Dissertationes Forestales 338

The role and value of data in advancing environmental sustainability with empirical evidence from tissue and textile businesses

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Academic Dissertation

To be presented, with the permission of the Faculty of Agriculture and Forestry of the University of Helsinki, for public examination in Porthania (PIII), Helsinki, on the 5th of April 2023, at 12 noon.

Title of dissertation: The role and value of data in advancing environmental sustainability with empirical evidence from tissue and textile businesses
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Dissertationes Forestales 338
https://doi.org/10.14214/df.338

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ISSN 1795-7389 (online)
ISBN 978-951-651-766-0 (pdf)

Publishers:
Finnish Society of Forest Science
Faculty of Agriculture and Forestry of the University of Helsinki
School of Forest Sciences of the University of Eastern Finland

Editorial Office:
Finnish Society of Forest Science
Viikinkaari 6, 00790 Helsinki, Finland
https://www.dissertationesforestales.fi

Luoma, P. (2023). The role and value of data in advancing environmental sustainability with empirical evidence from tissue and textile businesses. Dissertationes Forestales 338. 41 p. https://doi.org/10.14214/df.338

ABSTRACT

As the need for genuine sustainability transformation crystallises, data's digitalisation-enabled use creates opportunities to refine how businesses and societies operate. With the power of diverse data sources, available in increasing quantity, actors can set feasible environmental targets, identify improvement opportunities, implement actions, and follow development. The dissertation explores data's role and value for corporate environmental sustainability and specifically for circular economy from four perspectives: the customer-perceived value of data for environmental sustainability (considered via studying a tissue-paper supplier), how data' use influences sustainability pathways toward circular economy (specifically of textiles), paradoxical tensions that arise in utilising data to drive circular economy (in the textiles context), and how the literature characterises data's role and value in circular business models. A company case study, disaggregative Delphi and literature review were used as research methods. The work pinpointed availability of detailed, reliable product-specific data as crucial for supporting environmental sustainability and transparency of products' value chains. Also, capturing data's value here demands collaboration with customers and suppliers but also wider business networks, central to which are conditions for solid data-sharing. Consumers demand environmental sustainability, circularity, and accrue benefit from data-related decisions on individual purchases. The strategic and operative decisions/activities across business functions and throughout value chains further guide environmentally better-informed decisions. While use of data can be crucial to developing sustainable business models (for circularity specifically), the role varies less between models than with the activity supported. The results clearly implies that neither environment-related data nor initiatives utilising data automatically benefit the environment; the interactions are more complex. Still, the data are a critical business enabler, and anticipating future data needs should dovetail with systematically developing environment-related data-management capabilities. These findings provide rich insight as to the elements, mechanisms, and critical issues of data driving environmental sustainability and circular economy.

Keywords: business models; circular economy; data management; digitalisation; forest industry; textiles

ACKNOWLEDGEMENTS

Practical sustainability and corporate-responsibility work spanning more than two decades has provided a curious journey of continuously learning more about the world. I have benefited from the good fortune of a variety of perspectives, several contexts for future-oriented mindsets, and people willing to share their ideas to deepen understanding of the complexity of cultivating change. From such excellent starting conditions, I have always found it natural to look at opportunities, rather than limitations, and to trust that new openings will emerge even in fields beyond discovered horizons. For someone with this background, doctoral studies provided an excellent opportunity to address some of the emerging interdisciplinary developments that had interested me for a while already. One of these was the evident need for collaboration to create sustainable value jointly, and where could this need be more evident than for using digitalisation and data to enable environmental sustainability and circular economy? Now, with the research-driven insight gained in the course of pursuing my PhD degree, I can hardly wait to drive change in the real world. I enjoyed the PhD ride to the fullest. I was able to exploit my strengths and avoid most obstacles and dead ends. Also, my dream of living somewhere other than in Helsinki came true along the way. I offer sincerest thanks to my supervisors Anne Toppinen, Esko Penttinen, and Sami Berghäll for their constant encouragement and guidance throughout this project. I couldn't have hoped for better support as I explored the interdisciplinary territory of sustainability and digitalisation along my successful path to a doctorate. I would like to express gratitude also to other co-authors – Petri Tapio and Romana Rauter – for delightful collaboration and an opportunity to create something unforeseen together. Several other people deserve special thanks. Tobias Stern invited me to spend time at the University of Graz, in Austria, and Eric Hansen opened the doors to time in the US at Oregon State University. Both visits gave me invaluable inspiration and perspectives. I want to thank project steering-group members Samuli Patala and Pekka Pokela for insight and trust in me shown during the research project. My colleagues and clients at Impaktly and Gaia likewise receive my sincere thanks, for numerous fruitful discussions of sustainability and corporate responsibility – and of how to carry these into action. Finally, I extend great thanks to pre-examiners Karel van Acker and Rajat Panwar for their insightful comments and to Leena Aarikka-Stenroos for agreeing to act as my opponent in the public defence. Without financial support, this research would not have been possible. I warmly acknowledge Metsämiesten Säätiö Foundation for thus enabling my journey. It was financially sponsored also by KAUTE Foundation, and the travel involved was supported by Fulbright Finland and the University of Helsinki. I would like to express sincere gratitude for less tangible sustenance too – thanks to my friends for all the outdoor brainstorming sessions and for keeping me going. I am deeply grateful to my parents Helena and Simo for their unwavering support and belief in me ever since I was a little girl and to my loving sister Johanna for being there for me. Finally, thanks to Juha for joining the adventure.

Päivi Luoma
3 March 2023
Helsinki, Finland

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on two published research articles and two manuscripts. The articles are referred to in the text by their Roman numerals.

I. **Luoma P**, Rauter R, Toppinen A, Penttinen E (2023) (submitted manuscript) Data's value for environmental sustainability as perceived by the customers of a tissue-paper supplier.
II. **Luoma P**, Penttinen E, Tapio P, Toppinen A (2022) Future images of data in circular economy for textiles, Technol Forecast Soc 182, article id 121859, https://doi.org/10.1016/j.techfore.2022.121859.
III. **Luoma P**, Penttinen, E, Tapio P, Toppinen A (2023) (submitted manuscript). Paradoxical tensions at the interface of digitalization and circular economy: The case of the textile business.
IV. **Luoma P**, Toppinen A, Penttinen E (2021) The role and value of data in realising circular business models – a systematic literature review. Journal of Business Models 9(2): 44–71, https://doi.org/10.5278/jbm.v9i2.3448.

AUTHORS' CONTRIBUTIONS TO CO-AUTHORED ARTICLES

	I	II	III	IV
Concept and design	PL, RR, AT, EP	PL, EP, PT, AT	PL, EP, PT, AT	PL, AT, EP
Data collection	PL	PL	PL	PL
Data analysis	PL, RR	PL, PT	PL	PL
Writing of manuscript	PL	PL	PL	PL
Editing and reviewing	PL, RR, AT, EP	PL, EP, PT, AT	PL, EP, PT, AT	PL, AT, EP
Overall responsibility	PL	PL	PL	PL

PL = Päivi Luoma, AT = Anne Toppinen, EP = Esko Penttinen, PT = Petri Tapio, RR = Romana Rauter

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1. INTRODUCTION

As the need for a shift toward environmental sustainability grows clearer, the use of data, enabled by the rising speed of digitalisation, is opening opportunities to tune how businesses and societies operate. With the power of diverse data sources, available in increasing quantity, decisions can be improved, assets better utilised, operations efficiently managed, and customer experience extended (Chen et al., 2015; Günther et al., 2017). Corporations have an especially crucial role in the move toward environmental sustainability in that their operations, products, and services can both cause substantial negative environmental impacts and enable reducing them. Among the various notions applied to environmental and social performance – such as corporate responsibility, corporate social responsibility, and sustainability – the term 'corporate environmental sustainability' is used here, to stress the business focus while pointing specifically to the environmental factors and ensuring sufficient focus on the environmental impacts. Several concepts are identified as crucial for advancing environmental sustainability (D'Amato et al., 2017), with circular economy – transforming linear resource flows into cycles and thus eliminating waste (Bocken et al., 2016; Stahel, 1997) – being the concept given specific focus in the thesis project. Aimed at rendering business activities and practices circular rather than linear, circular economy opens up a host of opportunities from utilising data (de Mattos and de Albuquerque, 2018; Tura et al., 2019).

For managing corporate environmental sustainability, the use of data offers particular value for bringing environmental considerations into strategic and operative decision-making across a broad span of business functions, from product design to supply-chain management (Langley, 2022; Lopes de Sousa Jabbour et al., 2019). In this connection, data covering diverse aspects of product and service life cycles, the associated value networks, and related environmental impacts can be a valuable source of knowledge when the integration, discovery, and exploitation of this material (Miller, 2013) produce valuable insight in support of environmental sustainability. In general, data can be defined as objective facts about events and observations about the state of the world (Davenport and Prusak, 1998) or as symbols that represent properties of objects, events, and their environments (Ackoff, 1989). It is only after the transformation of data into knowledge by means of understanding said data in context and elaborating on the valuable patterns uncovered that the relevant data – 'environment-related data' for purposes of the doctoral project – can effectively improve environmental sustainability (Ackoff, 1989; Baskarada and Koronios, 2013; Frické, 2019; Rowley, 2007).

Data's ability to aid in setting plausible environmental targets, identifying improvement opportunities, carrying out actions, and monitoring the development on various fronts makes data-informed operations highly attractive in conjunction with organisations' work toward ambitious objectives they have set for themselves in relation to environmental sustainability, which address climate-change mitigation, circular economy, and biodiversity protection. When committing to science-based climate targets, for example, companies need to demonstrate progress on clearly defined pathways to significant reductions in greenhouse-gas emissions (Science Based Targets Initiative, n.d.). This demands better ways to manage their sustainability efforts.

At the same time, companies encounter increasing demands for transparency of their business activities and product value chains, from customers, investors, regulators, and other stakeholders (Herzig and Schaltegger, 2006). There is a strong driver for increased transparency in Europe is the EU regulation, including the sustainability information disclosure requirements by upcoming Corporate Sustainability Reporting Directive, the classification of sustainable activities by the EU Taxonomy, and the Digital Product Passport initiative to support circular economy. These requirements and commitments, which are moving toward the core of companies' strategies and promises to customers (Engert et al., 2016), encompass their own operations but also entire value chains (Comas Martí and Seifert, 2013; Dubey et al., 2019). These ambitious efforts call for better management of companies' environmental-sustainability agendas, which can be fuelled greatly by means of versatile data utilization (Busch et al., 2022; Liu et al., 2022; Rusch et al., 2022). However, various questions must be answered before their use of data can fully support environmentally better-informed decisions.

The interface of environmental sustainability and digital transformation amid increasing availability and utilisation of data is evolving rapidly, in both academia and practice. While the amount of research into the topic is growing (e.g., Bai et al., 2020; Ghobakhloo et al., 2021), with digitalisation and data recognised as forces toward environmental goals such as circular economy (see, e.g., Di Maria et al., 2022; George et al., 2021; Liu et al., 2022), little of it examines in more detail how the use of data can create value for environmental sustainability. The elements and mechanisms of using data to support environmental sustainability are not well-understood and understanding of critical issues of utilisation is lacking. Also, scholars have identified a clear need for more empirical research on applying digital paradigms for transition to environmental sustainability (Beltrami et al., 2021; O'Rourke and Lollo, 2021).

For tackling the dearth of research into how data can support that sustainability, the project was designed to explore data's value from four distinct perspectives (see Figure 1).

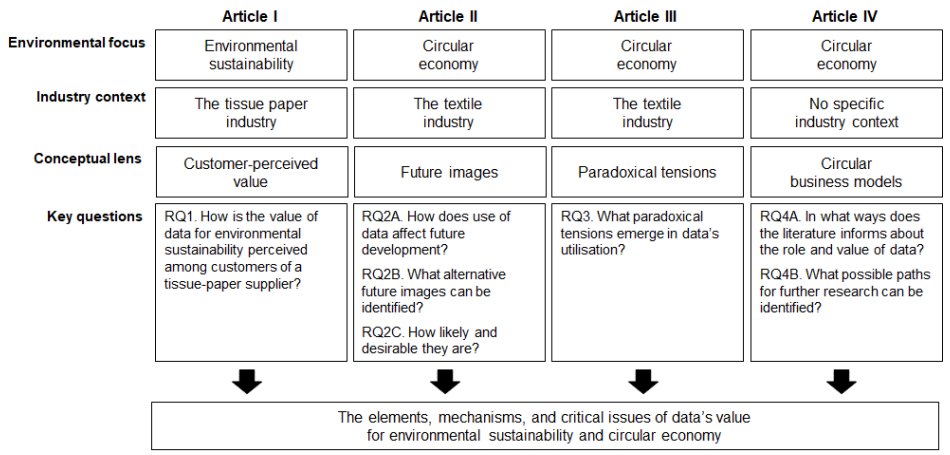

Figure 1. The positioning of the dissertation.

It does this by examining the value of data for environmental sustainability as perceived by customers of a tissue-paper supplier (Article I), exploring how the use of data may influence the sustainability paths leading toward future circular economy of textiles (Article II), understanding the paradoxical tensions that arise in utilising data to drive circular economy of textiles (Article III), and reviewing the literature on data's role and value in circular business models (Article IV). Specifically, the thesis addressed the following research questions:

> RQ1: How is the value of data for environmental sustainability perceived among direct business customers of a tissue-paper supplier? (Article I)
>
> RQ2A: How is the use of data going to affect the future development of circular economy related to textiles? (Article II)
>
> RQ2B: What alternative images of the future can be identified for the role of data in textiles' circular economy? (Article II)
>
> RQ2C: How likely and how desirable are the alternative images for the future related to textiles business? (Article II)
>
> RQ3: What paradoxical tensions emerge in the utilisation of data for implementing circular economy in the textile industry? (Article III)
>
> RQ4A: In what ways does the literature on circular business models inform us about the role and value of data in this set of models? (Article IV)
>
> RQ4B: Through a review, can one identify possible paths for further research related to the use of various forms of data in circular business models? (Article IV)

Multiple methodological approaches, appropriate for the various research questions addressed in different manuscripts, were applied and four conceptual lenses served establishing the scope for the theoretical and practical context of original-research papers within the project. Chosen to mesh with the goals, setting, and context of each respective study, these lenses supported conceptualising and articulating central constructs and aspects and facilitated understanding the relationships among these (Ravitch and Riggan, 2016). The description of perceived customer value produced enabled uncovering how customers regard the value of data (see Article I, responding to the first research question). Creating images of the future aided in understanding alternative future developments (see Article II, addressing RQ2A–C). Via the concept of paradoxical tensions, the project delved into potential contradictions in the development (see Article III, on RQ3). Finally, the concept of circular business models afforded assessment of data's link to them (see Article IV, on RQ4A and RQ4B). These various perspectives come together to create a versatile picture of data's value for environmental performance and circular economy.

The core contribution of the research lies in providing timely and rich insight pertaining to the elements, mechanisms, and critical issues surrounding the utilisation of data to drive environmental sustainability and circular economy. Theoretical and practical gaps are identified and filled with relevant empirical analyses. The empirical cases concretise related opportunities and challenges while also showcasing potential ways to move forward. The insight cultivated through them aids in exploring best practice for exploiting data in pursuit of environmental sustainability, also across value chains and industries, and, by means of experience, defining shared 'rules of the game' for utilising and sharing data for future

sustainability. Applying a future-oriented and explorative mindset ensures academic and practical relevance of this dissertation, even as the fields of environmental sustainability and digital transformation through increasing availability of data are evolving rapidly.

2. CONTEXTUAL BACKGROUND

2.1. Corporate environmental sustainability and circular economy

Considering environmental sustainability has become a necessity for any industry or business that desires to comply with stakeholder expectations and ensure its long-term business success. The objectives that companies have set themselves for environmental sustainability, not least in relation to climate-change mitigation, circular economy, and biodiversity protection, call for systematic reduction of negative environmental impacts of corporate activities (Khan et al., 2021) and for simultaneously reinforcing the positive impacts. Companies' activities for environmental sustainability are driven by growing demand from customers, investors, and regulators: customers ask for traceability of product value chains and ready verifiability of the environmental claims made (Rusch et al., 2022), investors call for business transparency and improvements in sustainability performance (Herzig and Schaltegger, 2006), and regulators want to ensure compliance and promote 'greener' production and consumption practices (Comas Martí and Seifert, 2013). Additional motivation to pursue sustainability may stem from expected economic benefits and the organisation's ethics commitments (Baumgartner and Rauter, 2017).

Corporate environmental sustainability is becoming less the legal-compliance matter of yore and more a strategic business issue, related to gaining a competitive edge and managing corporate reputation (Engert et al., 2016). It calls for integrating environmental considerations into business activities across functions from product design and supply-chain management to business development and sales (Meuer et al., 2020). Companies clearly need to ensure sustainability of practices throughout their supply chains (Sarkis et al., 2021; Sodhi and Tang, 2019) while also providing more sustainable purchasing and consumption alternatives for their customers and the ultimate consumers.

Development towards circular economy is among today's topical environmental-sustainability issues. It calls for eliminating waste and pollution, circulating products and materials responsibly, and regenerating nature. The aim in circular economy is to turn linear take–make–use–discard material flows into loops by extending customers' experience and products' service life, not just the reuse and recycling of materials (Bocken et al., 2016; Stahel, 2016, 2005; Tukker, 2015). Realising circular economy often requires changes that permeate the value network comprising customers, suppliers, manufacturers, and retailers (Awan et al., 2021; Saha et al., 2021; Urbinati et al., 2017); hence, this is an important context in which the opportunities represented by sustainable business models have been considered and studied (Rauter et al., 2022). So far, unclear short-to-medium-term business benefits have been hindering the realisation of circular economy (Huang et al., 2021; Yamoah et al., 2022), especially since circularity-oriented practices have been demonstrably driven by economic rather than environmental factors (Masi et al., 2018), and conflicts among diverse perspectives on sustainability could arise (D'Amato et al., 2019). However, rapid evolution is evident; for instance, EU-level regulatory pressure is creating

strong incentives for businesses to implement circular-economy-supporting strategies and practices (Awan et al., 2021; Gaur et al., 2021; Saha et al., 2021).

The value chains behind tissue papers and textiles currently face complex demands for environmental sustainability from a range of stakeholders that includes customers, investors, regulators, and other societal actors (Ghosal, 2015; Toppinen et al., 2017). Tissue papers' multi-tier supply chains, including forest management and harvesting, manufacture, logistics, retail sales, and use of the products, have implications for environmental sustainability (Vidal et al., 2010). Hence, climate change, resource-efficiency, and sustainable forest management have been prioritised on the industry's environmental agenda (Ranängen and Zobel, 2014; Tuppura et al., 2016). In the textile industry, meanwhile, a shift toward circular economy is regarded as specifically crucial to reduce the harmful environmental impacts connected with textiles (Niinimäki et al., 2020). Some interesting examples of textile circularity that emphasise long-term sustainability are appearing (Rovanto and Bask, 2021); however, some evidence exists that the industry is only beginning to implement associated practices (Saha et al., 2021).

2.2. The role of data in environmental sustainability and circular economy

The increasing availability of data, enabled by digitalisation, is changing how businesses operate. With the power of diverse data sources, digitalisation holds potential to be a key driver of environmental sustainability and circular economy (Demestichas and Daskalakis, 2020; Kristoffersen et al., 2020). In this connection, better use of data pertaining to diverse aspects of product and service life cycles, the connected value networks, and related environmental impacts can yield knowledge for improved environmental sustainability. The value of data in general is actualised via the transparency, optimisation, and deeper understanding (e.g., of customer needs) enabled (Chen et al., 2015). The specific value of data for environmental sustainability lies in the ability to bring environmental considerations to strategic and operative decision-making across business-functions boundaries and along entire value chains, including product design, supply-chain management, and the fundamental business models employed, not just atomic procurement and consumption choices (Langley, 2022; Lopes de Sousa Jabbour et al., 2019). Transparency of business activities and product value chains via digitalisation offers opportunities for performance improvements, supply chains' transformation, and collaborative innovation alongside customers and suppliers (Ebinger and Omondi, 2020; Garcia-Torres et al., 2019; Sodhi and Tang, 2019). The use of data could support, for example, enriching the customer experience via high-quality product and service design, extension of products' service life, and stronger user involvement (Ranta et al., 2021). Managing such data can also aid in optimising the environmental performance and resource utilisation of systems and value chains at a more technical and operations-oriented level (Masi et al., 2017; Tsolakis et al., 2021).

Most efficient utilisation of data to support environmental improvements calls for the data's application to power environmentally better-informed decisions (Chauhan et al., 2022; Lopes de Sousa Jabbour et al., 2018). Creating valuable information and knowledge through data's discovery, integration, and exploitation (Miller, 2013) holds promise for yielding such results as better use of one's assets, more efficient operations, cost savings, and extended customer experience (Chen et al., 2015; Günther et al., 2017). Through data's potential contribution to uncovering hidden patterns and heretofore unknown correlations

(Chen et al., 2015), this resource could afford more thorough understanding of businesses' impact on the environment and of improvement opportunities, such as those offered by circular economy. Making data-driven decisions in this context is seen as increasingly relevant along value chains in both directions, suppliers upstream and customers downstream (Dubey et al., 2019). This calls for better data management systems and integrations to efficiently share data across the actors along value chains (Gebhardt et al., 2021).

For promoting development towards circular economy specifically, exploiting data has been regarded as a significant enabler of corresponding strategies, practices, and business models (de Mattos and de Albuquerque, 2018; Tura et al., 2019). However, this is not without challenges such as difficulty and costs connected with gathering the data required, dataset-incompleteness problems, lack of common rules of the game, and the lack of clear benefits from data-sharing (Busch et al., 2022; Comas Martí and Seifert, 2013). Among the data relevant for circular economy are details of various aspects of product and service life cycles and more system-oriented data connected with value networks that can fuel knowledge-informed advances. Examples are product-specific details of effects on the environment (Rusch et al., 2022), material flow and emission data (Nascimento et al., 2019; Tseng et al., 2018), systems' performance data (Gupta et al., 2021), and data revealing customers' and consumers' behaviour and needs. The data-driven opportunities notwithstanding, it should be noted that data do not always represent the world accurately (Jones, 2018) and, also, data may lose some value when there are delays in gathering the material and translating it into usable information on which to act (Pigni, 2016).

Five intertwined themes with specific implications for better understanding of the role of data for circular economy can be identified from reviewing the literature, the same themes being relevant also in the wider context of environmental sustainability. Firstly, experts call for collecting and managing environment-related data such that they are available and accessible (Jia et al., 2020; Rajala et al., 2018). Specifically, they cite a need for product life-cycle data and for ability to manage and analyse heterogeneous life-cycle data efficiently (Ren et al., 2019). Also, data-sharing internal to value chains does not suffice to unlock data's value: each company's resources need to be connected with others', and data must be exchanged across vast networks for co-ordinated activities (Gebhardt et al., 2021; Tsolakis et al., 2021). Thirdly, the data must lead to better decision-making at strategic and operations level all the way along the value chain to, finally, customers and consumers (Gebhardt et al., 2021; Lopes de Sousa Jabbour et al., 2019). Environment-data-specific capabilities for business analytics are critical for interpreting and using the data well for solid business development, value-chain management, production planning, and product design (Kristoffersen et al., 2021; Lopes de Sousa Jabbour et al., 2019). Guiding consumers toward more sustainable consumption choices appears highly relevant (Freudenreich and Schaltegger, 2020; Mostaghel and Chirumalla, 2021).

Under the fourth theme, realising environmental sustainability overall (and circular economy specifically) ties in with new business models that data could support (Ferasso et al., 2020; Lüdeke-Freund et al., 2019). For instance, data can afford servitisation and product–service systems (Alcayaga et al., 2019; Bressanelli et al., 2018). Finally, data-driven initiatives that support environmental sustainability and circular economy should result in a positive environment impact. This does not follow naturally, though; it demands greater understanding of how data-driven initiatives change real-world production and consumption patterns and the related impacts (De Angelis, 2021; Kouhizadeh et al.,

2019). Table 1 summarises the five themes, with their implications specific to understanding the role of data for environmental sustainability and circular economy.

The untapped opportunities that digital transformation – alongside the increasing availability and utilisation of data – offers to drive environmental sustainability have been attracting greater interest in the literature (e.g., Bai et al., 2020; Ghobakhloo et al., 2021). The potential that digital technologies possesses to support climate-change mitigation, circular economy, and other environment-related goals is widely recognised (Di Maria et al., 2022; George et al., 2021; Liu et al., 2022), and the literature discusses their role in reducing resource-intensity, increasing energy-efficiency, cutting down on waste, and decreasing CO_2 emissions accordingly (Chiarini, 2021; Kerin and Pham, 2020; Niehoff, 2022). Specific digital technologies, as well as 'Industry 4.0' developments in general, are recognised for their prospects of supporting more sustainable business strategies, coupled with new business models, manufacturing practices, and more sustainable supply chains (Gupta et al., 2021; Ana Lopes de Sousa Jabbour et al., 2018). Still, more detailed examination of how data specifically can create value for environmental sustainability and circular economy has remained relatively limited. What goes into utilising data to support environmental sustainability and which mechanisms are suited to the latter are not well-understood yet, and awareness of critical factors in bringing data to bear for environmental improvements and circular economy remains lacking.

Table 1: Five intertwined themes with specific implications for understanding of the role of data for environmental sustainability and circular economy

Theme	**Collection and management of environment-related data**	**Sharing of environment-related data**	**Usage of environment-related data in decision-making**	**Data-driven sustainable and circular business models**	**Environ-mental impacts of data-driven initiatives**
Description	Availability of environment-related data and their efficient collection and management to make them easily accessible.	Collaboration to enable efficient flow of environment-related data along value chains including suppliers and customers.	Environmentally better-informed decisions in full value chains including different business functions, suppliers, and customers.	New business models supported by data that can shift production and consumption towards environmental sustainability.	The environmental impacts of data-driven initiatives that can be either positive or negative.

3. METHODOLOGY

The project applied several methods, aligned with the context and aims particular to each original article. Article I reports on a qualitative case study that employed Gioia analysis (Gioia et al., 2013) for structuring the body of data obtained via in-depth discussions of customer-perceived value of environment-related data. Behind Article II was a disaggregative Delphi study (Rowe and Wright, 1999; Tapio, 2003) involving alternative images of the future for data in textiles' circular economy. Article III presents qualitative analysis of the research data from the Delphi study, identifying paradoxical tensions at the interface of circular economy and data. Finally, Article IV represents synthesis. It is a systematic review of prior literature addressing the role and value of data in circular business models. Table 2 outlines the methods and data behind the four articles.

Table 2: Summary of the methods and data behind the original articles

	Article I	**Article II**	**Article III**	**Article IV**
Type of research	Case study	Disaggregative Delphi study	Disaggregative Delphi study	Literature review
Data	In-depth customer discussions	Quantitative and qualitative responses from two Delphi rounds	Reasoning and arguments from the Delphi work	Scientific articles
Analysis	Qualitative content analysis (Gioia analysis)	Hierarchical cluster analysis and summative content analysis	Qualitative analysis	Systematic review of the articles

Article I focuses on **the tissue-paper industry**, which, as a part of the forest industry, faces complex demands for environmental sustainability in its value chains from a range of stakeholders responding to the globalisation of that industry, growing sustainability-awareness, and increasingly strict regulation (Ghosal, 2015; Toppinen et al., 2017). Tissue papers, such as paper towels and toilet tissue, are used by households and professionals for everyday cleaning, wrapping, and personal use. Because of the significant amounts of wood-based fibre, water, energy, and chemicals that go into their production, climate-change mitigation, resource-efficiency, and sustainable forest management are the industry's central environmental issues today (Ranängen and Zobel, 2014; Tuppura et al., 2016). The industry players but also their customers are encountering rising pressure for environmental improvements in their supply chains and related to the products provided. These circumstances present a growing need for better sharing and use of environmental-performance-related data within tissue-paper product value chains.

Articles II and III focus on **the textile industry** with its significant environmental impacts from extensive use of natural resources and the vast quantities of wasted textiles (European Environmental Agency, 2019; Palacios-Mateo et al., 2021). Transformation favouring circular economy is regarded as necessary for the textile industry (Ellen MacArthur Foundation, 2017; European Environmental Agency, 2019), but implementation of any such shift is still in its infancy (Chen et al., 2021; Saha et al., 2021). Insight in this domain is especially valuable on account of not only the extensive environmental challenges but also the globalised and complex value chains. Globally, the textile industry has an immense economic footprint and is a significant employer globally (Ellen MacArthur Foundation, 2017). Opportunities come into focus especially as wood-based cellulosic fibres get introduced as less harmful alternatives to cotton and synthetic fibres (Islam et al., 2021; Kallio, 2021). Finally, Article IV has no specific industry focus.

3.1. Article I: Data's value for environmental sustainability as perceived by the customers of a tissue-paper supplier

Article I reports on a single-case study addressing data's value for environmental sustainability as perceived by customers of European tissue-paper manufacturer Metsä Tissue. The concept of perceived customer value was used to capture the multidimensional and context-dependent nature of value and elucidate its granular constructs (Macdonald et al., 2016; Tzokas and Saren, 1999; Woodruff, 1997). The work followed Robert Woodruff's (1997, p. 142) definition of customer value as the 'customer's perceived preference for and evaluation of those product attributes, attribute performance, and consequences arising from use that facilitate (or block) achieving the customer's goals and purposes in use situations' and built on understanding creation of customer value as a dynamic process (Grönroos, 2008; Tzokas and Saren, 1999), affected by users' accumulated experiences, perceptions, preferences, and evaluations, at both personal and social level (Helkkula et al., 2012; Woodruff, 1997). Perceived value can change over time (Woodruff, 1997), so viable businesses must anticipate what customers, in their own terms, will find valuable as the world continuously evolves (Rantala et al., 2019; Rintamäki and Saarijärvi, 2021).

The focus on this company hinged on the management's exemplary will to enhance its utilisation of data, alongside its customers, for better support of environmental sustainability. At the core of the project were discussions with eight of the case company's

retail and professional-sales customers held to illuminate how the value of data for environmental sustainability is perceived in their business. Among the prospective informants, identified in collaboration with the company's sales representatives, were customer representatives involved in systematic work on sustainability who had expressed interest in discussing better utilisation of data with their suppliers. Potential customers were contacted, and their interest in taking part was confirmed. In the end, nine informants, from eight customer companies, participated. The discussions were implemented as facilitated interactive Microsoft Teams sessions following an interview protocol based on three open questions. Those sessions, held in April to May 2022, were audio-recorded and transcribed (to about 50,000 words of text, from interviews lasting 38 to 58 minutes each).

For systematic analysis and structuring of these in-depth discussions' content, the study applied the Gioia method. The first step was to analyse all of the material to identify value-related aspects mentioned by the informants, which formed the first-order codes. This analysis was performed by one researcher and then checked by another one, to ensure its reliability. After this, the first-order codes were arranged under themes on the basis of their similarities. Finally, the second-order constructs (themes) were grouped into aggregate dimensions for understanding of phenomena, the relationships among the elements considered, and the literature consulted for related findings (Gioia et al., 2013).

3.2. Article II: Future Images of Data in Circular Economy for Textiles

For Article II, alternative images of the future were created, to reveal the utility of data in textiles' circular economy. Such 'future images' afford assessing possible developments and corresponding uncertainties related to the phenomenon under scrutiny (Bell and Mau, 1971; Daim et al., 2006; Polak, 1973). An image of the future is an 'expectation about the state of things to come at some future time' (Bell and Mau, 1971). Alternative images encourage considering a spectrum of futures rather than fixed circumstances, and they facilitate thinking about actions' consequences (Daim et al., 2006; Gausemeier et al., 1998; Polak, 1973). They are suited especially well to assessing complex and interrelated phenomena. In the study of data's utilisation for circularity, they supported mutual discussion of the development desired and of related uncertainties while also helping the actors assess their actions and the consequences thereof.

These alternative images of data's future role in circular economy for textiles were created and examined via a disaggregative Delphi study (Linstone and Turoff, 1975; Rowe and Wright, 2011; Steinert, 2009; Tapio, 2003) with two rounds, in May and June 2021. The Delphi method offers a technique to assess alternative future developments and change factors systematically on the basis of experts' views (Linstone and Turoff, 1975; Rowe and Wright, 2001). For the selection and invitation of experts, an expertise matrix (a tool developed first by Kuusi et al., 2006) was created to guarantee that the experts consulted covered the full range of subject-matter expertise, representing both industry and research. In total, 33 international experts took part in the first round and 26 in the second, of whom 14 were female and 12 male. About half of the experts were 30–44 years old or younger, and the group represented 10 nationalities, mainly centred in Europe and North America.

The first-round Delphi work employed 17 hypothetical future-oriented statements and three open questions on data's role in textiles' circular economy, developed on the basis of the study's conceptual background. The time horizon was the year 2035, and the statements covered the following themes: availability of circular-economy data, sharing of circular-

economy data, use of said data in decision-making, new circular-economy-based business models, and circular economy's impacts on the environment. The experts were asked to assess the probable and the desirable development in relation to each statement and explain the reasoning behind their replies. Via hierarchical cluster analysis of the quantitative data from the first round, the team created alternative future images (with SPSS, v. 26) (Tapio, 2003). Summative content analysis (Hsieh and Shannon, 2005) of the experts' qualitative comments supported producing brief narratives encapsulating the images' central content. In the second round, the experts assessed the likelihood and desirability of the three images, again supplying their reasoning. Second-round numeric results were analysed via descriptive statistics, and qualitative comments via summative content analysis. The set of qualitative material was extensive: round 1 yielded 416 and the second round 95 comments.

3.3. Article III: Paradoxical tensions in utilising data to drive circular economy of textiles

A vital conceptual tool employed for Article II to contribute to understanding of the complexities of utilising data in textiles' circular economy is paradoxical tensions, defined as 'contradictory yet interrelated elements that exist simultaneously and persist over time' (Smith and Lewis, 2011). This tool affords assessing complex and dynamic business environments with competing demands and conflicting yet interrelated concerns (Hahn et al., 2014; Smith and Lewis, 2011). It is seen as particularly valuable in managing wicked problems (Raisch and Krakowski, 2021; Schad and Bansal, 2018), such as the ones associated with sustainability transition, and is regarded as attuned well to interpreting the mutually contradictory demands that accompany transition to sustainable business (Hahn et al., 2014; Van der Byl and Slawinski, 2015).

Identifying paradoxical tensions in utilising data for textiles' circular economy involved analysing the qualitative material from the Delphi study described above – the arguments and reasoning the experts supplied to support their future-related assessments. This work systematically examined key content of the experts' comments to illuminate patterns of possible tensions visible from the research material. The assessment pinpointed various factors both driving and constraining data's utilisation; potential tensions were identified accordingly. Then, the preliminary list of tensions was scrutinised against the characteristics of paradoxical tensions, in a manner ensuring that the tensions presented in the final model express a clear link to both circular economy and data, and brief descriptions (with illustrative extracts from the experts' responses) were created.

3.4. Article IV: The Role and Value of Data in Realising Circular Business Models

Article IV addresses the role and value of data in deploying circular business models. New models of this type are recognised as necessary for implementing circular economy and for helping turn linear material flows into loops that eliminate waste (Bocken et al., 2016; Stahel, 1997). A business model captures the logic of how a given business creates value and delivers it to customers (Teece, 2010). So a circular business model is a business model that transforms linear flows into loops in aims of obtaining more value from the resources and simultaneously improving the sustainability of the production and consumption both (Bocken et al., 2016). This diverges from modern companies' typical linear value-creation logic (Hofmann, 2019). To aid in understanding data's potential value in this setting, the

work considered six distinct circular business model patterns: repair and maintenance, reuse and redistribution, refurbishment and remanufacturing, recycling, cascading and repurposing, and organic feedstock (Lüdeke-Freund et al., 2019).

To understand what the research as a whole reveals about the role and value of data in application of circular business models, the study identified, reviewed, and synthesised relevant literature. The literature search was restricted to peer-reviewed scholarly articles in academic databases (Scopus and EBSCO Business Source Complete) published between 1.1.2000 and 30.8.2019. In all, the queries returned 147 possibly relevant articles, of which 39 were identified as relevant with regard to the research questions. When this set was complemented with forward and backward searches (Levy and Ellis, 2006), the process yielded a final sample of 44 articles.

Systematic review of each article's content considered the theoretical, conceptual, and empirical contribution to answering the research questions. Relevant material from the publications was compiled in Microsoft Excel spreadsheets. The main themes receiving focus were the perspective taken to data / the value of data and, secondly, the latter's link to circular business models. Also, the survey considered the articles' characterisation of the type and sources of the relevant data, the nature of the data-driven activities, and the benefits and impacts expected and/or realised by means of the data. This enabled comparison and classification of the articles' content and systematic integration of the findings within a conceptual framework for reflection against the conceptual backdrop for the work. The findings aided in pinpointing further research opportunities.

4. FINDINGS REPORTED IN THE ORIGINAL ARTICLES

4.1. Findings presented in Article I, on data's perceived value for environmental sustainability

Two fundamental elements contributing to the perceived value of data for environmental sustainability were identified from the research material. Firstly, specific properties of data and related data management were pinpointed: the availability of detailed and reliable product-specific data, greater transparency of product value chains, and the establishment of workable data-management systems and interfaces suited to managing and sharing related data. Only with product-specific data – data capturing the products' content, origin, and environmental impacts – can one choose verifiably more sustainable product alternatives, comply with future regulations, and educate customers. The scope, themes, and detail covered by product-specific data are continuously expanding, and organisations demand, rather than general data, context-specific data enabling comparison of alternative products. Several challenges in making comprehensive product-specific data available were prominent in the material, though, as were challenges to ensuring the data's reliability and rendering the data comparable across products and brands. For better management and sharing of environment-related data, significant improvements in data-management systems and data integration are required, since the current systems are insufficient for handling the rising volumes of product-specific and environment-related data.

Secondly, diverse uses for data were identified that support potential environmental improvements. Among them are creating added value for customers' own customers and final consumers, supporting better business decisions, guaranteeing compliance with

regulations, and strengthening stakeholder trust. In relation to the first of these uses, data can assist in responding to customers' and consumers' environment-related questions and data requests reliably and efficiently. Also, data linked to environmental performance allow citing environmental factors in price discussions that influence purchase decisions and consumption choices. These data simultaneously help vendors to support their customers' environment-related business goals. The respondents stated in addition that such data can promote learning and changes to how people think about products. In addition, data and the ensuing transparency serve to strengthen credibility in customers' eyes. As for the second use identified, data can drive better business decisions and target-setting related to environmental sustainability by offering a benchmark for the work toward the environmental targets set and revealing the organisations' progress. At the same time, data can reveal important aspects of supply chains and of related risks and improvement opportunities. Company-internal learning may benefit too. Thirdly, in the context of ensuring compliance with regulations and strengthening stakeholder trust, high-quality data can help each entity but also its partners respond to stricter regulatory requirements for reporting and documentation while, in addition, possibly supporting investor-facing materials that convey an impression of credible environmental performance, for example. The use of data help to concretise avenues for environmental improvements and, similarly, the impacts of changes, without the spectre of 'greenwashing'.

The findings point to an evident need for more voluminous and detail-level data on product value chains and related environmental impacts, to provide transparency and present the environmental performance of full supply chains. The findings make obvious that, to be valuable for environmental performance, environment-related data must guide numerous activities and decisions – and clearly better than at present. Ideally, data should support environment-critical decisions across business functions and along product value chains, including consumers. The future potential is especially strong for data-driven decisions along product value chains (e.g., for improving product portfolios and nudging consumers toward sustainable purchasing). A customer-driven approach to the value of data lets companies prioritise their data-based development initiatives in line with customers' coming needs and continuously deliver value to them. In the process, companies benefit as they systematically hone their environmental-performance-related data capabilities, including their data-management systems and their skills and practices related to analysing and utilising data to support environmentally informed decisions.

4.2. Results identified in Article II, addressing future images of data in textiles' circular economy

Article II articulates three alternative images of the future role of data in textiles' circular economy – named Transparency, Conflicting Interests, and Sustainable Textiles. In the Transparency image, every product has provenance, with sustainability data integrated into business-management systems. Common data standards are in place for product life-cycle data, so it is hard to make unsubstantiated environmental claims. The Delphi-experts stressed that policy, consumers, and the business world create strong pressure toward such an image, but they expected data to be used to tackle more complex challenges than transparency alone. Therefore, most informants assessed the desirability of this image as only moderate or high. Likewise, the probability of this image ultimately becoming reality was assessed to be moderate or high.

The drivers behind the Conflicting Interests image are competition and lack of trust in textiles' value chains. In this future, circular practices remain fragmented and the related data are guarded jealously. Here, businesses remain unprepared for transparency that might reveal the industry's 'dirty secrets', and consumers lack motivation to engage in circular practices. This future image was commonly seen as a failure of scalable response to sustainability needs. The desirability of Conflicting Interests was predominantly very low, and this future was considered the least likely. Various drivers toward transparency and environmental sustainability were identified as acting counter to this future.

Finally, in the Sustainable Textiles image, digital identities and open data sources are commonplace. A business with a good story to tell in terms of sustainability can drive others toward circular practices and versatile use of data. Conscientious consumers make informed consumption choices, and regulators and investors reward openness in the industry. The experts regarded Sustainable Textiles as clearly the most desirable of the images. Most of them deemed the realisation of this scenario moderately or highly likely. For the Sustainable Textiles image to become reality, the experts commented, collaboration across the entire industry is crucial, enabling change at the speed and scale required.

The experts' indications of the probability and desirability of the hypothetical future statements, on the basis of which the images of the future were created, indicate that the informants saw the role of data in textiles' circular economy as more advanced in the preferred future than the probable one. A remarkable gap between the probable and the preferable future was visible for most of the statements, which can be interpreted as a sign of the experts' pessimism about the pace of development. They identified both inhibiting and driving forces for all statements except the one on embedded intelligence. The most significant uncertainties seem linked to companies' readiness for the transformation, collaboration, transparency, and customers' willingness to adopt more sustainable consumption practices.

The findings point to the significance of three factors in determining the future of circular economy and the role of data therein: commitment by the businesses, high awareness on consumers' part, and regulatory impetus. This conclusion is consistent with earlier research (Fischer and Pascucci, 2017; Saha et al., 2021). All these factors must be present if broad-based exploitation of data in pursuit of circular economy is to be possible. Also, the study attests that business supply chains and value networks require more collaboration in sharing, managing, and utilising circular-economy data; this finding too is in line with prior literature (Gebhardt et al., 2021; Kristoffersen et al., 2020; Tsolakis et al., 2021). Better transparency of products' life cycle and of business operations along the whole value chain is a necessity for environmental sustainability, the importance of which scholars recognise as fundamental for genuine transition toward circular economy (Agrawal and Pal, 2019; Luján-Ornelas et al., 2020).

The findings showcase also that development toward circular economy, and the role of data therein, is not without potential conflicts, such as mutual contradiction among individual sustainability goals or issues related to the environmental impacts of specific digital technologies. Thus far, however, these tensions have remained largely overlooked in academic research (among the exceptions are Kouhizadeh et al., 2019; Upadhyay et al., 2021). The study also defined and operationalised the term 'circular-economy data' so as to capture drawing together diverse sources of product and service life-cycle data with value-network data to lead to valuable knowledge for the shift toward circularity.

Business managers, industry associations, and other leaders in the textile industry can gain from the images created as they encourage joint discussion of the development desired

and of related uncertainties. The images of the future highlight that the role of data intertwines with circular-economy aspirations: the more ambitious the objectives, the more vital the role of data. However, the real-world interface of data and circular economy is multifaceted and complex, with some forces acting against each other also. Utilising data for circular economy demands that reliable and meaningful circular-economy data be available, shared throughout the value networks, and put to efficient use in decision-making. This calls for stronger sustainability-related data capabilities in companies, including managing their data assets and infrastructure. In light of the results, companies are encouraged to take responsibility for exploring the best uses of data for future circular economy in collaboration with all actors in their value networks.

4.3. Article III and paradoxical tensions in utilising data to drive textiles' circular economy

The third article identifies nine paradoxical tensions at the interface of data and textiles' circular economy. These cohere around three themes. Four of the tensions are connected with consumer concurrence. 1) Consumers are seen as finding increasing value in environmental sustainability, but experts point out that consumers tend not to act on sustainability data – they are rather price-sensitive in their purchase decisions. 2) Sharing data connected with their use of textiles might bring the consumers social benefits and grant them insight related to their behaviour and its impact, yet at the same time they might find this type of data on products' use too intimate for conscious sharing. 3) New ownership models that benefit from data could reinforce businesses' attention to textiles' life-cycle optimisation; however, the same models could cause consumers to take less care of the textiles. Finally, 4) personalised textiles might support consumers' attachment to them, thereby extending their use and lifetime, yet there is no guarantee of them getting used for a longer time, and, if they are hard to resell and recover, the amount of waste might even grow.

Three of the paradoxical tensions identified are related to business transparency. 5) Common data standards for circular economy would be necessary for avoiding siloed and non-integratable data; however, global-level collaboration on data standards is highly challenging in the fragmented value chains of the textile industry, and actors' readiness to discuss the topic varies greatly. Secondly, 6) open life-cycle data for textiles could support business interests by strengthening companies' sustainability story, yet this is a highly competitive industry that is not used to open data-sharing, and the organisations might see it as counter to their business interests. In the last tension in this set, 7) the industry encounters increasing demands for a shift toward circularity and more open use of data; however, this calls for an extensive business-process transformation, which would challenge current ways of working and the power balance among the actors.

The last two tensions involve technology relevance. Firstly, 8) embedded intelligence (such as sensors in textiles) could contribute to understanding of the customers' use of the products; however, this might well hamper textiles' recycling (any attached sensor must be removed before recycling). Secondly, 9) distributed-ledger technology (blockchain etc.) could afford tracking products and materials throughout their life, but – here too – the technology itself has its costs: extensive energy demands and other environmental impacts.

The set of paradoxical tensions identified draws attention to the powerful role of consumers in realising textiles' circular economy and full exploitation of related data.

Consumers act both as producers and as users of circular-economy data, and they determine the broader acceptance of data-driven circularity. The literature recognises the vital part played by consumers in acceptance and implementation of textiles' circular economy (Huynh, 2021; Saha et al., 2021), and the work behind Article III only emphasises that role's importance in terms of the utilisation of related data. Also, the tension framework renders it explicit that data-driven circular economy challenges the industry's current practices and demands openness to collaboration. This involves directing industry's mindset toward data-sharing and transparency, with its potential benefits but also challenges such as costs of gathering data and navigating the competition landscape (Ebinger and Omondi, 2020; Garcia-Muiña et al., 2018).

The findings clearly demonstrate that data-driven circular economy's support for environmental sustainability cannot be taken for granted. Use of data-supported circular business models, such as new ownership approaches and personalisation of textiles, does not automatically yield environmental benefits. Rather, the real-world impact of these models depends on how the models lead to change in consumption and production practices (Daddi et al., 2019; Ki et al., 2021). Finally, potential benefits notwithstanding, utilising digital technologies (sensors, blockchain, and others) to manage and optimise textile value chains is bundled with evident environmental costs from considerable consumption of energy and other resources (Grigore et al., 2020; Kouhizadeh et al., 2019).

Business practitioners should address these tensions when attempting to utilise data successfully to promote circular economy in complex and dynamic business environments. Business decision-making ought to factor in both the positive and the negative effects, in the short and long term, of utilising data in implementing circular economy, so as to guarantee that the data-driven initiatives' societal benefits exceed the disadvantages. Understanding the complex interplay of data-driven approaches to circular economy helps business develop strategies for managing the related tensions efficiently.

4.4. Article IV, on data's role and value in application of circular business models

The literature review revealed that data and related digital technologies are increasingly identified as important enablers of circular economy (e.g., de Mattos and de Albuquerque, 2018; Tura et al., 2019), with lack of appropriate data getting identified as a hindrance to following circular business models (Saidani et al., 2018; Vermunt et al., 2019). Irrespective of increasing interest at the nexus of circular business models and digital technologies, the body of knowledge is still fragmented. The articles reviewed point to a broad spectrum of circular business models that benefit from data, specifically emphasising opportunities to exploit data for deploying product–service systems (see, for example, Alcayaga et al., 2019; Bressanelli et al., 2018; Frishammar and Parida, 2019) and closed-loop supply chains (see, for example, Aid et al., 2017; de Mattos and de Albuquerque, 2018; Tseng et al., 2018). The role of data varies less from one business model to another than it does with the activity that the data can support.

Two mutually supportive approaches to gaining value from data in circular business models are visible from the literature: an outward- and an inward-oriented one. In the outwardly focused approach, data get utilised to enhance the customer experience in respect of circular-economy objectives (Bressanelli et al., 2018; Zheng et al., 2018). In the inward-focus approach, data inform managing and optimising the performance of circular systems and supply chains (Rajala et al., 2018; Zhang et al., 2017). The former necessitates data

related mainly to products' and services' performance over their full life cycle and to customers' behaviour and preferences, and the latter demands real-time and historical data on system/process flows and performance.

The review identified four general categories of data as especially relevant for circular business models. Firstly, the literature emphasises that data on the customers' behaviour and preferences can offer insight into, for example, their use of products. Secondly, data on products' and services' life cycle can assist in understanding matters such as how use has affected the reuse opportunities. The third type of data, covering the operation of larger technical or organisational systems, can aid in, for instance, optimising supply chains. Finally, material-flows data can lead to insight – e.g., revealing waste streams that could be avoided. To be valuable for circular business models and their goals, data of any of these sorts must be refined into information and knowledge. Only then can the data guide more informed decision-making in efforts to steer supply chains, value networks, and customer experience toward circular economy (Alcayaga et al., 2019; Khan et al., 2018). Therefore, businesses need to develop their abilities to orchestrate and analyse data streams, constantly (Frishammar and Parida, 2019; Pigni, 2016).

This literature review represents one of the first comprehensive reviews addressing the topic. It highlighted that understanding of the path from data to circular business models and onward to environmental impacts must be further strengthened. The work indicates also that the value of data in the context of circular business models is closely linked to data's general contribution to managing and optimising operations, performance, and customer experience. Data-driven optimisation of this nature can yield resource savings and environmental benefits even without specific circular-economy objectives. However, comprehensive circular-economy value-creation rationales demand deeper understanding of the opportunities, challenges, and impacts of circularity in a specific context. The literature reviewed ignores the substantial investment in capabilities needed for fully exploiting data in a way that results in environmental improvements. Taking this factor into consideration requires awareness of various possibly non-linear and adverse effects/consequences connected with sustainability.

The main implication of the literature review for practice stems from illuminating how data in the context of circular business models may be conceptualised as a source of value. An approach that entails awareness of circular business models' connection to data, various ways of obtaining value from data in this context, and the types of data that hold value specific to circular business models can inform efforts to put data to use for the benefit of circular economy by adding business-relevant insight to the picture.

5. DISCUSSION AND CONCLUSIONS

5.1. Synthesis of key findings

The research provides multifaceted insight shedding light on the elements, mechanisms, and critical issues related to applying data to drive environmental sustainability and circular economy – particularly through the five intertwined themes with specific implications for data's value for corporate environmental sustainability and circular economy: collection and management of data, sharing of said data, the data's application in decision-making, data-driven business models, and environmental impacts of data-driven initiatives.

Firstly, the findings highlight that the availability of detailed, reliable product-specific data to support environmental sustainability and more transparent value chains is getting more important, a conclusion consistent with other recent work (Elias Mota et al., 2020; Rusch et al., 2022). Finer-granularity data on products' materials and their origin would enable greater transparency of business activities, the product value chains in their entirety, and the environmental impacts. This availability, in turn, would support data's use to guide, for example, choosing sustainable product alternatives, educating customers in sustainable consumption choices, and improving brands' and retailers' product portfolios. That said, ensuring and safeguarding the availability and reliability of this type of detailed data is recognised as challenging in contexts of often complex and global product value chains that lack transparency and comparability of data across buyers and suppliers. Furthermore, the literature points to gaps in the availability of even the simplest product supply-chain data and comparability of environment-related details (Comas Martí and Seifert, 2013; O'Rourke and Lollo, 2021). All this highlights the fact that we need to find more effective and sufficiently reliable ways to make use of data for environmental sustainability even when the quality of data is incomplete. Efficiently gathering and managing product-specific and environment-related data calls for the establishment of appropriate data-management systems and integration, both between different data management systems inside the company and with customers, suppliers, and partners. This is specifically the case in the context of circular economy where real gains call for systemic understanding on the interaction of the different elements. Most companies still lack efficient systems and practices for managing environment-related data (O'Rourke and Lollo, 2021; Ren et al., 2019), but some are starting to integrate such data into their product- and supply-chain management systems.

Secondly, the findings imply that deeper collaboration with customers and suppliers, also encompassing the business network more generally, is needed for capturing data's value for environmental sustainability. At the core of the collaboration is creating the conditions for efficiently sharing data. This includes agreeing on common definitions and standards for environment-related data, to facilitate availability of data along entire supply chains and the data's reliability and comparability. Collaboration is also a prerequisite for generating business, customer, and environmental value from data: value creation could be seen as a continuous process of co-creation between data-providers and data-utilisers (Ballantyne, 2004; Grönroos and Voima, 2013). Both affect the outcome, implications, and acceptance of data-driven initiatives, and their roles may even overlap or change (e.g., data-utilisers can function as data-providers). Hence, researchers have identified a collaborative

approach to data-sharing and the efficient flow of data along the supply chains as crucial specifically in the networked context of circular economy (Gebhardt et al., 2021; Kristoffersen et al., 2021); the approach required demands ample trust and ability to resolve any confidentiality issues that might arise (Rajala et al., 2018; Tseng et al., 2018). The thesis project's findings indicate that such an approach to sharing data throughout the value chains and networks runs counter to today's business mindset and practices; this conclusion too is consistent with prior literature (Ebinger and Omondi, 2020; Garcia-Muiña et al., 2018). Accordingly, actors have to be open to the change in mindset needed.

Thirdly, this work makes a strong case that environmental considerations need to be brought into a variety of strategic and operative decisions and activities across business functions and value chains, to steer environmentally better-informed decisions. This necessitates cultivating the data into information and knowledge relevant for each decision-making context in the business itself, in its value chains, and among stakeholders (Miller, 2013), whether for serving quarterly management updates, continuous improvement of product design, or communication with consumers and other stakeholders. The spectrum along which environment-related data can function to such ends stretches from setting feasible environmental targets and identifying improvement opportunities to implementing actions and following the development, with all of this potentially driving environmental improvements throughout the networks and value chains (Langley, 2022; Lopes de Sousa Jabbour et al., 2019). The findings imply that some of data's most interesting potential may lie in pulling product value chains toward environmental sustainability, in support of stronger product portfolios and nudging toward sustainable purchasing choices.

Also, consumers' role in decisions related to environmental sustainability, circularity, and data becomes evident in connection with deciding on individual purchases and with wider acceptance of data-driven environmental sustainability and circularity (wherein consumers act both as producers and as users of product- and environment-related data). The vital role of consumers for acceptance and implementation of environmental sustainability and circular economy is well-recognised in the literature (Huynh, 2021; Saha et al., 2021), and the findings from the work reported upon here further emphasise that role's importance for solid utilisation of related data. Scholars have already issued calls for new ways to communicate with consumers and improve those users' knowledge of environmental issues (Freudenreich and Schaltegger, 2020). Therefore, the powerful role of consumers demands that companies look at the downstream portion of their value chains if wishing to understand, for example, how the data-derived insight related to consumers' behaviour and preferences could serve rendering consumption patterns more sustainable. Highlighting the role of consumers does not eliminate responsibility from businesses in the complex realm of sustainability transformation, but rather emphasizes the importance of getting consumers on board.

Fourthly, the findings imply that data can be a crucial component in sustainable business models – circular business models specifically. This project hence backs up previous reports (e.g., Alcayaga et al., 2019; Bressanelli et al., 2018). In fact, on account of the models' transformative nature, use of data often is integral to their design and/or implementation. That said, the role of data depends more on the activity that the data can support (e.g., providing a service instead of products, extending the product's lifetime through better design, or orchestrating the necessary resources and activities) than on the model. There are two sets of underpinnings for data-driven approaches to circular business. One of them involves applying data to enhance the customer experience in respect of circular-economy objectives. This necessitates data on products' and services' performance

over their entire life cycle and also on customers' behaviours and preferences, to guide product and service design, extension of product life, and stronger user involvement. In the second approach, data serve to improve the performance and productivity of circular systems and supply chains. This necessitates data on system or process performance and on related flows, for such goals as optimal processes and less use of materials. A similar set of two sources is identified in the literature on circular business models (Urbinati et al., 2017). In any case, data-supported circular business models do not automatically lead to environmental benefits; the real-world impact depends on how the models change consumption and production practices, such as by extending the lifetime of products, as related literature stresses (Daddi et al., 2019; Ki et al., 2021).

The final aspect of the real-world environmental impacts of data-driven initiatives aimed at environmental sustainability is connected with the findings' clear implication that neither the availability of environment-related data nor of initiatives utilising such data (e.g., projects focused on data-driven circular business models) automatically results in positive environmental impacts. Rather than offer a straightforward path to positive environmental impacts, the interface of data and environmental sustainability involves a branching route full of counteracting forces. One example is the contradiction between the potential benefits of some digital technologies, such as blockchain, and the potential negative impacts that they bring with them (considerable consumption of energy etc.). Putting data to use to drive environmental sustainability calls for factoring in environmental but also social and economic impacts in the short and long term to guarantee that the benefits of utilising data exceed its costs and disadvantages.

In another contribution to dialogue, the research project defined and operationalised the key terms 'environment-related data' and 'circular-economy data', with the former comprising all sorts of data that a company collects, produces, processes, and shares in relation to its activities, products, and value chains (customers included) that could stimulate insight connected with the organisation's environmental impacts and improvement opportunities. The latter term, again, involves drawing together diverse sources of product and service life-cycle data with value-network data to generate valuable knowledge for the shift toward circularity.

Table 3 sums up the key elements and critical issues of data's value for corporate environmental sustainability on the basis of the findings from the research reported upon here.

Table 3: Key elements and critical issues of data's value for corporate environmental sustainability

Theme	Key elements identified	Critical issues identified
Collection and management of environment-related data	Availability of product-specific data and transparency of products' value chains	Appropriate management systems and integration for managing product-specific and environment-related data
Sharing of environment-related data	Conditions for efficiently sharing data with suppliers, customers, and wider business networks	Change in the business mindset and practices related to sharing of data and co-creating value out from data
Use of environment-related data in decision-making	Variety of activities and decisions wherein data are / could be utilised to support environmental sustainability	Making the data take consumption choices in a more sustainable direction
Data-driven sustainable and circular business models	Variety of data-driven circular business models and related activities	Changes in real-world production and consumption
Environmental impacts of data-driven initiatives	Real-world environmental impacts, positive and negative, of data-driven developments	Understanding the complex interplay among data-driven approaches to environmental sustainability

5.2. Managerial implications

The findings highlight the importance of considering environment-related data as a critical business-enabler: a source for better management of corporate responsibility, heightened customer value, and driver of environmental improvements. The use of data seems intertwined with aspirations for corporate environmental sustainability – the more ambitious the objectives are, the more vital the role of data. These ambitions when coupled with external stakeholder demands for transparency dictate that companies must manage their environmental sustainability agendas better, by exploiting versatile data among other means.

Anticipating future requirements and opportunities regarding the use of data is critical if a business is to be able to respond to customers' and stakeholders' future needs, continuously deliver customer value, and ensure its compliance with regulations. However, current uses of environment-related data focus mainly on provision of company-level information such as sustainability reporting compliance with reporting standards and sustainable-investing ratings. Some of the promising areas for future attention are making product-specific environment-related data available, in a useful form, and supporting such decisions in the product value chains as selection of more environment-friendly products for one's product portfolios and more sustainable consumption choices. Anticipating future needs and requirements for data should be combined with exploring data-driven opportunities to support environmental sustainability and circular economy, in constant awareness that the outcome is not self-evidently good for the environment. The many possible results of any actual change in consumption and production practices must be borne in mind.

Overall, the project's findings render the challenges inherent to managing and utilising environment-related data explicitly. As things now stand, forms of data can be found scattered across multiple systems, with varying definitions and formats, so managing the data remains labour-intensive. Accountability issues and limited coverage of the value chains exacerbate the current problems with data's use in practice. Resolving these challenges calls for systematically developing environment-related data capabilities that encompass solid data-management systems alongside skills and practices that facilitate analysing and utilising data in ways that support environmentally aligned decision-making. In the development of the capabilities needed, gained expertise on sustainability must cross-pollinate with knowledge of digitalisation and data management and, perhaps just as much, of strategic business development, procurement, and work at the customer interfaces. Better integration of environment-related data into decision-making systems would improve the data's availability and usability, as would common standards for sharing data throughout and between value chains – and even across industries.

5.3. Limitations of the research

The research reported upon here is not without limitations. Firstly, although the research clearly advanced understanding on the use of data in sustainability transformation, it had the opportunity to examine only a part of the whole. The complication arises from the complexity inherent to the two foci – environmental sustainability and increasing availability of data enabled by digitalisation – and the large number of dimensions arising from their conjunction. Though the research examined this multidimensional interface from several angles, it could only highlight some of the factors and paint a partial, rather simplified picture of the related phenomena. In the context of transformation toward sustainability, the most important question that remains to be answered is that of whether and how data actually support the shift to sustainability. Highlighting some contradictions and complexities in utilising data to support environmental sustainability contributes to this discussion, but a comprehensive picture is still lacking. With such highly complex interactions, obtaining one may even be impossible. That endeavour is further complicated by several social impacts beyond the scope of the research. Consideration of those elements too would be important for thorough understanding of sustainability.

Second, from a host of disciplines, studies on environmental sustainability in the context of circular economy are accumulating continuously, and so is work on digitalisation and data. At the same time, these areas of opportunity and of interwoven possibilities and requirements are evolving rapidly, with related business practices and technologies showing especially rapid change. Hence, this research is bound to its temporal context in the starting point it offers for scholarship of this nature that examines and facilitates utilising data to support development in environmental sustainability and circular economy.

Third, the various intertwining approaches, concepts, and definitions display somewhat blurred boundaries, and some of these facets of environmental sustainability, push toward circular economy, and digitalisation and data are indeterminate to a certain extent. Shared vocabulary and frameworks for understanding their interfaces across discipline boundaries and between fields of expertise are lacking. For example, sustainability experts find it hard to grasp the technical terms used in data management, while data experts have difficulties in understanding the substance of sustainability. The thesis project was not immune to issues arising from the lack of a common vocabulary. For example, to support stronger

understanding, the formulation of the statements for the Delphi study (Articles II and III) could have accounted more fully for the absence of established definitions for some key terms used.

Finally, the research design placed data (covering diverse aspects of product and service life cycles, the connected value networks, and related environmental impacts) at the heart of the analysis. While data constitute an enabler and potential source of value supporting a shift toward environmental sustainability, this source is valuable only when it is exploited well, to generate helpful information/knowledge and, in turn, wisdom that supports environmental sustainability. Therefore, creating value necessitates setting the data in context: understanding which details are relevant, what said data's meaning is, and how best to respond. Increasing the quantity of data alone does not automatically strengthen one's knowledge; this is why scholars call for collecting accurate and truthful data, not just collecting data (van Meter, 2020). Furthermore, there are limitations related to the conceptualisation of data. The data available might not reflect the world accurately, if, by not representing what they are presumed to represent, the data are 'false'. A distorted view may result, detracting from rather than increasing knowledge. In addition, it often proves difficult to capture data from the most important phenomena. However crucial they are to understand, they may be too complex or otherwise non-quantifiable. A picture created via relying on unsuitable data may hold much less value for decisions and, accordingly, for enhancing environmental sustainability.

5.4. Avenues for further research

The dissertation points to several significant areas for future research that could enrich understanding of the interface of environmental sustainability and digital transformation in conditions of greater availability and utilisation of data.

Firstly, broader-based understanding of how companies may, with data, support their, their customers', and supply chains' strivings for environmental sustainability is needed. Scholars and practitioners alike would benefit from solid reporting on real-world cases of data supporting improvements to environment-informed decisions by businesses and larger value chains. Among the potentially fruitful areas for attention are assessment of the environmental and business impacts involved, and examination of how the preferences and behavioural patterns revealed via data could serve as input to environment-linked decisions and to advance improvements that meet both business and broader societal needs. Research pertaining to environment-linked data could apply a more forward-looking approach, with attention given to strategic use of data instead of the rather narrow focus on compliance that currently predominates. In-depth understanding of the specific data-use context would guarantee research that delivers tangible results. In the case at hand, the context demands system-level understanding of circular phenomena and strategies for designing data-driven circular business models. It is necessary to combine expertise in relevant subjects related to sustainability with in-depth expertise in data's management and utilisation. This synthesis, which has been largely absent from both research and practice thus far, should ensure that studies consider not only the opportunities represented by data-driven initiatives and the prerequisites to them but also the challenges (incl. potential disadvantages) that they could bring in the complex reality of dynamic business environments.

The second research avenue ties in with this. Moving toward data-driven environmental sustainability and circular economy involves tensions and controversial elements that merit

more detailed scrutiny. Closer attention to the challenges and unintended consequences of exploiting digitalisation for environmental sustainability is needed. Studies could fruitfully examine and conceptualise the origins of the conflicts and tensions, then discover and articulate ways to manage them. For understanding tensions in various business and societal contexts, empirical studies appear especially promising. These could tackle multifaceted contradictions and paradoxes that range from consumers' behaviour vs. perceptions, through business interests' and practices' alignment with data-driven developments, to the actual environmental impact of digital technologies employed in pursuit of data-driven circular economy. Studying both the roots of the tensions and ways of managing them should enrich knowledge of how a positive impact of digital tools can be necessarily created: factoring in the actual short- and long-term environmental, economic, and overall societal impacts should guarantee that the benefits for humanity from utilising data exceed its costs and disadvantages.

Thirdly, we need a more in-depth awareness of how data could support environmentally aware strategic and operative decision-making and inform activities across business functions and throughout value chains. Again, the use of data must yield context-relevant information and knowledge before fully supporting environmental sustainability; therefore, greater awareness of the path from data to information and onward to knowledge is a vital research pursuit. For example, empirical studies could strengthen this awareness via concrete cases of bringing environment-related data into assessing investment options, creating circular business models, or making other environment-informed decisions. The crucial element here is acknowledging the link between the data and the decision-making – e.g., how the data may inform assessing the related environmental impacts and business value. In such work, research and practice should look not only to the upstream value chains but increasingly downstream – at customers and consumers – for understanding how the insights cultivated via details of consumers' behaviour and preferences could serve encouraging more sustainable production and consumption practices.

Finally, more research is needed if we want to understand the multifaceted role of cross-actor collaboration in enabling data's utility for environmental sustainability. Fuller understanding of this role is of special significance in the context of circular economy, where the actions of one actor in a networked setting are rarely enough to make a difference – turning linear production and consumption practices into circular ones requires co-operation on the loops. Among the topics of interest in this connection are data-sharing-related prerequisites, benefits, challenges, and value-network-wide best practice. Also, the research field requires better understanding of how the benefits of sharing data could be evaluated and data's value shared among the actors. Likewise, studies of the mechanisms by which data-providers and data-utilisers can co-create value by means of data (for instance, which data could be shared, in what manner, and to what end) would be of interest. It could be worth understanding the picture further by shedding light on what rationale lies behind companies' strategic decisions on data openness in the first place. We need better understanding of the other end of the path to data-driven environmental sustainability too: how such collaboration and open sharing of data could be encouraged and facilitated for actually benefiting the environmental sustainability. More generally, understanding how data can support environmental sustainability calls for interdisciplinary approaches and solid collaboration between academic disciplines, possibly joint initiatives of business and academia, just as the desired sustainability transformation requires all actors to play a part.

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