhtar-Danesh 2017). For the KMSU factors extracted from the literature, the factor analysis shows that 18 KMSU factors can be grouped into four principal factor classifications, as depicted in Table 6.

After the Varimax rotation, Factor Grouping 1 (interpreted as *digital decarbonisation and KM practices*) accounts for 25.45% of the total variances between KMSU factors, whereas Factor Grouping 2 (interpreted as *dark data management and risk mitigation strategies*) accounts for 18.92% of variances between KMSU factors. Factor Grouping 3 (interpreted as *energy-efficient IT operations and sustainable hardware practices*) accounts for 18.80% of the total variances between KMSU factors, and Factor Grouping 4 (interpreted as *knowledge reusability strategies*) accounts for 10.44% of the total variances between KMSU factors. These four factor groupings account for 73.61% of the total variances among KMSU factors.

The open-ended question enquired whether respondents wanted to suggest organisational strategies and practices related to KM that might be considered to manage dark data and, ultimately, digital decarbonisation, and 381 qualitative comments were captured. The analysis excluded comments in which respondents did not add any strategies, for example 'N/A', 'nothing further', 'comprehensive survey', and others, resulting in 315 lines for analysis. The comments were categorised by creating the themes depicted in Table 7 (Oates et al. 2022). Table 7 shows the theme, implementation guideline type, keywords and phrases contributing to the theme, as well as the count indicating the number of comments, of which some occurred more than once, contributing to the particular theme. The implementation guideline type was allocated based on the three branches of strategy suggested by Johnson et al. (2020), that is context, content and process. The Factor Grouping description relevant to that theme was inserted in the 'Factor' column based on the detailed description of the particular theme. The 'Other' category was excluded for further analysis.

TABLE 6: Rotated factor matrix (loading) of knowledge management practices to address digital carbonisation and sustainability.

Component†	1	2	3	4
We regularly conduct workshops and training sessions where employees share strategies for optimising server usage and reducing unnecessary data storage to support our sustainability objectives.	0.77	-	-	-
Our organisation has implemented a centralised database that tracks carbon emissions from all digital operations, allowing us to monitor and reduce our digital carbon footprint.	0.75	-	-	-
Employees are provided with guidelines on sustainable software development, including how to write energy-efficient code and minimise computational waste.	0.74	-	-	-
We have integrated digital decarbonisation targets, such as reducing data centre energy use by a specific percentage, into our KM and operational policies.	0.73	-	-	-
Our KMS includes tools and protocols for analysing energy consumption data across all IT systems, helping us identify areas for improvement in energy efficiency.	0.70	-	-	-
Our organisation combines various pieces of documented knowledge to create comprehensive strategies for managing dark data.	0.64	-	-	-
We have implemented effective strategies to identify and manage dark data within our data storage systems.	-	0.73	-	-
We prioritise the secure and compliant handling of dark data to ensure it does not pose a threat to our organisation.	-	0.73	-	-
Our organisation regularly reviews and analyses dark data to uncover valuable insights and reduce unnecessary data storage.	-	0.64	-	-
Our organisation is aware of the potential risks and challenges associated with managing dark data.	-	0.63	-	-
Our IT department has implemented significant measures to reduce the energy consumption of servers and computers.	-	-	0.73	-
Our organisation has implemented comprehensive e-waste management policies, including responsible disposal, recycling and reuse of outdated IT equipment.	-	-	0.72	-
We prioritise the procurement and use of IT hardware designed for sustainability, including the use of environmentally friendly materials and energy-efficient devices.	-	-	0.72	-
Our software development practices emphasise energy efficiency, ensuring our applications minimise processing power and energy usage.	-	-	0.71	-
The adoption of virtualisation and cloud computing in our organisation has significantly reduced the physical footprint and energy consumption of our IT operations.	-	-	0.68	-
We have established clear goals and metrics to track the progress of our energy efficiency initiatives within IT operations.	-	-	0.68	-
The practice of discarding single-use knowledge after its immediate use reduces opportunities for reusing valuable insights.	-	-	-	0.74
Single-use knowledge, valuable only for a specific purpose and not retained for future use, often leads to inefficiencies in our organisation.	-	-	-	0.74

KM, knowledge management; KMS, knowledge management system; IT, information technology.

†, Rotation converged in seven iterations; Extraction Method: Principal component analysis; Rotation Method: Varimax with Kaiser normalisation.

TABLE 7: Additional knowledge management strategies and practices suggested by respondents.

Themes	Factor associated	Respondent comments as description of the themes	Count
Business process	Knowledge reusability strategies	Improve business processes; process protocols to minimise steps across different departments and platforms; increase efficiency; processes related to the key components of our operational areas.	5
Data governance and stewardship	Dark data management and risk mitigation strategies	Conduct regular data audits; data generation and management policies, data governance and stewardship; data inventory; data governance framework; data literacy; data regulation and appropriate monitoring; encourage life-cycle management of data products.	36
Data management	Dark data management and risk mitigation strategies	Assessing the usefulness of such data; classifying the data based on the type of information; clean data strategy; collecting only necessary data; data classification and categorisation; identifying and cataloguing dark data sources, locations, and formats; data scraping and enrichment to deal with sparse and incomplete data; enterprise data management; metadata management.	53
Data security	Dark data management and risk mitigation strategies	Advanced security system; be more encrypted, more passwords, database, and security; firewall implementation and use of modern technology for better security and management of dark data; fully automatic security services.	16
Decision-making	Digital decarbonisation and KM practices	Data visualisations; data-driven decision-making; unlock insights; wisdom.	6
Interdisciplinary collaboration	Knowledge reusability strategies	Collaboration with external partners fosters innovative solutions; encourage cross-departmental collaboration to share knowledge on data management practices with a focus on reducing duplication of data; foster interdisciplinary projects or initiatives that require employees to work together across functional boundaries.	10
Knowledge and information management	Digital decarbonisation and KM practices	Create a knowledge repository with best practices, case studies, and lessons learned from managing dark data, enabling continuous organisational learning and improvement; documentation organisation, centralised consolidation hubs; implement KM and organisational learning strategies; taxonomy and ontology development; use the information efficiently.	34
Measurement	Digital decarbonisation and KM practices	Define goals; carbon footprint analysis; establish metrics and monitor systems to track effectiveness; define measurable targets. Regular review and optimisation; track sustainability impact; visibility on total data utilisation, i.e., data regularly utilised versus data largely dormant.	14
Organisational culture	Knowledge reusability strategies	Promote a culture of innovation across all levels; promote a culture of knowledge-sharing; promote a culture of continuous learning and sustainability.	5
Organisational goals	Energy-efficient IT operations and sustainable hardware practices	Long-term strategic plan that roadmaps a route towards sustainability goals; digital transformation strategies must incorporate overall governance and management of dark data and digital decarbonisation; IT strategic roadmaps; strategic goals to develop the work system within the organisation; sustainable products.	17
Organisational learning	Digital decarbonisation and KM practices	Build a data-responsible organisation using training and awareness; continuous learning; educate employees on data management best practices, data quality, and data governance; employees should be well informed and be aware of the goal of digital decarbonisation; knowledge related to KM and organisational learning; learn how to analyse dark data, making the concept and risks thereof clear to everyone in the organisation; ongoing research; online webinars to discuss changes and implement; organisational learning through data governance frameworks; publications and focus groups to spread information correctly.	59
Technology	Energy-efficient IT operations and sustainable hardware practices	AI-powered software and machine learning can help categorise dark data through analysis; cloud computing and storage; collaborative platforms; digital twinning; implement robust data discovery tools that use AI and machine learning to identify, classify, and categorise dark data; implement energy-efficient data storage and processing practices; invest in the right tools and technologies; invest in sustainable IT infrastructure; optimise data processing and storage.	51
Organisational structure	Knowledge reusability strategies	Department of specialists for troubleshooting; developing a separate department for managing dark data; using incentives and penalties; hiring knowledgeable personnel	6
Other	N/A	A total enterprise reinvention; improving customer experiences; time, commitment, and money	3
Total			**315**

KM, knowledge management; IT, information technology; AI, artificial intelligence; N/A, not applicable.

Table 7 presents 13 KM strategies and practices suggested by respondents, incorporating suggestions at a detailed level.

Discussion

This study sought to examine sustainability and dark data KM strategies and KM practices in support of digital decarbonisation. Factor Grouping 1: *digital decarbonisation and KM practices* consists of 6 KMSU factors, all reflecting high factor loadings (Williams, Onsman & Brown 2010). The following factors had the strongest association (0.771, 0.748, 0.737, 0.726, and 0.703, respectively): *creating awareness among employees to share strategies for optimised server usage*; *a centralised database that tracks, monitors and reduces the digital carbon footprint*; *employee guidelines on sustainable software development*; *integrating the digital decarbonisation target into KM and operational policies*, and *tools and protocols for analysing energy consumption data across all IT systems*. All of these factors are essential to advancing digital sustainability. The next KMSU factor, with a strong association of 0.640, calls for a strong focus on dark data management through documented knowledge. Organisations should develop comprehensive strategies for managing dark data by documenting and converting personal experience-based knowledge into usable formats while effectively sharing tacit knowledge among employees. This approach ensures a seamless flow from data to wisdom, enabling the extraction of valuable insights from dark data.

Factor Grouping 2: *dark data management and risk mitigation strategies* consists of four KMSU factors – all with strong association. The first two factors are: *effective strategies to identify and manage dark data* (0.734) and *prioritise the secure and compliant handling of dark data* (0.728). Effective strategies should be implemented to identify and manage dark data securely and compliantly, minimising potential risks to the organisation while managing the impact of dark data regarding digital decarbonisation. The next two KMSU factors: *conducting regular reviews* (0.624) and *analysing dark data to uncover valuable insights and reduce unnecessary data storage* (0.628). These factors create awareness of the potential risks and challenges associated with managing dark data. Organisations should review and analyse dark data proactively to uncover valuable insights, minimise unnecessary storage, and address potential risks and challenges.

Factor Grouping 3: *energy-efficient IT operations and sustainable hardware practices* consists of six KMSU factors – all with strong association. The first four KMSU factors are the following: *the implementation of measures to reduce the energy* *consumption of servers and computers* (0.732); *the implementation of e-waste management policies, including responsible disposal, recycling, and reusing outdated IT equipment* (0.717); *the procurement and use of IT hardware designed for sustainability* (0.716); and *implementing software development practices that emphasise energy efficiency* (0.708). Organisations should introduce measures to decrease energy consumption across servers and computers while establishing robust e-waste management policies for responsibly disposing, recycling, and reusing outdated IT equipment. In addition, sustainable procurement practices prioritise eco-friendly and energy-efficient hardware, and software development focusses on minimising computational energy use. The next two KMSU factors constitute: *adopting virtualisation and cloud computing in an organisation* and *establishing clear goals and metrics to track the progress of energy efficiency initiatives within IT operations*, with a factor loading of 0.677 and 0.676, respectively. By adopting virtualisation and cloud computing, organisations can reduce the physical footprint and energy consumption of their IT operations, supported by clearly defined goals and metrics to monitor energy efficiency progress.

Factor Grouping 4: *knowledge reusability strategies* consists of two KMSU factors with high loadings: *discarding single-use knowledge after its immediate use reduces opportunities for reusing valuable insights* (0.740) and *single-use knowledge not retained for future use often leads to inefficiencies in an organisation* (0.738). Discarding single-use knowledge after its immediate use limits opportunities to reuse valuable insights and often creates inefficiencies within the organisation. Single-use knowledge should be documented and stored for future reference, enabling its integration into broader knowledge-sharing practices to address this effect.

The four factor groupings with their KMSU factors will directly impact the application of KM in achieving digital decarbonisation. By implementing KM strategies, organisations can reduce the accumulation of dark data, thereby lowering the demand for data centres and minimising their associated carbon emissions. Through the efficient use, reuse and disposal of data, KM practices promote sustainable digital operations and align with broader environmental goals, thus contributing to both organisational efficiency and global efforts to reduce carbon footprints. The factor analysis through dimension reduction provides valuable insights by categorising KMSU factors into these coherent themes. The application of these themes in an organisational context facilitates targeted interventions. These groupings enable organisations to prioritise specific KM-driven approaches that align with their sustainability goals, enhancing both their operational efficiency and contribution to environmental stewardship.

By integrating the factor groupings (Table 6) with the themes identified from the qualitative feedback (Table 7), the study denoted specific KM strategies and practices promoting digital decarbonisation, as shown in Table 8. Guidelines were extracted and collated from the factor analysis descriptions and the qualitative comments provided by respondents (Table 7). Table 8 operationalises the findings of the study into a set of easily understandable and executable guidelines to apply KM as a practice towards achieving digital decarbonisation.

Knowledge management strategies and practices in promoting digital decarbonisation and sustainability

Because KM strategies and practices supporting digital decarbonisation and sustainability focus on the interaction between people and technology in the workplace, the KM strategies and practices in Table 8 were categorised according to a socio-technical framework to operationalise this study's findings. Trancossi, Pascoa and Mazzacurati (2021) have proposed a socio-technical framework consisting of four key components. The *technical sub-system* includes tasks (work, activity, and participation) and the physical system (hardware, software, and infrastructure). The *social sub-system* encompasses the employees (people) and the structure of the organisation. Optimal functioning of the work system occurs when people have the necessary competencies and production knowledge to manage digital decarbonisation and sustainability effectively. The technical sub-system is designed to be reprogrammable to accommodate changes in activities. This adaptive feature of the technical system is initiated by the workforce leveraging their knowledge and skills to enhance digital decarbonisation and sustainability efforts (Margherita & Braccini 2020).

This article proposes a socio-technical work system to operationalise the findings while recognising that the interaction between people and technology requires a socio-technical design for KM strategies and practice. The study applied the conceptual top-down and bottom-up approaches for architecting technology transitions proposed by Davis, Mazzuchi and Sarkani (2013) to create a socio-technical work system that the organisations could apply when defining their KM strategies and practices in support of digital decarbonisation and sustainability as depicted in Figure 1.

Figure 1 shows the two parts of a socio-technical system, with the identified KM strategies and the KM practices allocated based on their relevance to that particular socio-technical system component. Organisational goals are defined by incorporating specific sustainability targets that would guide efforts in the socio-technical work system to change the current state and focus on sustainability. Two KM strategies, namely business process and data management, were associated with *Task* in the technical system, and two KM strategies, that is technology and data security, were associated with the *Physical* system. Tasks are a key aspect of the technical system, requiring alignment between technology, people and processes. Linking these KM strategies to task management ensures that organisational activities are structured and measured effectively to support both technical efficiency and overall organisational objectives. Three KM strategies, namely decision-making, organisational

TABLE 8: Knowledge management strategies, practices and guidelines in support of digital decarbonisation and organisational sustainability.

Strategy	Practices	Guidelines
Digital decarbonisation and KM practices	Data governance and stewardship	• Conduct regular data audits • Establish data generation and management policies • Implement data governance and stewardship practices • Maintain a data inventory • Develop a data governance framework • Promote data literacy across the organisation • Ensure data regulation and appropriate monitoring • Encourage life-cycle management of data products • Conduct stewardship workshops and training sessions on reducing data storage
	Data management	• Assess the usefulness of data • Classify data based on the type of information • Implement a clean data strategy • Collect only necessary data • Perform data classification and categorisation • Identify and catalogue dark data sources, locations, and formats • Utilise data scraping and enrichment to address sparse and incomplete data • Practice enterprise data management • Manage metadata effectively • Conduct workshops and training sessions on optimising data storage • Combine documented knowledge to develop dark data management strategies • Prioritise secure and compliant handling of dark data to mitigate organisational risks • Implement effective strategies to identify and manage dark data within data storage systems
	Data security	• Implement advanced security measures (encryption, password management and firewall implementation) • Use modern technology for better security and management of dark data • Implement fully automatic security services
	Organisational learning	• Build a data-responsible organisation through training and awareness initiatives • Promote continuous learning in data management practices • Educate employees on data quality and governance best practices • Ensure employees are informed about the goals of digital decarbonisation • Enhance knowledge related to KM and organisational learning • Teach employees how to analyse dark data effectively • Clarify the concepts and risks of dark data to all members of the organisation • Conduct ongoing research to stay updated on best practices • Host online webinars to discuss changes and implement new strategies • Foster organisational learning through data governance frameworks • Utilise publications and focus groups to disseminate information accurately
Dark data management and risk mitigation strategies	Decision-making	• Preserve knowledge used for specific purposes to increase opportunities for reuse • Avoid discarding valuable insights after immediate application to boost organisational efficiency • Leverage data visualisations to improve comprehension • Foster a culture of data-driven decision-making • Extract insights from data to guide strategic actions • Convert insights into wisdom for informed decision-making • Regularly review and analyse dark data to uncover valuable insights
	Knowledge and information management	• Develop a centralised knowledge repository for best practices, case studies, and lessons learned from managing dark data • Establish centralised hubs for organising and consolidating documentation • Implement comprehensive KM strategies to enhance organisational learning • Create taxonomies and ontologies to structure and categorise knowledge effectively • Optimise the use of information to maximise its value • Retain single-use knowledge to enhance opportunities for reuse and reduce inefficiencies • Utilise tools and protocols in the KMS to analyse energy consumption data
	Measurement	• Recognise potential risks and challenges associated with managing dark data • Define clear goals for data management and sustainability • Establish clear goals and metrics to track energy efficiency initiatives within IT operations • Conduct carbon footprint analysis to assess environmental impact • Establish metrics and monitoring systems to track effectiveness • Set measurable targets for data management and sustainability initiatives • Regularly review and optimise data management practices • Regularly review and analyse dark data to uncover valuable insights and decrease unnecessary storage • Ensure visibility of total data utilisation, differentiating between regularly used and largely dormant data
Energy-efficient IT operations and sustainable hardware practices	Organisational goals	• Formulate a long-term strategic plan that provides a roadmap for achieving sustainability goals • Align digital transformation strategies with the governance and management of dark data and digital decarbonisation • Develop IT strategic roadmaps that support organisational objectives • Set strategic goals to improve the work system within the organisation • Focus on creating sustainable products • Recognise the potential risks and challenges related to managing dark data
	Technology	• Implement collaborative platforms for data management • Adopt virtualisation and cloud computing to reduce the physical footprint and energy consumption of servers and computers • Leverage digital twinning technology • Implement robust data discovery tools that use AI and machine learning for dark data identification, classification, and categorisation • Implement and optimise energy-efficient data storage and processing practices • Invest in the right tools and technologies and sustainable IT infrastructure • Implement comprehensive e-waste management policies (responsible disposal, recycling, and reuse) of outdated IT equipment • Prioritise procurement of sustainable IT hardware (environmentally friendly materials, energy-efficient devices) • Emphasise energy efficiency in software development to minimise processing power and energy usage • Provide guidelines on sustainable software development and energy-efficient coding
Knowledge reusability strategies	Business process	• Implement a centralised database to track carbon emissions from digital operations • Integrate digital decarbonisation targets into KM and operational policies • Improve business processes by minimising steps across departments and platforms • Increase efficiency in processes related to key operational areas
	Interdisciplinary collaboration	• Collaborate with external partners to foster innovative solutions • Encourage cross-departmental collaboration to share knowledge on data management practices • Focus on reducing duplication of data through collaborative efforts • Foster interdisciplinary projects that require collaboration across functional boundaries
	Organisational culture	• Promote a culture of innovation throughout the organisation • Foster a culture of knowledge-sharing among team members • Encourage a continuous learning mindset focussed on sustainability • Foster a culture of continuous learning to ensure valuable insights are preserved for future use
	Organisational structure	• Establish a specialised department for troubleshooting and managing dark data • Introduce incentives and penalties to promote proper management of dark data • Recruit knowledgeable personnel to strengthen dark data management efforts

KM, knowledge management; IT, information technology; AI, artificial intelligence; KMS, knowledge management system.

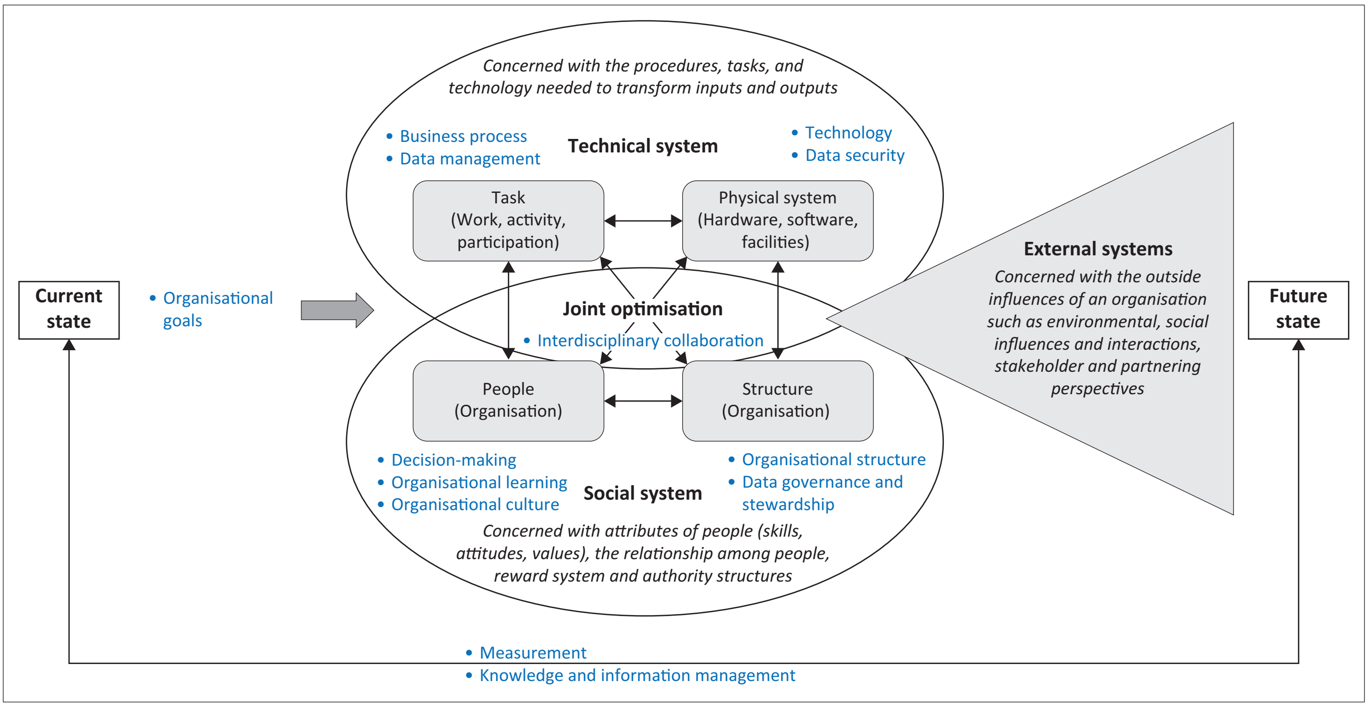

FIGURE 1: The knowledge management strategy and practice socio-technical work system supporting digital decarbonisation.

learning and organisational culture, were associated with people in the social system, highlighting the importance of aligning skills, knowledge and social dynamics to foster effective collaboration and informed decision-making within organisations. Two KM strategies, namely organisational structure and data governance and stewardship, were associated with *Structure* in the social system. Interdisciplinary collaboration is associated with joint optimisation and also incorporates external influences such as input from suppliers (e.g., cloud) or partners. Performance against the organisational goals and progress towards the future state is measured, and learning is incorporated in (or drawn from) the knowledge and information management system. The cyclical nature of the work system ensures that performance alignment with sustainability goals is constantly measured and continuously improved.

Key considerations associated with each of these KM strategies and KM practices are presented in and visualised in Figure 1, guiding organisations in the socio-technical environment to progress from data to green insights and on how to navigate this complex environment. The application of the guidelines in real-world scenarios may include an organisation that conducts regular data audits and establishes a robust data governance framework to ensure effective digital decarbonisation. In another case, an information communication technology (ICT) organisation could classify its data, implement a clean data strategy and develop secure protocols for handling dark data, thus reducing its carbon footprint by optimising energy usage in data storage. From a healthcare organisational perspective, an organisation might leverage interdisciplinary collaboration to share knowledge on data management practices, thus fostering a culture of continuous learning. In addition, organisations can adopt cloud computing and virtualisation to reduce physical hardware requirements, minimising environmental impact while maintaining operational efficiency. These practical use case examples demonstrate how the proposed guidelines can be successfully applied across industries to support sustainability and performance optimisation because the guidelines accommodate holistic thinking. Examples of organisations successfully implementing similar KM strategies and practices for sustainability include the Bayerische Motoren Werke AG (BMW) Group, which integrates digital decarbonisation through smart manufacturing, using data insights to reduce carbon emissions in production processes. They employ data management strategies to optimise energy consumption in their plants and use digital tools such as cloud computing and AI to reduce the environmental impact of their operations. Bayerische Motoren Werke AG also works on creating a circular economy model for its vehicles, leveraging digital data to minimise waste and carbon footprints (https://www.bmwgroup.com/en/sustainability.html). Google has invested in sustainable IT practices, including energy-efficient data storage and processing. The data centres of the company have been carbon-neutral since 2007, and it is working towards running its operations on 100% renewable energy. Google further utilises AI and machine learning for data-driven decision-making to reduce energy consumption and improve the overall efficiency of its cloud services (https://sustainability.google/).

Conclusion

This study strove to examine KM practices in support of digital decarbonisation and present a contextualised representation of what KM factors organisations must consider in support of digital decarbonisation. The researchers collected 539 questionnaire responses and analysed the data through a factor analysis for the Likert scale questions and thematic analysis for the open-ended question to identify the KM strategies and KM practices related to digital decarbonisation and sustainability. A total of 13 key KM strategies and KM practices were identified, each described by a list of guidelines. The KM strategies and KM practices were incorporated into a socio-technical work system to guide organisations in applying their KM capabilities to achieve digital decarbonisation and sustainability organisational objectives.

The study highlights several key factors, including the importance of digital decarbonisation, effective KM practices and dark data management strategies in promoting sustainability. It underscores the need for comprehensive data governance, data security and continuous learning within organisations to enhance both digital decarbonisation efforts and organisational performance. The study also emphasises the value of implementing energy-efficient IT practices, developing centralised knowledge repositories and fostering interdisciplinary collaboration to address dark data risks.

This research contributes to advancing KM strategies, particularly in managing dark data, to support digital decarbonisation goals. It provides actionable guidelines for organisations to integrate digital decarbonisation into their operations and decision-making, which will improve organisational efficiency, reduce carbon footprints and promote the reuse of valuable data insights. This study enriches the core discipline of KM by connecting it to emerging sustainability needs and organisational performance optimisation.

Future research could focus on empirically testing socio-technical work systems to better operationalise their application in organisational contexts. Such research might involve conducting longitudinal case studies across various industries to track the long-term impact of the socio-technical framework or implementing pilot projects in specific sectors to assess its practical viability. In addition, the proposed framework must be validated by examining its scalability and adaptability across differing organisational sizes, industries, and geographical regions. Such empirical testing would provide valuable insights into the effectiveness and potential for broader implementation of the socio-technical approach in driving organisational transformation.

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Authors' contributions

H.S. and A.v.d.M. conceptualised the study and contributed to validation, writing—review and editing, discussing the results and commenting on the manuscript. H.S. contributed to methodology, software, formal analysis, investigation, data curation, writing—original draft preparation and project administration. A.v.d.M was involved in supervision.

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Data availability

The data that support the findings of this study are not yet openly and readily available because of the data being part of an ongoing study and will be available from the corresponding author, H.S., upon reasonable request.

Disclaimer

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