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Future images of data in circular economy for textiles

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ABSTRACT

Rapid expansion of digitalization and in the volume of data available constitutes a major driver toward circular economy. In the textile industry, with its vast quantities of waste and huge environmental impact, transformation toward such circularity is necessary but challenging. To explore how the use of data could support building sustainability-aligned pathways to circular economy of textiles, a study employing a two-round disaggregative Delphi approach (engaging 33 experts in the first round, in May 2021, and 26 in the second, in June 2021) articulated alternative images of the future. The three images, dubbed Transparency, Conflicting Interests, and Sustainable Textiles, imply that the role for data is intertwined with sustainability aspirations. The results highlight that exploiting data in pursuit of circular economy is a collaborative effort involving business value networks that include consumers and regulators. Availability and sharing of accountability-affording, meaningful data on textiles' life cycle and value network function as a key enabler. By working with the images developed, actors can better assess their circular-economy commitments, planned actions, and the consequences of these. Furthermore, the images provide a tool for mutual discussion of the development desired and of related responsibilities and uncertainties.

1. Introduction

Textiles – whether clothing, toweling and bedding, or technical fabrics – are deeply woven into day-to-day life, but the impact of their production and consumption is far from invisible. They create substantial environmental impacts through excessive use of natural resources (water, land, and many others) and of various chemicals (European Environmental Agency, 2019; Palacios-Mateo et al., 2021). The textile industry consumes 98 million tons of non-renewable resources every year, such as oil and the raw materials for fertilizers and treatment chemicals (Ellen MacArthur Foundation, 2017). At the same time, the volume of textile waste is considerable, and only 13 % of the material used for clothing gets recycled, with even that being directed mostly toward lower-value applications (ibid.). It is estimated that apparel and footwear alone account for roughly 8 % of the global climate impact (Quantis, 2018). In addition to environmental effects, textile value chains make sizeable economic and social impacts. Globally, the clothing industry, with a $1.3 trillion annual turnover, employs more than 300 million people along its value chains, often in low- to middle-income countries (Ellen MacArthur Foundation, 2017).

The textile industry formed the heart of industrial and global manufacturing revolutions (Moore and Ausley, 2004), but it is now facing new challenges. Higher incomes and living standards, together with ballooning populations, have created rising pressure for production and consumption of textiles (Niinimäki et al., 2020). Against this backdrop, a shift toward circular economy is seen as critical for reducing harmful environmental impacts of textiles, just as with many other goods and services (Ellen MacArthur Foundation, 2017; European Environmental Agency, 2019). The aim in such efforts is to turn linear take–make–use–discard resource flows into loops via extending products' service life as well as reuse and recycling of materials, for example (Bocken et al., 2016; Stahel, 2016, 2005; Tukker, 2015). While textiles' history is rooted in cotton and synthetic fibers, new materials are sought today, especially wood-based cellulosic fibers, in pursuit of a smaller environmental impact (Felgueiras et al., 2021; Islam et al., 2021). With more environment-friendly production technologies emerging, wood-based fibers provide an opportunity to alter textile-related material flows by replacing the traditional ones (Kallio, 2021; Luján-Ornelas et al., 2020).

As the need to reduce textiles' environmental impact grows clearer,

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digitalization is opening opportunities to tune how businesses and societies operate. With the power of diverse data sources, available in increasing quantity, digitalization holds potential to be a key driver of circular economy (Demestichas and Daskalakis, 2020; Kristoffersen et al., 2020; Nasiri et al., 2017; Ranta et al., 2021; Vermunt et al., 2019). The value of circular-economy data, covering the many (highly varied) product and service life cycles and the associated value networks, lies chiefly in an ability to support better decision-making (Bag et al., 2021; Chauhan et al., 2022; Lopes de Sousa Jabbour et al., 2018; Luoma et al., 2021). For example, digital product identities can supply product-related data to the various actors in the value chain (Rajala et al., 2018), and distributed-ledger technology facilitates verifying circular supply chains (Agrawal and Pal, 2019; Böckel et al., 2021).

Implementation of circular-economy practices in the textile industry is still in its infancy (Chen et al., 2021; Saha et al., 2021). The fragmentedness of this industry's value chains has slowed the introduction of digital solutions (Fromhold-Eisebith et al., 2021), and the players have been late to adopt data management related to, for example, product life cycles and related details (Conlon, 2020). The complex and global nature of textile value chains renders the exchange of data among diverse actors especially important (Perry and Towers, 2013), however, and the companies are starting to recognize the need to improve their value chains' performance (Kuo et al., 2014). In general, the industry recognizes the strong support that digital technologies and related capabilities offer for circular-economy implementation and collaboration among the supply-chain actors, within and beyond industry boundaries (Bag and Rahman, 2021; Gebhardt et al., 2021; Tsolakis et al., 2021).

There already exist textile-business companies founded on principles connected with circular economy, emphasizing long-term sustainability (Rovanto and Bask, 2021), and benefiting from data. They build new business models that involve such activities as rental, leasing, updating, repairing, and reselling of textiles – models that enable longer product lifetimes and encourage more sustainable textile consumption (Fischer and Pascucci, 2017; Huynh, 2021; Niinimäki et al., 2020), yield personalized textiles intended for extending life cycles and reducing waste (Freudenreich and Schaltegger, 2020), and create foundations for collaborative-consumption-oriented online platforms for rental and resale (Arrigo, 2021). Pressure for change in such directions from established companies and new entrants alike could be one driver for a shift toward circular economy in the textile industry (Jia et al., 2020).

In this complex and evolving context, numerous technological, organization-linked, and societal forces, of several types, shape the future of circular economy and the role of data therein – in anticipated and unexpected ways both. Various questions must be answered before use of data, covering diverse product and service life cycles and the connected value networks, can fully support better decision-making for the benefit of textiles' circular economy. One way of facilitating consideration of alternative developments and related uncertainties is to assess alternative images of the future (Bell and Mau, 1971; Daim et al., 2006; Jiang et al., 2017; Polak, 1973). It encourages actors throughout society whose decisions tie in with circular economy to reflect on their actions' consequences and on responsibilities related to future developments (Bell and Mau, 1971; Gausemeier et al., 1998; Polak, 1973). The extensive environmental challenges bound up with textiles' production and consumption, together with globalized value chains whose actors pursue varying goals, make building future-related insight in this domain especially valuable.

Finding textile-based circular economy topical, scholars have assessed associated drivers and opportunities but also the challenges and barriers facing efforts to implement it (Chen et al., 2021; Huang et al., 2021; Saha et al., 2021). Studies have examined related practices (Jia et al., 2020), circularity-focused business models (Rovanto and Bask, 2021), and incentives for circular-economy implementation (Fischer and Pascucci, 2017) also. Other studies have assessed struggles specific to incumbent firms (Franco, 2017) and new materials for textiles, alongside their fit to circularity (Kallio, 2021; Provin et al., 2021). In addition, specific themes linked to textiles' circular economy, such as corporations' and individuals' responsibilities in such initiatives' implementation (Ki et al., 2021) and the issue of traceability in textile and clothing supply chains (Agrawal and Pal, 2019), have been addressed.

Although the interface between circular economy and digitalization has attracted greater research interest recently (see, for example, Kristoffersen et al., 2020; Ranta et al., 2021; Rosa et al., 2020; Tseng et al., 2018; Zeiss et al., 2021), very few studies have examined the role of digitalization and data specifically for textile-related circular economy (for exceptions, see Choi and Chen, 2021; Conlon, 2020). All in all, the implications of digitalization and data for circular economy even in general are best characterized as under-researched (Chiaroni et al., 2019; Luoma et al., 2021), and scholars call for integrating research and practice to address the issue (Ingemarsdotter et al., 2020; Kristoffersen et al., 2020; Rosa et al., 2019).

To our knowledge, no futures studies so far have examined how the use of data, enabled by increasing speed of digitalization, will influence the sustainability pathways leading toward future circular economy of textiles. To fill this gap, we posed the following research questions: 1) how will the use of data affect the future development of circular economy related to textiles, 2) what alternative images of the future can be identified for the role of data in textiles' circular economy, and 3) how likely and how desirable are the alternative images for the future thus identified?

We used the disaggregative Delphi method to paint these pictures of the future (Linstone and Turoff, 1975; Rowe and Wright, 2011, 1999; Steinert, 2009; Tapio, 2003). Specific consideration was given to wood-based textiles, with particular attention to the potential of wood-based cellulosic fibers as a novel raw material for textile products. The two rounds of consultation in the Delphi approach were conducted in May and June 2021. Participants, who consisted of 33 experts in the first round and 26 in the second, represented both industry and research, and their expertise covered circular economy, the textile business, and data management and digitalization. The time horizon chosen for the study extended to 2035 for balance between room for emergence and an anchor in concrete developments.

2. The conceptual framework

2.1. Circular economy of textiles

Textile-linked value chains are increasingly complex, and their environmental impacts reverberate worldwide (Niinimäki et al., 2020; Turker and Altuntas, 2014). The textile fashion market especially is characterized by short product life cycles, high product variety, low predictability, and high levels of impulse purchasing (Turker and Altuntas, 2014), together yielding large amounts of textile waste (Niinimäki et al., 2020). The increasing variation in design and material options and the multitude of highly varied production, consumption, reuse, and recycling cycles that the textiles and their materials undergo complicate efforts to understand their environmental impact (Islam et al., 2021). From fiber production (including agriculture and petrochemical production) to manufacturing, several steps in a host of processes, which encompass weaving, dyeing, washing, sewing, etc., follow each other in a variety of contexts, with spectrums such as emerging economies to the most developed countries (Luján-Ornelas et al., 2020; Niinimäki et al., 2020). Every additional actor and logistics stage adds complexity to the value chain and creates obstacles to traceability and transparency of business operations and products' life cycle (Agrawal and Pal, 2019; Franco, 2017).

More environment-friendly substitutes for cotton and oil-based synthetic textiles are sought as contributions to low-carbon operations and circular economy (Felgueiras et al., 2021; Kallio, 2021; Luján-Ornelas et al., 2020). Synthetic fibers, accounting for about 60 % of textile fibers globally, are estimated to require more than 70 million barrels of oil each year (European Environmental Agency, 2019). Most of the remaining fibers come from cotton, which puts heavy demands on land and water for its cultivation (Niinimäki et al., 2020). Consumption of wood-based cellulosic fibers has steadily grown in tandem with overall total demand for textiles (Food and Agriculture Organization, 2021). In parallel, more environmentally friendly technologies for producing those fibers have emerged, such as mechanical production that does not require the use of harmful chemicals (Felgueiras et al., 2021). In the wood-based value chains, guaranteeing that the fibers have sustainable sources is regarded as crucial for avoiding illegal logging and biodiversity loss. Awareness is growing of the value chains' further environmental issues also, such as their water footprints (Felgueiras et al., 2021; Niinimäki et al., 2020).

In circular economy, value is often co-created throughout the value network of customers, suppliers, manufacturers, and retailers (Awan et al., 2021; Saha et al., 2021; Urbinati et al., 2017). Efforts to realize circular economy for textiles highlight the complexity of global value networks and supplier–buyer relationships; multiple aspects of the value chain require changes and innovation. Among these are product design and material choices in earlier stages and, further along, take-back and regeneration programs (Franco, 2017). Responsible management of the supply chain (Shen, 2014; Turker and Altuntas, 2014) and transparency and traceability along the entire value chain (Bag and Rahman, 2021; Kumar et al., 2017; Luján-Ornelas et al., 2020) are recognized as fundamental for transition to more sustainable textile business. In addition, strivings for circular practices need to take into account the possible variations in objectives among the decision-makers along the value chain (Choi and Chen, 2021). Collaborative relationships over supply chains facilitate development toward circular economy in any industry (Bag and Rahman, 2021), yet many practices supporting circularity have been confined to individual companies rather than shared by all parties in the supply chain; also, they tend to represent a narrow focus on resource- and energy-efficiency (Masi et al., 2018).

In addition to the textile industry itself, end users and regulatory bodies play a role in the development of related circular economy (Saha et al., 2021). Consumers' and other customers' awareness of sustainability issues and the value they perceive in circularity influence their decisions, thereby enabling or inhibiting the advent of longer product lives and circular business models (Jia et al., 2020; Mostaghel and Chirumalla, 2021; Turker and Altuntas, 2014). Uncertainty remains as to whether customers on a larger scale would accept more sustainable and circular but potentially also more expensive solutions or would welcome and support new ways of consuming textiles – e.g., adopting "sharing economy" practices (Fromhold-Eisebith et al., 2021; Weber and Schaper-Rinkel, 2017). In any case, new ways to communicate with consumers and improve their knowledge of environmental issues are seen as necessary (Freudenreich and Schaltegger, 2020).

Regulatory pressure creates incentives for businesses to implement circular-economy-supporting strategies and practices (Awan et al., 2021; Gaur et al., 2021; Jia et al., 2020; Moktadir et al., 2020; Saha et al., 2021). The European Union has pushed forward various measures to support circular economy, including product-as-service models and greater transparency (European Commission, 2021). Also, the so-called EU taxonomy calls on investors to be aware of whether their investments are consistent with environmentally sustainable economic activities (European Commission, 2021). All of these factors are likely to change the operation environment of the textile industry in the European Union while also generating spillover effects globally.

Lack of financial, technological, and human resources has been identified as a key challenge to circular economy's implementation in the textile industry (Saha et al., 2021). Among further challenges are poor awareness and little sense of urgency, or indifference to sustainability, among both businesses and end users (Choi and Chen, 2021; Saha et al., 2021). Some of the other barriers are low customer demand for recycled-textile products, lack of high-quality recycled materials, undeveloped circular business models, and the challenge of producing collaborative innovation (Huang et al., 2021). The barriers identified as hampering circular-economy implementation more generally, not only for textiles, include the significant up-front investment often needed (Choi and Chen, 2021; Masi et al., 2018), the unclear short-to-medium-term business case for circular economy (Huang et al., 2021; Yamoah et al., 2022), and circularity practices being driven by entirely economic rather than environmental considerations (Masi et al., 2018). Complicating matters even further, the hurdles are far from uniform: developing countries are likely to differ from developed ones in terms of the challenges that resource availability, government policies, and local consumer behavior create for operations (Patwa et al., 2021). Overall, stiff competition in the textile industry and the perception that circular-economy practices yield minimal short-term benefits might result in avoiding them if they are not economically feasible (Saha et al., 2021).

In this multifaceted context for textile-based circular economy's emergence, company-level resources, abilities, and competencies, in areas such as management and leadership, substantially influence circular economy's implementation (Jia et al., 2020; Saha et al., 2021). Top-management commitment and visionary thinking is highly crucial for all businesses aiming for circular economy (Dubey et al., 2019; Ibn-Mohammed et al., 2021; Moktadir et al., 2020). Fundamentally, development toward circular economy is a process of organizational change (Santa-Maria et al., 2021).

2.2. The role of data in textile-based circular economy

The increasing availability of data, coupled with digitalization, is changing how businesses and societies operate. Through data's discovery, integration, and exploitation, valuable information and knowledge gets created (Miller, 2013). Data can add value by enabling transparency, optimization, rapid learning, and deeper understanding of, for example, customer needs (Chen et al., 2015). Efficient use of circular-economy-related data can be a significant enabler in realizing circular economy (see, for example, Gupta et al., 2021; Kristoffersen et al., 2021a; Ranta et al., 2021). In this connection, circular-economy data consist of a body of data on diverse aspects of product and service life cycles and more system-level value-network data that can provide knowledge for development toward circular economy. Data of these kinds can be used to improve our understanding pertaining to the material and product flows/loops, associated value, and environmental impacts in complex value networks that extend across geographical borders; between actors, technologies, and industries; and over the full lifetime of the products and services (Luoma et al., 2021). The data could inform, for example, enriching the customer experience and guiding it toward circular economy via high-quality product and service design, extension of product life, stronger user involvement, and building of product–service systems (Luoma et al., 2021; Ranta et al., 2021). In addition, such data can serve as input to optimizing the environmental performance of circular systems and value chains at a more technical and operations-oriented level, for more optimal resource utilization (Luoma et al., 2021; Masi et al., 2017; Tsolakis et al., 2021).

More efficient collection, management, and use of circular-economy data requires suitable technological and information systems (Jia et al., 2020), including data-oriented infrastructure and such digital technologies as well-designed Internet of Things (IoT) systems and Big Data analytics. Solid infrastructure for data links material flows with their virtual representations (Bag et al., 2021; Rajput and Singh, 2019; Ren et al., 2019), thus enabling the monitoring, assessment, and optimization of the customer value, material flows, and environment-related performance associated with products, services, and systems (Luoma et al., 2021; Tsolakis et al., 2021). Also, systems for sharing digital information and platforms for joint decision-making can support collaboration that spans supply chains, improve resource-sharing, and allow for co-creation of knowledge (Gebhardt et al., 2021). Alongside these, taking advantage of all the relevant data demands the aforementioned organizational capabilities, including that of coordinating the skills and resources required (Awan et al., 2021; Bag et al., 2021; Pigni, 2016). For example, well-managed data-analytics capabilities can mediate collaborative supply-chain relations and aid in adopting circularity practices (Bag and Rahman, 2021).

A survey of the literature helped us recognize five interwoven themes with specific implications for better understanding of the role of data in textiles' circular economy. These themes (synthesized in Table 1, below) formed the backbone for our collection of data for the empirical study.

Firstly, circular-economy-related data must be *available* – collected and managed such that they are accessible. Product life-cycle data form a prerequisite for circular economy. So far, though, lack of interoperability has precluded efficient management of the heterogeneous life-cycle data, and advanced analytics solutions for in-depth analysis of such data remain absent (Ren et al., 2019). For example, digital product identities have been proposed as a way to make these details available to all actors in the value network (Rajala et al., 2018). With regard to data related specifically to the use phase of textiles, embedded intelligence and user sharing of data are among the mechanisms proposed (Ingemarsdotter et al., 2019; Jia et al., 2020; Lopes de Sousa Jabbour et al., 2018; Mostaghel and Chirumalla, 2021).

Secondly, the data must be *shared* within value networks. Hence, harnessing the value of data in a networked circular-economy setting necessitates collaboration in collection and sharing of the data, in combination with efficient flow of information along the supply chain (Bag and Rahman, 2021; Brown et al., 2019; Gupta et al., 2018; Luoma et al., 2021). Each company's resources need to be connected with others', and data must be exchanged across vast networks for coordinated activities and resources (Bag and Rahman, 2021; Baraldi and Nadin, 2006; Gebhardt et al., 2021; Tsolakis et al., 2021). Clearly, unlocking the data's value demands more collaboration, and open data sources represent potential value for the industry in this regard (Luoma et al., 2021). In practice, data access is complicated by not just technical hurdles but also matters of content and use. Data sources with relevance for textile value chains encompass sensitive business details such as stock levels, customer activity, product returns, consumer feedback, emerging trends, and knowledge about competitors (Braglia et al., 2021). Today's competitive, global textile-based value chains call for common practices and data standards, such that all parties can be assured of fairness and interoperability in their data management.

The third theme connected with circular-economy data's value specifically for business involves the ability to be *supportive of decision-making* at strategic and operations level, thus facilitating business development, value-chain management, production planning, and product design (Lopes de Sousa Jabbour et al., 2019). Circular-economy specific business analytics capabilities are critical for data to be interpreted and used in operationalizing circular economy (Kristoffersen et al., 2021b). The data can inform decision-making by other parties too, whether acting elsewhere in the supply chain or in society at large (Gebhardt et al., 2021). As the role of data in circular-economy-related decision-making increases, the reliability and accuracy of said data will become increasingly important (Rajala et al., 2018). Accountability and trust constitute the key for sharing data (Gupta et al., 2018; Rajala et al., 2018), whereas discrepancies and gaps in the input could hamper the use of this resource (Tseng et al., 2018).

Fourthly, realizing circular economy demands an approach *connected with new business models* (Ferasso et al., 2020; Lüdeke-Freund et al., 2019). Data can afford servitization and product–service systems (Alcayaga et al., 2019; Bressanelli et al., 2018) that entail companies' innovation at customer interfaces (Ranta et al., 2021). At the same time, meshing data with circular business models is justified by the potential environmental benefits alone; for instance, applying new ownership models has been demonstrated to create a sense of responsibility for the materials and incentives for product quality, thus resulting in positive environmental impacts (Fischer and Pascucci, 2017).

Finally, solid use of data could reinforce circular economy's positive *environment-affecting* ripples. As textile value chains and their environmental impacts reverberate worldwide (Islam et al., 2021; Niinimäki

Table 1
Dimensions with specific importance for understanding the role of data in textiles' circular economy.

Dimension, with description	References
Availability of circular-economy data	
Use of digital identities: Product life-cycle data form a prerequisite for circular economy. Digital product identities have been proposed as one way to make these details available to all actors in the value network.	Rajala et al., 2018; Ren et al., 2019
Use of embedded intelligence: Embedded intelligence enables monitoring product and material flows across value chains and throughout life cycles. Via the data generated, processes and supply chains could be optimized and controlled, for greater efficiency and value.	Awan et al., 2021; Ingemarsdotter et al., 2019; Lopes de Sousa Jabbour et al., 2018
Textile-users' sharing of data: Data on the use phase of textile products enable, for example, improved product design and models geared for servitized business. In addition, it could increase awareness among customers as to their use of textiles and its impact.	Freudenreich and Schaltegger, 2020; Jia et al., 2020; Mostaghel and Chirumalla, 2021
Traceability of textiles: The complex and global nature of textile value chains raises the question of traceability of products and materials, including that of wood-based materials with biodiversity impacts. Data can add value by affording traceability.	(Agrawal and Pal, 2019; Kumar et al., 2017; Niinimäki et al., 2020) (Agrawal and Pal, 2019; Kumar et al., 2017; Niinimäki et al., 2020)
Sharing of circular-economy data	
Availability of open life-cycle data: Implementing circular economy in textile value chains renders the exchange of data among its actors important. The use of open data sources, for life-cycle data especially, could enable collaborative efforts toward circular economy.	Brown et al., 2019; Gupta et al., 2018; Luján-Ornelas et al., 2020; Perry and Towers, 2013
Existence of global data standards: The competitive business environment of the global textile industry is likely to discourage companies from sharing data unless common standards exist. Global standards enable interoperability across actor and system boundaries.	Fromhold-Eisebith et al., 2021; Niinimäki et al., 2020; Turker and Altuntas, 2014
Existence of European Union regulation: Enabling regulation is needed if a level playing field and incentives for circular economy's implementation are going to be created. In the European Union, several circular-economy-related initiatives are yet to be executed.	Awan et al., 2021; Gaur et al., 2021; Jia et al., 2020; Moktadir et al., 2020; Saha et al., 2021
Use of distributed-ledger technology: Distributed-ledger technology (blockchain etc.) can multiply the transparency and reliability of circular-economy operations. It can assist in verifying, for example, the source of materials or products and the actors involved.	Agrawal and Pal, 2019; Böckel et al., 2021; Kouhizadeh et al., 2019; Upadhyay et al., 2021
Use of circular-economy data in business decision-making	
Integration into business-management systems: Integrating circular-economy data into business-management systems enables monitoring and analysis of such factors as the waste generated and resource-efficiency. It	Lopes de Sousa Jabbour et al., 2019; Rajput and Singh, 2019

(*continued on next page*)

Table 1 (*continued*)

Dimension, with description	References
could support strong strategic and operations-level decision-making.	
The share of structured data: Usually, applying data analytics to extract value from data demands the availability of sufficiently structured data. However, vast volumes of today's data are generated in unstructured form.	Abiteboul, 1997; McCallum, 2005
Reliability of the data: As the role of circular-economy data in decision-making grows, reliability will be increasingly important. Exploiting data on wood-based textiles' value chains could build on the data-management systems already in place in the forest industry.	Gupta et al., 2018; Rajala et al., 2018; Tseng et al., 2018
Data-ownership problems: Contractual and ownership arrangements might limit the use of circular-economy data. The emerging value chains for wood-based textiles could introduce practices that offer transparency of data ownership.	Brown et al., 2019; Lopes de Sousa Jabbour et al., 2018; Spring and Araujo, 2017
New circular business models	
Existence of new ownership models: Fresh ownership models could extend companies' ownership of products over their full service life. This sort of data is required for value creation and for an optimal service life.	Alcayaga et al., 2019; Fischer and Pascucci, 2017; Huynh, 2021
The presence of personalized textiles: Personalized textiles could make textiles more valuable for the customers, thus increasing their utility and lengthening their time in use. Both this personalization and the efficiency of the operations related to it require data.	Freudenreich and Schaltegger, 2020; Huynh, 2021
Circular economy's impacts on the environment	
The share of recycled fibers: Introducing recycled fibers as alternative raw materials for textiles cycles today's waste to tomorrow's new value. These fibers herald circularity-oriented transformation of textile value chains, including customer acceptance.	Ellen MacArthur Foundation, 2017; Niinimäki et al., 2020
The share of wood-based fibers: More environment-friendly substitutes for cotton and oil-based synthetic textiles are sought. Wood-based cellulosic fibers, with more environment-friendly production technologies emerging, provide an alternative.	Felgueiras et al., 2021; Islam et al., 2021; Kallio, 2021
Use of digital nudging: Sustainable consumption choices are needed for reducing the environmental impact of textiles. Digital nudging that exploits digitalization and related data could serve as a tool to encourage circularity-focused consumption choices.	Freudenreich and Schaltegger, 2020; Weinmann et al., 2016

et al., 2020), understanding the impacts, and data's part in them, is not simple. In any case, wood-based and recycled materials as alternative inputs are relevant for textiles' circular economy (Felgueiras et al., 2021; Islam et al., 2021; Niinimäki et al., 2020). Supplier and buyer misconceptions as to the quality, price, and availability of recycled materials (post-consumer materials especially) are still rife (Fischer and Pascucci, 2017), and data could be of help here. In addition, guiding consumers toward more sustainable consumption choices appears highly relevant in this context (Freudenreich and Schaltegger, 2020; Mostaghel and Chirumalla, 2021).

2.3. *Images of the future in understanding alternative developments*

In this context with its specific complications, deeper insight as to future developments allows identifying effective responses and breaking away from path-dependency (Gausemeier et al., 1998; Rohrbeck and Kum, 2018). Articulating alternative images of the future provides a systematic way to assess possible futures (Bell and Mau, 1971; Polak, 1973), where an image of the future is defined as an "expectation about the state of things to come at some future time" (Bell and Mau, 1971). The aim is to understand multiple possible directions of development and encourage decision-makers to consider a spectrum of futures rather than fixed circumstances (Daim et al., 2006; Jiang et al., 2017). Here, images differ from scenarios: the latter are often linked to a specific baseline and represent a path to the future described (Kahn, 1962; Nowack et al., 2011).

In addition to rendering alternative futures and choices among these visible, the value of working with images of the future lies in encouraging action (Bell and Mau, 1971; Polak, 1973). This approach builds on the idea that "modern man can alter his future" by selecting both goals and ways of reaching them (Bell and Mau, 1971). Proceeding from alternative images assists in understanding the consequences of actions, alongside the responsibilities and uncertainties linked to particular potential developments (Bell and Mau, 1971; Gausemeier et al., 1998; Polak, 1973). A need for this is abundantly evident in the context of textiles-based circular economy, where the complexities and interdependencies are hard to comprehend. Images of the future are influenced by the beliefs, expectations, and assumptions of the actors defining them, such as perceptions of how society and the environment should be managed and what role technology may play (Bell and Mau, 1971; Boschetti et al., 2016). Clarifying these holds promise for advances to scholarship and practice. Also, the images may have contradictory elements that are likely to remain hidden if not made explicit (Rubin, 2013). In any case, considering them is vital on account of their connections with power and their impact on decision-making and choices (Rubin, 2013).

3. The research design

3.1. *An overview of the research design*

To construct alternative images of data's future role in circular economy for textiles, we employed the Delphi approach, which provides a systematic way to assess alternative future developments and related change factors on the basis of experts' views (Linstone and Turoff, 1975; Rowe and Wright, 2001). The specific form we chose for our study is a non-consensual disaggregative Delphi exercise (Nowack et al., 2011; Steinert, 2009; Tapio, 2003) to create images that capture a range of possible futures (see Bell and Mau, 1971; Gausemeier et al., 1998; Nowack et al., 2011). The approach is suited to developing insight and knowledge related to complex problems and emerging phenomena in conditions where change factors converge and enable several possible trajectories (Linstone and Turoff, 1975; Steinert, 2009; Tapio, 2003). In applying this Delphi method, we sought to enhance the creativity, objectivity, and credibility represented by the images of the future created (Nowack et al., 2011). We concluded that examining experts' views is the most feasible approach where other types of data that could shed light on the future are scarce and the goal is to understand an emerging phenomenon such as rapidly evolving circular economy in combination with digital technologies. For the time perspective, we opted for a 2035 horizon, which should allow sufficient room for clarity of evolutionary development toward circular economy.

The disaggregative method also allowed us to analyze qualitative and quantitative data jointly, for triangulation that enriches analysis (Steinert, 2009; Tapio, 2003). For us, taking a disaggregative approach entailed, rather than attempting to find consensus among the experts, grouping their views on the quantitative variables (from the statement-based questionnaire) into clusters and complementing these clusters with qualitative arguments so as to pinpoint the alternative futures (Tapio, 2003). Among the crucial elements for successful implementation of such a Delphi process are careful selection of the experts and their ongoing commitment (Rowe and Wright, 1999; Welty, 1972), in combination with iterative feedback and assured anonymity (Nowack et al., 2011; Rowe and Wright, 1999). Hence, we gave special weight to these factors when designing the process. Fig. 1 presents this Delphi process's six steps.

3.2. Development of the future-oriented statements

We developed the conceptual background and, through it, hypothetical statements for our first-round questionnaire instrument on the basis of a systematic review of literature on the role of data in circular economy supplemented both by the latest research on the interface of data, digitalization, and circular economy and by the literature on circular economy in the textile field. We incorporated the dimensions identified into the instrument's items, which took the form of statements for estimation tasks. To guarantee relevance, coverage, and a reasonable number of items, we developed the formulation iteratively with the research group and pilot respondents (Rowe and Wright, 2001). The questionnaire was finalized in line with feedback from two of the textile industry's circular-economy experts. Our final questionnaire for the first round of the Delphi process had 17 closed statements (four of them specific to wood-based textiles), each accompanied by a space for qualitative arguments, and three open questions. These are reproduced in Table 2.

3.3. Selection and invitation of the experts

We created an expertise matrix (a tool developed first by Kuusi et al., 2006) to make sure the Delphi panel represented the necessary full range of expertise and for transparent selection of the sample. In this two-dimensional matrix, the subject-matter expertise, or cognitive expertise (Nowack et al., 2011; Varho and Tapio, 2013), covered circular economy, data and digitalization, the textile industry, and wood-based value chains. With the second dimension, we covered several types of background organization, reflecting the experts' societal position (Varho and Tapio, 2013). Thus, we made sure to include experts from both industry and the research domain, with the institutions selected to address different parts of the textiles' life cycle and value chains. After preliminary identification of candidates globally to reflect the dimensions of the matrix, we refined and complemented the list until it reflected sufficient and balanced expertise.

In total, 85 experts were invited to take part in round 1, of whom 33 submitted responses. We sent the second-round questionnaire to 44 experts (those who had taken part in round 1 plus the ones who had accepted the first-round invitation but not submitted answers). In the second round, 23 of the 33 first-round experts and an additional three from the original list took part in the Delphi process. Table 3 presents the details of the experts' background, as reported in the second round. As for other variables, there were 14 female and 12 male experts, and about half of the experts were in the 30–44 age band or younger, making this panel younger than is usual for Delphi studies but unsurprising in light of the demographics of circularity and textiles specialists. The experts represented a wide range of nationalities, with 10 countries covered, mainly in Europe and North America.

3.4. Execution of the Delphi process's first round

In the first round, we gathered data for constructing the images that would later inform the second round, in which the focus was on the panelists' reflection on the images of the future. The first-round instrument asked the experts to assess the probable and the desirable development that is realistically attainable with regard to each future-oriented statement. This assessment was performed on an 11-point scale from 0 (meaning either a 0 % share or "not at all") to 100 (for a 100 % share or "always/exclusively/fully required"/"worldwide standards"). In addition to their quantitative assessment of the statements, experts supplied the reasoning behind their replies and answers to the open-ended questions. For both rounds, the online platform eDelphi (www.edelphi.org) served as a user-friendly real-time interface (see Gordon and Pease, 2006) whereby the experts could see and comment on one another's anonymous responses in the course of the process.

3.5. Construction of the images of the future

To create the core of the alternative future images, we conducted hierarchical cluster analysis for the quantitative data from round 1 (with SPSS, v. 26) (Tapio, 2003). In the analysis, each panelist's set of answers as to the probable future or desirable future was treated as separate cases (Rikkonen and Tapio, 2009). Because cluster analysis considers only cases with complete sets of answers, and only 13 of the 33 experts answered everything, we made some adjustments to guarantee wider perspectives on the images of the future. Where a respondent gave a response for at least 10 out of the 17 statements, we used the average of other respondents' replies for those statements without answers. To obtain more reliable results, we examined whether the cases with several adjusted data points interfered with the clustering process. They did not, so we could retain most of the rich body of qualitative data in our construction of the images. Thus, we could include 54 cases (27

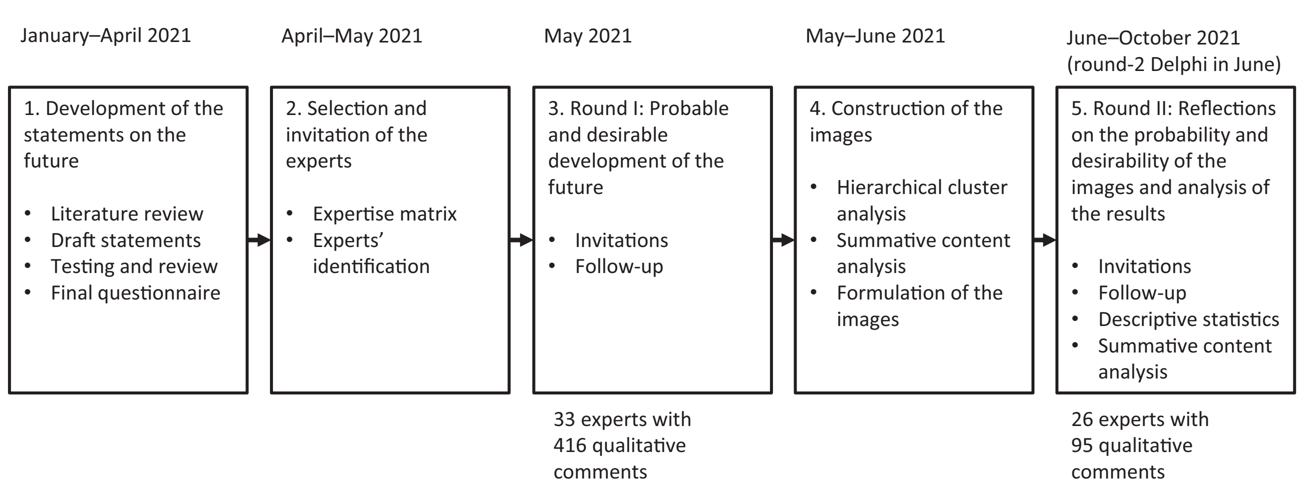

Fig. 1. The disaggregative Delphi process followed in the study.

Table 2
The first-round statements about the future for the Delphi process.

Statement	
Availability of circular-economy data	
1	**Use of digital identities.** Please estimate the probable/desirable share of textiles having an attached digital identity, such as a "digital biography" or "digital passport," with information on the product's life cycle in digital form in 2035 (as a percentage of the volume of textiles produced worldwide).
2	**Use of embedded intelligence.** Please estimate the probable/desirable share of textiles (as a percentage of the volume of textiles produced worldwide) containing embedded intelligence – sensors embedded in the textiles – that can collect and access data, such as details on usage patterns and item condition, throughout the product's life cycle in 2035.
3	**Textile-users' sharing of data.** Please estimate the percentage of textile-users who will probably/preferably share data with the textiles' retailers and/or producers during the product's service life. An example is data on how often the product gets used.
4	**Traceability of textiles.** Please estimate the share of wood-based textiles (as a percentage of the volume of wood-based textiles produced worldwide) for which traceability of all wood-based fibers' origin back through the value chain will be probable/desirable in 2035.
Sharing of circular-economy data	
5	**Availability of open life-cycle data.** Please estimate the share of textiles (as a percentage of the volume of textiles produced worldwide) for which it is probable/desirable that products' life-cycle data will be publicly available via open data sources and, hence, free for anyone to use or redistribute.
6	**Existence of global data standards.** Please estimate the extent to which there will probably/preferably be global data standards in place for textiles' circularity-linked lifetime data (enabling data-sharing and interoperability between stakeholders) in 2035.
7	**Existence of European Union regulation.** Please estimate to what extent the European Union regulations in force in 2035 will probably/preferably require that textiles' circularity-related lifetime data be freely available.
8	**Use of distributed-ledger technology.** Please estimate the probable/desirable share of textiles (as a percentage of the volume of textiles produced worldwide) for which the raw materials' origin (e.g., initial location) is verified by distributed-ledger technology, such as blockchain, in 2035.
Use of circular-economy data in business decision-making	
9	**Integration into business-management systems.** Please estimate to what extent circular-economy data will probably/preferably be integrated into business-management systems and other software in textile-related business in 2035.
10	**The share of structured data.** Please estimate the probable/desirable share of structured data – data with a standard format through which the data are easily accessible and exploitable – as a percentage of all data used in the context of circular economy in 2035.
11	**Reliability of the data.** Please estimate how often issues of data reliability will probably/preferably restrict the use of data for circular economy in wood-based textile value chains in 2035.
12	**Data-ownership problems.** Please estimate to what extent data-ownership issues will probably/preferably restrict data's utilization for 2035's circular economy in wood-based textile value chains.
New circular business models	
13	**Existence of new ownership models.** Please estimate the probable/desirable share of textiles that will be owned by the producer or retailer throughout their life cycle in 2035 (as a percentage of the volume of textiles produced worldwide).
14	**The presence of personalized textiles.** Please estimate the probable/desirable share of textiles (as a percentage of the volume of textiles produced worldwide) that in 2035 have been personalized on the basis of the user's needs (e.g., via digital services that recommend or design products in line with user preferences).
Circular economy's impacts on the environment	
15	**The share of recycled fibers.** Please estimate the probable/desirable share of textiles produced from recycled fibers in 2035 (as a percentage of the volume of textiles produced worldwide).
16	**The share of wood-based fibers.** Please estimate the probable/desirable share of textiles produced from wood-based cellulose fibers in 2035 (as a percentage of the volume of textiles produced worldwide).
17	**Use of digital nudging.** Please provide your view on how widely digital nudging (encouraging consumers toward more sustainable consumption choices) will probably/preferably be applied to guide textile-users toward sustainable consumption in 2035.

Table 3
The second-round Delphi panelists' organization type and area of expertise.

Substance expertise[a]	Both circular economy and textiles	10
	Circular economy and also data and digitalization	6
	Circular economy, textiles, and data and digitalization	4
	Circular economy	3
	Textiles	3
Organization type[a]	Industry entity	6
	Research institution	10
	Organization involved with both industry and research	9
	Public authority	1
In total		26

[a] As reported by the experts themselves. The experts were free to identify several organization types and/or areas of expertise if relevant.

probable + 27 desirable cases) in the cluster analysis. The latter analysis involved grouping similar answers together via Ward's algorithm. Since squared Euclidean distance is its distance metric, this method allows for defining a cluster's essence via only a few variables and is useful for finding the most crucial points of variation rather than focusing on small differences across the full dataset.

The cluster analysis informed creating three alternative images of the future (Tapio, 2003). The number of clusters emerged from analyzing graphical output from the clustering process, the dendrogram in the appendix. It suggested a choice of three vs. five clusters. We found that, of these options, using three images reflected the data well. A five-cluster conceptualization would not have displayed clearly distinct clusters that we could interpret as separate images, while a three-cluster one revealed distinct aspects of data's role in textiles' circular economy.

To support the creation of the images, we subjected both the experts' qualitative comments about their numeric assessments and their responses to the three open questions to summative content analysis (Hsieh and Shannon, 2005). We began by grouping the qualitative responses on the basis of the three clusters. This entailed identifying the key content of the comments within each cluster, such as the themes, arguments, and assumptions. The aim here was to understand and interpret their contextual meaning (Hsieh and Shannon, 2005). With a sense of the reasoning embedded in the answers (e.g., the assumptions made and what realization of the future images would require), we further illustrated and verified the images (Varho and Tapio, 2013). Then, we used our insight from the summative content analysis to generate brief narratives highlighting the images' central content and fundamental differences (see Fig. 2, below).

3.6. The second round's execution and analysis of the results

The second-round survey elicited the experts' views on how likely and desirable the three images are and, in addition, requested their comments on the reasoning behind these answers. For round 2's numeric results, we relied primarily upon analysis of descriptive statistics, mainly frequency tables, to illustrate consensus or polarization of the views. In this stage too, we examined the qualitative comments via summative content analysis. Doing so yielded further insight as to the experts' views on the future images. All comments were reviewed, their content identified, and their meaning in the context of the study interpreted. We focused specifically on detecting the reasoning behind the participants' identification of particular drivers of future development and behind their assessment of the probability and desirability of each image of the

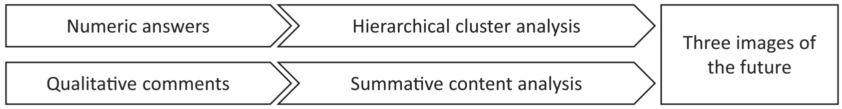

Fig. 2. The quantitative and qualitative answers combined to form the images.

future.

All in all, the qualitative material supplied was rich and extensive, reflecting the commitment of the experts and their interest in the topic. The first-round Delphi work yielded, in all, 416 comments with reasoning for the replies or answering the open questions, and a further 95 were submitted in round 2. Our choice of method allowed us to exploit qualitative and quantitative data comfortably in connection with each other as the analysis unfolded, and it proved to be reasonable for studying precisely such an evolving and complex topic as textiles' circular economy and the role of data therein.

At this point, it is worth remarking on one limitation that often faces Delphi-based research formulating questions about the future. In the first round, we asked the panelists to characterize a probable and a desirable future by assessing a set of statements (to construct a variety of future images); then, in round 2, they were asked to assess the probability and desirability of specific images. Using these two types of question brought the best sides of both to the study. Without soliciting answers about both likelihood and desirability in the first round, instruments of this nature do not aid in constructing alternative images of the future. If interaction with the panel stops there, without work on the images, the work is only half done: the full panel's probability and desirability estimates for the images ultimately developed remain unknown.

4. Results

Our presentation of results begins with what emerged overall from the first Delphi round (namely, the panel's views on the future-oriented statements), after which we elaborate on the results by discussing the three images of the future. The final part of this section (Section 4.3) is devoted to describing the panel's sense of the probability and desirability of the three images of the future, in light of the second round.

4.1. *Delphi round 1: views on the impact of data in textile-based circular economy*

4.1.1. *The results in overview*

When assessing the probability and desirability connected with the future-oriented statements presented in the first-round survey, the experts indicated – for all the statements – that the role of data in textile-related circular economy will be more advanced in their preferred future. The responses manifest a striking gap between the probable and the preferable future for most of the statements, as Table 4, below, attests. This can be interpreted as a sign of pessimism about the future among the experts in the sense that they would prefer to see stronger development by 2035 than what they deem likely. Furthermore, the participants' comments pinpoint inhibiting as well as driving forces for all statements except the one on embedded intelligence. Although they acknowledged strong drivers for circular economy, and a role of data therein, companies' readiness for the transformation and their will for more collaboration and transparency seemed questionable.

4.1.2. *Availability of circular-economy data*

With regard to the availability of circular-economy data, our quantitative assessment of responses to the statements revealed that common use of digital identities with information on the product's life cycle forms part of the experts' desired future. If we judge by the average across all preferable-future answers, 73 % of the volume of textiles produced worldwide should have an attached digital identity by 2035. Also, 71 % of wood-based textiles and their fibers ought to be traceable back to their origin. The corresponding figures for the probable future are substantially lower, at 28 % and 34 %, respectively. A role for embedded intelligence was deemed neither very probable nor desirable. The proportion of textile-users sharing data through a product's service life was seen as similarly limited in the probable and preferable future both.

Table 4
Assessment of the hypothetical statements.

No.	Statement	Probable[1] futures		Desirable[1] futures		All answers	
		Mean	SD	Mean	SD	Mean	SD
Availability of circular-economy data							
1	Use of digital identities	28.3	17.6	73.1	25.7	50.7	31.5
2	Use of embedded intelligence	12.1	9.4	20.0	10.7	16.1	10.8
3	Textile-users' sharing of data	19.7	13.0	42.1	26.0	30.9	23.4
4	Traceability of textiles	34.3	23.0	71.3	26.1	52.8	30.8
Sharing of circular-economy data							
5	Availability of open life-cycle data	23.6	14.4	68.6	24.6	46.1	30.2
6	Existence of global data standards	42.0	26.8	80.8	22.1	61.4	31.3
7	Existence of European Union regulation	39.6	25.1	67.4	24.4	53.5	28.4
8	Use of distributed-ledger technology	31.9	22.3	67.0	30.6	49.4	32.1
Use of circular-economy data in decision-making							
9	Integration into business-management systems	45.9	24.5	79.6	20.8	62.8	28.3
10	The share of structured data	34.3	18.4	77.0	18.5	55.7	28.2
11	Reliability of the data	51.5	25.2	19.0	21.2	35.3	28.4
12	Data-ownership problems	56.7	24.6	17.6	14.1	37.1	28.0
New circular business models							
13	Existence of new ownership models	16.1	8.2	34.6	18.0	25.4	16.8
14	The presence of personalized textiles	13.8	7.9	33.5	22.9	23.7	19.7
Circular economy's impacts on the environment							
15	The share of recycled fibers	26.4	10.8	60.0	19.5	43.2	23.0
16	The share of wood-based fibers	17.0	10.8	31.1	12.0	24.1	13.4
17	Use of digital nudging	47.2	28.2	62.8	22.9	55.0	26.9

[1] The experts assessed both the probability and the desirability of each statement on an 11-point scale from 0 (meaning either "a 0 % share" or "not at all") to 100 (for a 100 % share or "always/exclusively/fully required"/"worldwide standards").

The qualitative data point to a perception that the utility and benefits of digital identities still need to be proven and fully exploited. Respondents' hesitancy with regard to whether the gains will exceed the costs of digital identities explains the difference between their quantitative assessments of the desirable and the probable futures. The experts consistently indicated that embedded intelligence would hamper recycling and increase the costs of textiles while yielding relatively limited benefits, as the following quote illustrates:

> *"I do not see embedded IoT as a solution – it is a slippery slope to creating a recovery nightmare."*
> *(Respondent AO, an industry and academic expert on circular economy and on data and digitalization)*

Moreover, the experts expressed varied views in their comments on whether consumers would be ready to share data. On one hand, data could give consumers valuable insight for understanding their behavior and its impact. However, the experts did not envision consumers as motivated to collect and share data, with some pointing out also that such details might seem too intimate.

4.1.3. Sharing of circular-economy data

According to the quantitative results, the materialization of global data standards for circularity-linked life-cycle data by 2035 is regarded as more probable and desirable than most of the other developments presented in the statements. Its strength in the results for both probable and preferable outcomes is relatively high, with scores of 42 for the former and 81 for the latter. The average for the extent to which availability of textiles' life-cycle data via open data sources was considered likely is 24, which differs substantially from the average for desirability, 69. The average emerging for the extent to which European Union regulations are likely to require free availability of textiles' circularity-related lifetime data is 40. Respondents' average for probable developments suggests that distributed-ledger technology will verify the origin of the raw materials for about a third of textiles by worldwide production volume.

In their comments, the experts cited transparency and traceability as key drivers for sharing of circular-economy data. Specifically, they indicated that trailblazing companies would want to differentiate themselves in the marketplace and make more informed decisions, thereby stimulating others' development.

> *"[T]hose with a good story would embrace this opportunity [to open life-cycle data], for instance, in product passports or other such means."*
> *(Respondent AG, an industry expert on circular economy)*

On the other hand, respondents characterized the industry as afraid of how sharing of data might affect competition. Industry players were portrayed also as unprepared to share data unless required to do so. The experts regarded data standards as necessary for preventing monopolistic platforms and siloing of data, but they saw such standards as tricky to achieve at global scale. European Union regulation for sharing of life-cycle data was viewed as a sensitive matter for the textile industry, because of its potential impact on competition between EU and other markets. This view, reflected also in the substantial difference in the quantitative assessments for probable and preferable futures with regard to EU standards, ties in with the aforementioned views on distributed-ledger technology verifying raw materials' origin: the experts doubted the global textile value chains' readiness for this level of transparency. Nonetheless, they saw transparency and traceability as increasingly necessary in most countries, with distributed-ledger technology forming a part of the data infrastructure needed.

4.1.4. Use of circular-economy data in decision-making

Per the quantitative assessment of their scores for the statements, the experts found integration of circular-economy data into business-management systems and software more probable and preferable than most of the other hypothetical developments. On a scale of 0 for no integration at all to 100 for full integration, the average score for the likely future is 46 and that for the desirable one is 80. In the future the respondents deemed probable, data-reliability and data-ownership issues restrict the use of data for circular economy in wood-based textile value chains, with the average responses coming to 52 and 57, respectively, where 0 = not at all and 100 = always restricted.

The experts commented that both business opportunities and reporting requirements may be expected to create pressure for integrating circular-economy data into business-management systems and software. They described this integration as crucial for scaling of circular-economy strategies and business models.

> *"Until data is linked to business-management practices, major change will not happen and the circularity projects will stay in the corners of R&D, communication, and Corporate Social Responsibility departments."*
> *(Respondent AM, an industry and academic expert on circular economy and textiles)*

The experts expressed doubts as to whether, even with such integration in place, the data would truly inform decisions or actions, and they stressed that access to information does not imply choosing the most sustainable option. According to the respondents, issues with the reliability and ownership of data are likely to contribute to restricted utilization of data not only for wood-based textiles but in all textile value chains.

4.1.5. New circular-economy business models

The quantitative results point to a relatively limited role for new ownership models and a modest rise of personalized textiles in the probable future but accentuate a noteworthy role in the desired future. According to the averages, 16 % of textiles will be owned by the producer or retailer throughout their life cycle and 14 % will be personalized on the basis of the user's needs. The corresponding figures for the desirable future imply shares of 35 % and 34 %, respectively.

In the qualitative data, the experts point to a need for new ownership models that could enable textiles' circular economy. They indicated also that, because breaking through the perceived barrier of consumers' lack of ownership will prove difficult, these models are likely to focus on niche fields, such as technical textiles. While digitalization presents opportunities for personalizing textiles, they stressed that personalized textiles are not necessarily in line with sustainability, circular economy, and reduced environmental impact.

> *"Digital services personalize our offers already but [are] not doing any good in terms of slowing down consumption."*
> *(Respondent AJ, a circular-economy research expert)*

The experts indicated a wish for consumers and other users to become more aware of the environmental price of textiles and to be willing to pay for sustainability. However, they recognized that actual steps in this direction might end up limited to selected product types and countries.

4.1.6. Circular economy's impacts on the environment

The experts' average for the probable percentage of final textiles produced from recycled fibers, by global volume, is 26 %. The average for their "preferable" responses points to hopes for a substantial share, as high as 60 %. The respondents expected use of wood-based cellulosic fibers to develop more modestly, with figures of 17 % for the probable future and 31 % for their preferred one. Digital nudging to guide textile-users toward sustainable consumption was considered both likely and preferable; the average score for this factor was 47 for "probable" and 63 for "preferable" responses (where 0 = "not at all" and 100 = "exclusively").

The experts' qualitative responses emphasize the need to internalize externalities – namely, the environmental and social costs of textiles – in pursuit of better circular economy and a smaller environmental impact. The experts would prefer that textiles be viewed not as consumables but as assets.

> *"Many consumers globally are price-sensitive by necessity, don't know about circularity, and have more immediate and pressing issues to deal with."*

(Respondent AZ, a public-authority figure who is an industry expert and an academic researcher focusing on circular economy and textiles)

Although they saw challenges in communicating to users and customers what is sustainable, the experts doubted that digital nudging will be used to support circular economy as opposed to still higher consumption.

4.2. The first round in depth: the three possible futures

4.2.1. The images in overview

Based on the first-round Delphi results, three alternative images of the future were developed. Table 5 outlines the key features of these. The role of data in the Transparency prospect arises from traceability and transparency needs, while circularity gains from the use of data remain secondary. In the Conflicting Interests image, competition concerns and lack of trust in global value chains outweigh the promise of data-derived value and circularity practices. Finally, exploitation of data in the Sustainable Textiles image emphasizes support for circular economy through patterns of sustainable production and consumption of textiles.

Fig. 3 presents the strength of the various statements in the three images, on the basis of the results from the first-round survey. The Conflicting Interests image differs substantially from the other two images, with rather modest development perceived for the role of data and the implementation of circular economy in textiles activities. The distinction between Transparency and Sustainable Textiles is a subtler one. In the Transparency future, the increasing use of data is driven mainly by transparency- and traceability-related demands from regulators, investors, and other stakeholders. In contrast, businesses and consumers in the Sustainable Textiles vision are motivated to put data to use in reconsidering their approach to the sustainability aspects of textiles' production, consumption, and appreciation, with a role for circular-economy principles.

In the cluster analysis that facilitated identifying the three images, eight out of the 54 cases were linked to the Transparency image, 29 to Conflicting Interests, and 17 to Sustainable Textiles. The Transparency image included only cases addressing the preferred future, while the other clusters factored in both probable and preferable cases: 25 probable and four preferable cases for Conflicting Interests and, correspondingly, two and 15, respectively, for Sustainable Textiles.

Next, we look more deeply at each of the three alternative future images identified.

4.2.2. Transparency

In the Transparency image, the role of data is driven by efforts to guarantee the transparency and traceability required for the textile industry's continued social license to operate. This is a future in which every textile product has provenance and where operations involving wood-based fibers benefit from solid traceability. Here, textiles' origins can be verified, and transparency renders it hard for the industry to make unsubstantiated claims. This outcome would be supported by global data standards for textiles' life-cycle data and by integrating circular-economy data into business-management systems. While textiles' digital identity and life-cycle data do feature circular-economy and environment-related details in this future, the data would not be shared for free unless legislation or investors require this. In the Transparency prospect, the value provided by data for resolving circular-economy-linked challenges is relatively limited since neither businesses nor consumers see a strong need to move toward environmentally sustainable, circular economic practices.

In the Transparency image, investors move their focus away from non-green companies, thus making traceability and transparency a necessity for the global textile industry. Also, EU policy incentives for the industry's traceability and transparency will spread further, exerting global influence. Doubt will remain, however, as to any concrete effect of the associated data on circular economy and on the excessive consumption and production of textiles. In this future, fully open sharing of data related to environmental sustainability and product life cycles is considered detrimental to the business interests of the global textile industry. Complexities related to textiles' sustainability might further hinder circular economy and data's use for related aims.

Table 5
The main features of the three images of the future.

Feature category	Transparency	Conflicting interests	Sustainable textiles
Emphasis in relation to circular economy	Circular economy and environmental impacts as secondary; wood-based fibers benefiting from relatively easy tracing	Circular-economy and environmental-sustainability gains overshadowed by competition and lack of trust	Versatile circular-economy practices with positive environmental impacts and an increased role of recycled and wood-based fibers
Role of data	Data enabling traceability and transparency of textiles' value chains	Data treated as a business secret	Support for conscious production and consumption choices
Main actors driving change	Regulators and investors in the primary role	Scattered impetus	Business and consumers as major drivers

4.2.3. Conflicting Interests

A future unfolding in accordance with the Conflicting Interests image would see competition in global value chains and the actors' lack of mutual trust take priority over value from environmentally sustainable, circular-economy-related strategies and practices and over the potential gains brought by data. Here, lacking incentives to exploit or share their data for the benefit of environmental sustainability, businesses regularly ask who would pay for the data and the necessary investments. Any standards for circular-economy data remain fragmented, and data-ownership and reliability issues impede traceability and open availability of data. Businesses guard the related data jealously, and consumers lack motivation to engage in circular practices. A siloed approach dominates, neglecting digital identities and distributed-ledger technology. Globally, the share of recycled and wood-based fibers stays marginal.

The Conflicting Interests image manifests clearly immature circular-economy developments for textiles. One stumbling block to moving toward environmental sustainability globally is the associated need for dramatic changes to the industry and its business mindset. The experts indeed questioned the global textile industry's readiness to increase transparency and foster a culture of open data-sharing. They did not regard environmentally aware consumers as a strong driver, and they indicated that the value of using and openly sharing data would remain unclear to both the industry and consumers. In addition, many uses of data, such as digital nudging or personalization of textiles, might actually encourage additional consumption rather than guide very many people toward greater environmental sustainability.

4.2.4. Sustainable Textiles

In the final image, exploitation of data for circular economy transforms how textiles get appreciated, produced, and consumed. The Sustainable Textiles future entails data strategies driven by the need for better environmental performance. In this image, the textile industry's increased emphasis on sustainability enables more conscious, fact-based consumption choices, related to long-lasting products and raw materials. Textiles have digital identities with information on the product's life cycle and related environmental impacts, and open data sources make the related data publicly available. Raw materials' origin is verified through distributed-ledger or similar technology. Here, the industry's business models take advantage of circular economy; for example,

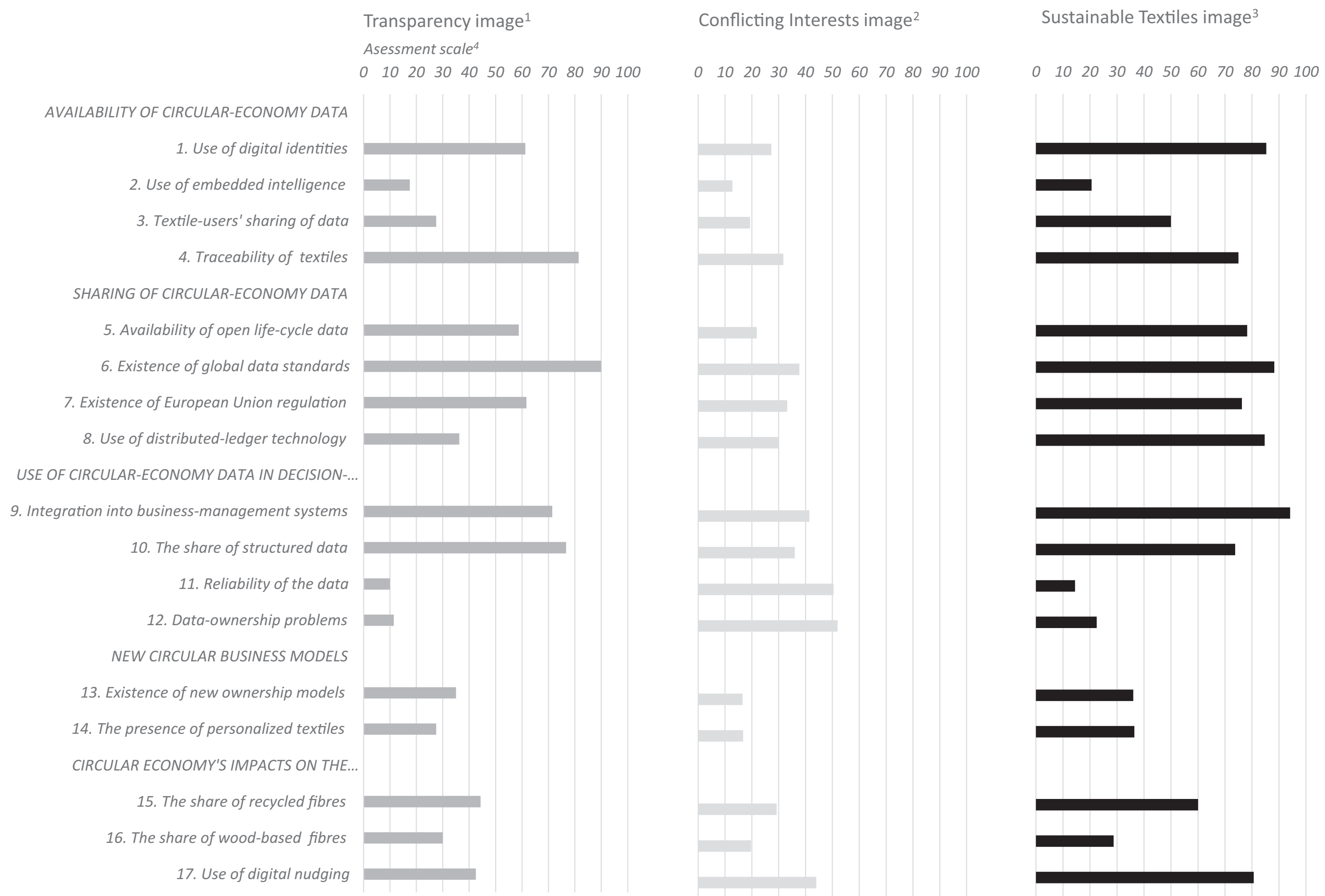

Fig. 3. The strength of the various statements in the three images.
[1] Transparency image includes eight cases (all preferable cases).
[2] Conflicting Interests image includes 29 cases (25 probable and four preferable cases).
[3] Sustainable Textiles image includes 17 cases (two probable and 15 preferable cases).
[4] The assessment was performed on an 11-point scale from 0 (meaning either a 0 % share or "not at all") to 100 (for a 100 % share or "always/exclusively/fully required"/"worldwide standards").

textiles-as-a-service business models are popular, and the users share data with the retailers and producers throughout the textiles' service life. Circular-economy practices have reached the mainstream, and the share of recycled and wood-based fibers is significant globally.

In this image of the future, business opportunities created via new circular business models and strategies push the textile industry toward environmentally sustainable circular-economy practices and versatile use of data. Businesses with a good story to tell embrace the opportunity for a shift that gives impetus to others, and large multinationals adopt practices that impose global pressure for change, also in terms of international regulations and policies. This is a vision in which the industry's significant investments in digitalization bear fruit in greater environmental sustainability and further circular-economy gains. Simultaneously, regulatory requirements, demands of investors, and consumers' commitment would support moving toward environmentally sustainable practices and multifaceted use of products' life-cycle and environment-related data in the textile industry.

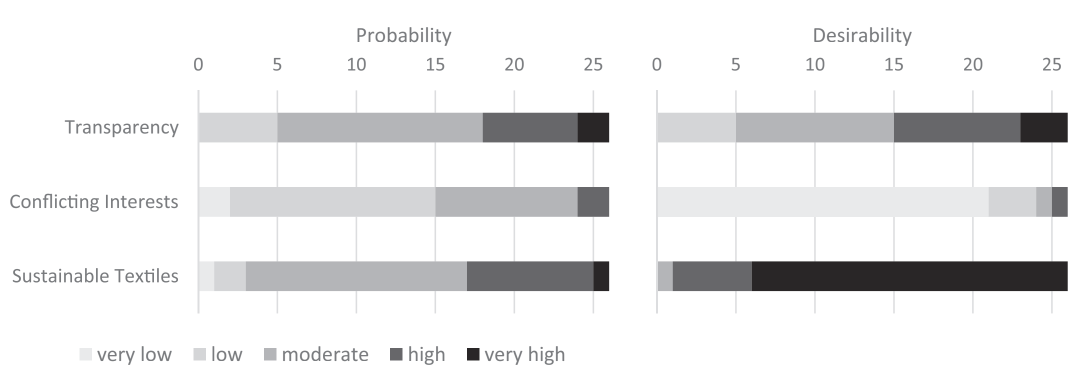

Fig. 4. The probability and desirability of the future images according to the 26 second-round responses.

4.3. Delphi round 2: assessment of the images

In the second-round Delphi survey, the panelists assessed the probability and desirability of the three images described above. Actualization of the Conflicting Interests alternative was considered the least likely, with most participants assigning it low or moderate likelihood (see Fig. 4, below), even though this image comprised mostly cases deemed probable in round 1. The experts' comments identified growing pressure for transparency and environmental sustainability as acting counter to this possible future. Extension of participation and trust globally, with interoperable digital systems and shared data included, was cited as required for keeping Conflicting Interests from becoming reality.

> *"We are currently moving towards more open production chains, but for sure if there are big political changes globally, the good progress might take a step back[ward]."*
>
> *(Respondent AF, an academic expert on textiles)*

The other two images were rather similar to each other in their probability assessments, with the largest proportion of the experts deeming their realization moderately or highly likely. Respondents pointed to several strong drivers specific to Transparency; however, they expected data to be used to tackle problems much more complex than transparency and traceability alone. They saw key drivers for transparency as stemming from policy, consumers, and the business world itself. For instance, some cited investors themselves as pushing for more transparency and traceability.

> *"Investors will set the pace for the direction industry will move, and demand for transparency and traceability will extend beyond EU borders [because of] where raw-material origins and textile-processing hubs exist."*
>
> *(Respondent BS, an industry expert in circular economy, data and digitalization, textiles, and wood-based value chains)*

For the Sustainable Textiles image to become reality, the experts commented, collaboration across the textile industry is crucial for the speed and scale of change required. Per the respondents' comments, all drivers should act together to create a circle of reinforcing action in which forerunners act as an example to others and propel change. Some experts stated that realizing this vision by 2035 is "too good to be true," though it could serve as an excellent target for the industry. Sustainable Textiles was assessed as clearly the most desirable image, with the comments identifying it as the "only 'harmonious' scenario that leaves no inefficiencies" (respondent BB, an industry expert on circular economy and data/digitalization).

The desirability of Conflicting Interests, at the other end of the spectrum, was predominantly very low. The experts identified it as a highly undesirable future that represents "a failure of scalable response to sustainability needs" (respondent BE, an industry expert on circular economy, data and digitalization, and textiles). The Transparency image lay between the other two prospects in the respondents' assessment: desirable for the most part but, according to the qualitative data, displaying an overly simplistic approach and not yielding sustainability. Following such an approach thus far "has helped bring attention to issues in the supply chain and also some improvements […] but hasn't fundamentally changed the industry" from being "still linear" (respondent AJ, a research expert on circular economy).

5. Discussion and conclusions

5.1. Implications for theory

The findings from the study have several implications for scholarship and theory-based inquiry. Firstly, the framework identified three factors to be critical both for the future of circular economy and for the role of data therein – namely, the commitment of the businesses, high consumer awareness, and regulatory impetus. This finding is consistent with earlier literature, which depicts implementation of circular economy as necessarily a joint effort of the business world, consumers, and policymakers (Bag et al., 2021; Fischer and Pascucci, 2017; Masi et al., 2018; Saha et al., 2021).

This is evident in the Sustainable Textiles image, where all actors favor versatile circular-economy practices and in which exploitation of data transforms how textiles get appreciated, produced, and consumed. Actualizing the Sustainable Textiles image requires businesses that possess well-aligned resources and the necessary capabilities for implementing circularity and exploiting circular-economy data in their decision-making, aspects that the recent literature too highlights (Awan et al., 2021; Bag et al., 2022, 2021; Jia et al., 2020; Saha et al., 2021). Scholars have identified top-management commitment and leadership skills in particular as crucial for implementing circular economy (Dubey et al., 2019; Moktadir et al., 2020; Yamoah et al., 2022), and these are critical also for reaping benefits from data. The business analytics capability of a company, as well, is linked with the ability to excel in circular economy (Kristoffersen et al., 2021b). Even with excellent knowledge on circular economy and high degree of digital maturity, companies might need to focus on fostering a culture where trust and collaboration drive data-driven decision-making for circular-oriented innovation (Kristoffersen et al., 2021a).

Consumers, in turn, play a vital role for acceptance and implementation of circular economy, related practices, and business models, as some recent work emphasizes (Durán-Romero et al., 2020; Huynh, 2021; Jia et al., 2020; Mostaghel and Chirumalla, 2021; Saha et al., 2021). Consumers both produce and use circular-economy data, and they determine the broader acceptability and, hence, feasibility of data-driven solutions. Our study revealed the magnitude of the impact a regulatory push can have on how circular-economy data will be managed and shared, in a conclusion supported by previous research (Gaur et al., 2021; Jia et al., 2020; Moktadir et al., 2020; Saha et al., 2021). In this regard, it also identified a key threat suggested by the literature (Fromhold-Eisebith et al., 2021): without enabling regulation, companies, in fear of losing know-how and data sovereignty, might favor isolated solutions and avoid sharing data.

Secondly, the results highlight that, for broad-based exploitation of data in pursuit of businesses' and societies' move toward circular economy, more collaboration is needed on sharing, managing, and utilizing circular-economy data throughout supply chains and value networks. Data sharing needs to cross companies' organizational boundaries, both upstream and downstream in their value chains, and build on collaboration, transparency, and trust internally and externally (Kristoffersen et al., 2021a). This finding is in line with literature stressing the role of collaboration within and beyond industry boundaries for implementation of genuine circular economy (Bag and Rahman, 2021; Brown et al., 2019; Durán-Romero et al., 2020; Frishammar and Parida, 2019) and for obtaining value from data in networked circular-economy settings (Gebhardt et al., 2021; Gupta et al., 2018; Rajala et al., 2018; Tsolakis et al., 2021).

The Conflicting Interests image speaks to the other side of collaboration, a future where sharing of data and circular-economy gains are overshadowed by competition and lack of trust. Prior work has recognized the competitive and global nature of textile value chains as a potential threat to circular economy's implementation in the industry (Choi and Chen, 2021; Saha et al., 2021). Addressing it calls for common practices and data standards that guarantee fairness and interoperability in data management. However this is done, solid supplier–customer relationships and capabilities connected with digital technologies (and related areas) will be assets in circular value networks, in which collaboration and competition often coexist. While the literature attests to this (Bag et al., 2021; Moktadir et al., 2020; Yu et al., 2021) and the need for collaboration is well-recognized, our results point to something more.

Availability and sharing of circular-economy data do not guarantee actually using the data for decisions or circular-economy measures. Yet the value of data lies chiefly in an ability to support better strategic and operations-level decision-making (Bag et al., 2021; Chauhan et al., 2022; Gebhardt et al., 2021; Lopes de Sousa Jabbour et al., 2018), and true collaboration calls for alignment with a common aim of circular activities and for developing – and sustaining – joint circularity-oriented decision-making and digital sharing of information so as to improve resource-sharing and allow joint knowledge creation (Brown et al., 2019; Gebhardt et al., 2021). This is especially vital since circular supply chains feature many decision-makers, whose objectives may even be mutually contradictory, further complicating decisions (Choi and Chen, 2021).

Thirdly, there is a strong need for greater transparency of products' life cycle and of business operations along the whole value chain. The Transparency image reflects this demand, the importance of which scholars recognize as fundamental for the transition toward circular economy (Agrawal and Pal, 2019; Bag et al., 2022; Kumar et al., 2017; Luján-Ornelas et al., 2020). Meaningful circular-economy data with inherent accountability not only help managers to learn more about their operations and product value chains but can assist consumers, investors, and other stakeholders in their decision-making (Sodhi and Tang, 2019). There are obvious benefits when, for example, data verify products' origins or furnish proof of environment-related claims. While research has identified such clear benefits of transparency as better supply-chain performance and greater consumer and investor trust, several factors still hinder development in this direction – among them the difficulty and cost of gathering information and the absence of uniform definitions and methods (Ebinger and Omondi, 2020; Garcia-Torres et al., 2019; Sodhi and Tang, 2019).

The study indicates also that development toward circular economy, and the role of digitalization and data in this, is far from uncontested and displays complex interdependencies. Various impacts on environmental sustainability are still subject to controversy, and several fault lines are emerging on the basis of tensions between environmental and other goals. Likewise, specific digital technologies display paradoxical elements that obscure their potential to drive positive change. Although recent years have witnessed a growing interest in academic research that delves into the role of digitalization in implementation of circular economy, most scholars are content with the general conclusion that digitalization represents an opportunity (see Lopes de Sousa Jabbour et al., 2018; Nascimento et al., 2019; Rajput and Singh, 2019). Thus far, circular-economy literature has largely neglected to consider the web of (sometimes contradictory) demands and implications related to the interface of the two (among the exceptions: Kouhizadeh et al., 2019; Upadhyay et al., 2021). Multifaceted consideration of potential paradoxes is especially relevant amid today's rapid evolution in the use of digitalization for implementing circular economy, while related policies and practices remain in their early development.

Finally, our study contributed a definition and operationalization of the term "circular-economy data." This draws together diverse sources of product and service life-cycle data with value-network data. In combination, these data can lead to valuable knowledge for development toward circular economy. Our results indicate that understandings related to circular-economy data remain vague and, therefore, call for clarification of the concept. Further work toward common understanding and interpretation is necessary, for thorough awareness of what kinds of data are relevant for bringing about circular economy. In addition, further insight as to the best ways to collect, manage, and share circular-economy data and use said data in decision-making – aspects underlined also in previous research (see, for example, Ren et al., 2019) – would be valuable.

5.2. Management implications

The study pinpointed several ways in which business practitioners could advance their use of data for the benefit of circular economy, and it identified specific elements that they should address. Firstly, the images of the future accentuate that the role of data is tightly intertwined with circular-economy aspirations. The more ambitious the circularity objectives are, the more vital the role of data becomes. Moving toward circular economy requires data's utilization for tackling more complex problems than mere transparency and traceability: the data must support systemic shifts toward environment-friendly production and consumption. Also, as the importance of data rises, the need for accurate data becomes even more critical.

In addition, extensive exploitation of data to guide businesses toward circular economy demands that circular-economy data be available, shared throughout the value networks, and used efficiently in decision-making. Companies must make sure that their data assets and infrastructure, coupled with their data and management capabilities, support the realization of circular economy. Also, they should identify whether any given business-data initiative supports environmental sustainability or, instead, has more negative environmental impacts.

In light of the results, companies and industries are encouraged also to be proactive in considering the best uses of data for future circular economy. They should take responsibility for exploring these in collaboration with their value networks. This would support discovering successful and future-proof practices for the use and management of circular-economy data. The same is true for fair principles for sharing the data. Here, the novel wood-based textile value networks could set an example by building on the pulp and paper industry's experience in areas such as tracing the origin of fibers back to the forest and guaranteeing sustainable forest management.

A final point accentuated for managers is that the real-world interface of data and circular economy is multifaceted and complex, with some forces acting against each other also. At the same time, geographical and other factors influence businesses', consumers', and regulators' views of how to advance circular economy, environmental sustainability, and the place of data in these. While they are simplistic representations of alternative futures, the three images offer a tool for companies' reflection on their strategic goals and priorities against the backdrop of potential future developments. They can help practitioners consider what kind of future they would like to create and how to influence development accordingly.

Alongside business managers, industry associations and other leaders can gain from the alternative images of the future. This framework's possible benefits extend much further also, to such arenas as policy, academia, and the world of consumers. With the aid of alternative images, all parties can better assess their circular-economy commitments, planned actions, and the consequences of these. The images constitute a tool for joint discussion of the desired future and of the related responsibilities and uncertainties along the journey. This kind of insight is valuable in any context but especially in that of textiles, with its extensive challenges to establishing circular patterns, its complex global value chains, and actors with varied and divergent goals.

5.3. Methodological considerations and further research

This study entailed some limitations. Firstly, the experts on the Delphi panel were from Europe, the US, and South Africa, while other parts of the world were not represented. This may have limited the views in some respects. Also, there was less expertise in data and digitalization than initially intended – it turned out to be hard to find circular-economy and textiles experts who possessed knowledge of this as well. Secondly, the statements imposed limitations: we kept their number limited and restricted them to elements that are rather straightforward to formulate as questionnaire items. Hence, they may have given less weight to complex issues (e.g., management capabilities required for obtaining value from the data). The third limitation we recognize is another one related to the statements. When viewed in retrospect, some of them could have been formulated to support more consistent understanding. This issue was visible with, for example, the future availability of "structured data." Finally, the state of the art imposed limitations: because discussion of the role of data in the context of circular economy is fairly new and continuously evolving, some key terms lack commonly recognized and accepted definitions.

Several questions remain for further research. Future work could examine what particular circular-economy data, from among the many sources of value-network and (product and service) life-cycle data, can provide the most valuable knowledge for the implementation of circular strategies and operations. The resulting understanding of collaboration principles and best practice for sharing circular-economy data across value networks would be valuable. So would fuller awareness of how said data could support decision-making efficiently and leverage value, in business activities and society at large. Experts show particular interest in how open sharing of data could be encouraged and facilitated for the benefit of circular economy. Finding answers will require interdisciplinary research and solid collaboration between business and academic domains.

CRediT authorship contribution statement

Päivi Luoma: Conceptualization, Methodology, Investigation, Formal analysis, Writing – Original Draft, Writing – Review & Editing **Esko Penttinen:** Conceptualization, Writing – Review & Editing **Petri Tapio:** Methodology, Writing – Review & Editing **Anne Toppinen:** Conceptualization, Writing – Review & Editing.

Declaration of competing interest

None.

Data availability

The authors do not have permission to share data.

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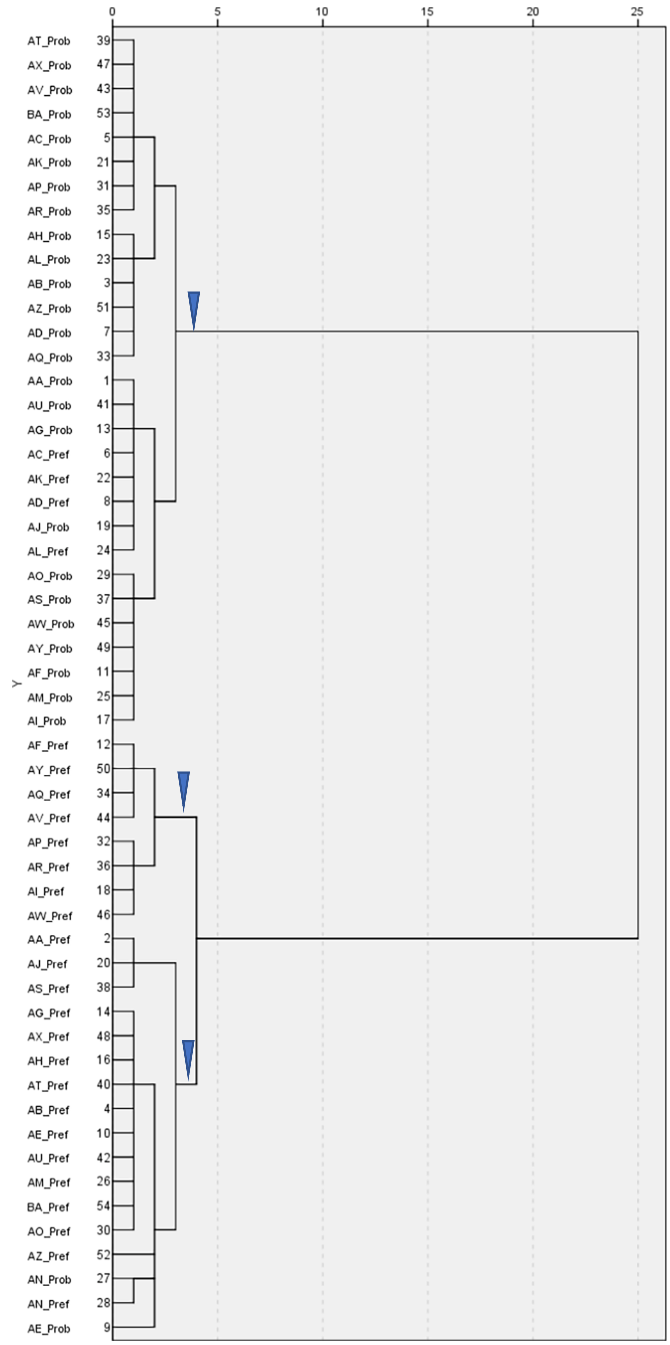
Appendix A. Dendrogram from the first-round results' cluster analysis (selected final cluster partition marked with arrowheads)



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