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Industry-specific digital compasses for the green transition

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VTT

beyond the obvious

Report's title	
Industry-specific digital compasses for the green transition	
Customer, contact person, address Emilia Gädda/Marja-Liisa Niinikoski Finnish Textile & Fashion (Suomen Tekstiili & Muoti ry), Eteläranta 10, 00130 HELSINKI	**Order reference** VTT-223574-23
Project name Industry-specific digital compasses for the green transition (Toimialakohtaiset vihreän siirtymän digikompassit),	**Project number/Short name** 137032 /TT_T3 kompassi

Summary

The "Industry-specific digital compasses for the green transition" project was implemented by researchers from VTT, the Technical Research Centre of Finland Ltd., together with representatives of Finnish Textile & Fashion (Suomen Tekstiili & Muoti), Chemical Industry Federation of Finland (Kemianteollisuus ry) and Service Sector Employers (PALTA ry). The project implementation period was June 2023 – March 2024.

The study investigated the following subject: "Which digitalisation solutions contribute to the green transition with business edge conditions, especially in the clothing manufacturing value chain?" In the research, a general reference framework for the green transition through digitalisation was drawn up, and the production chain of traditional clothing manufacturing, which has significant environmental impacts, was examined as a case study. The research utilised the results of surveys and interview studies carried out in the companies of industry associations and literature research.

According to the textile questionnaire and interviews, the common issue on the twin transition roadmap is the upcoming digital product passport. Companies need to prepare for both the product passport and other regulations and reporting requests for sustainability and the circular economy. Companies can start by collecting material information and integrating their internal systems, e.g. using software robotics. Digitalisation starts with making your processes more efficient and expands to the data management of subcontracting networks. Virtual technologies (3D design, AR/VR, metaverse) have a positive environmental impact because the use of materials is eliminated or at least reduced. Optimisation of manufacturing, e.g. decreasing energy or materials, is possible with the help of digital technologies (e.g. IoT, digital twin, artificial intelligence). The platform economy can support textile manufacturing in all stages as well as in the new services of the circular economy (repair, rental, reuse and recycling of used clothes).

Logistics is an essential function for manufacturing industries – including the chemical and textile industries – and the need for transparency and reporting capability on the emissions generated through this process will increase. Logistics has become attentive to greenhouse gas emissions calculation and reporting, both upstream and downstream, in the supply chain.

Oulu 16 April 2024

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Confidentiality Public

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Distribution (customer and VTT)

The report is public and VTT will share it in its publication system (PURE) in pdf format. The contributors, such as company representatives in interviews, respondents of questionnaires, and steering group members will receive the report via email.

Raportin nimi

Industry-specific digital compasses for the green transition

Asiakkaan nimi, yhteyshenkilö ja yhteystiedot	**Asiakkaan viite**
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Projektin nimi	**Projektin numero/lyhytnimi**
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Tiivistelmä

“Toimialakohtaiset vihreän siirtymän digikompassit” -hankkeen toteuttivat VTT Teknologian tutkimuskeskus Oy:n tutkijat yhdessä Suomen Tekstiili & Muoti ry:n, Kemianteollisuus ry:n, sekä Palvelualojen työnantajat, PALTA ry:n edustajien kanssa. Hankkeen toteutusaika oli 1.6. 2023 – 31.3.2024

Tutkimuksessa selvitettiin: “*Mitkä digitalisaatioratkaisut edesauttavat vihreää siirtymää liiketoiminnallisin reunaehdoin erityisesti vaatteen valmistuksen arvoketjussa”.* Hankkeessa laadittiin yleinen viitekehys vihreään siirtymään digitalisaation keinoin, sekä tarkasteltiin case-kohteena perinteisen vaatteen valmistuksen tuotantoketjua, jolla on merkittäviä ympäristövaikutuksia. Tutkimuksessa hyödynnettiin kirjallisuustutkimuksen lisäksi toimialaliittojen jäsenyrityksissä tehtävien kysely- ja haastattelututkimusten tuloksia sekä työpajoja.

Tekstiiliteollisuuden kyselyn ja haastattelujen mukaan yhteinen yrityksiä huolestuttava asia on tuleva digitaalinen tuotepassi. Yritysten tulee valmistautua sekä digitaalisen tuotepassin että kestävän kehityksen ja kiertotalouden sääntelyn ja raportointivaatimusten tulemiseen. Yritykset voivat aloittaa materiaalitiedon keräämisellä ja omien sisäisten järjestelmien integroinnilla esim. ohjelmistorobotiikkaa hyödyntäen. Digitalisaatio lähtee omien prosessien tehostamisesta ja laajentuu alihankintaverkostojen datan hallintaan. Virtuaalisilla ratkaisuilla (3D-suunnittelu, AR/VR, metaverse) on positiivinen ympäristövaikutus, koska materiaalin käyttö poistuu tai ainakin vähenee. Valmistuksen optimointi esim. energian tai materiaalien suhteen on mahdollista digitaalisten teknologioiden (esim, IoT, digitaalinen kaksonen, tekoäly) avulla. Alustatalous voi tukea tekstiilien valmistusta kaikissa vaiheissa sekä kiertotalouden uusissa palveluissa (korjaus, vuokraus ja käytettyjen vaatteiden uudelleenmyynnissä ja kierrätyksessä).

Logistiikka on oleellinen toiminto kaikelle valmistavalle teollisuudelle - mukaan lukien kemianteollisuus ja tekstiiliteollisuus - ja tätä kautta syntyvien päästöjen läpinäkyvyyden ja raportointikyvykkyyden tarve tulee kasvamaan. Logistiikka on jo herännyt kasvihuonekaasupäästöjen laskentaan ja raportointiin myös toimijaverkoston yli, eli sekä ylä- että alavirtaan.

Oulu 16. huhtikuu 2024

Laatija

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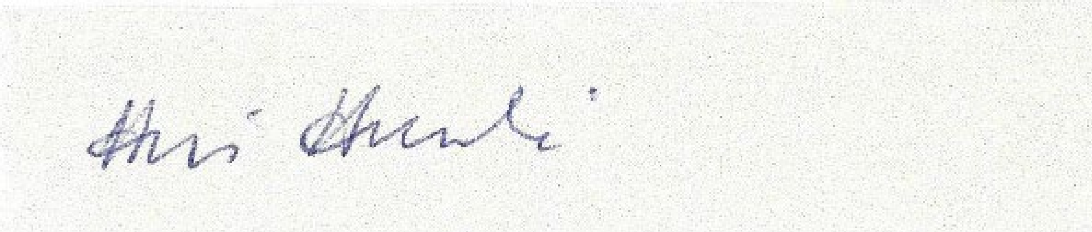
VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD

Date: 16 April 2024

Signature: 

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Acronyms

AI Artificial Intelligence

AR Augmented Reality

B2B Business to Business

B2C Business to Customer

BoL Beginning of Life

CE Circular Economy

CRM Customer Relationship Management

DPP Digital Product Passport

EPR Extended Producer Responsibility

EoL End of Life

ERP Enterprise Resource Planning

ESPR Ecodesign for Sustainable Production Regulation

ETA Estimated time of arrival

EU European Union

GHG Green House Gas

GLEC Global Logistics Emissions Council

GS1 Global Standards, GS1 is a not-for-profit organization providing barcodes globally

IoT Internet of Things

OSME Open Smart Manufacturing Ecosystem

MoL Middle of Life

SaaS Software as a Service

SME Small and Medium Size Enterprises

RFID Radio Frequency Identification

RPA Robotic Processing Automation

QR Quick-response

VR Virtual Reality

Contents

1. Description and objectives

The study investigated the following topic: *"Which digital solutions contribute to the green transition with business edge conditions, especially in the clothing manufacturing value chain?"* In the research, a general reference framework for the green transition through digitalisation was drawn up, and the production chain of traditional clothing manufacturing, which has significant environmental impacts, is examined as a case study. The research utilised the results of survey and interview studies carried out in the companies of industry associations, as well as literature research.

The "*Industry-specific digital compasses for the green transition*" project was implemented by researchers from VTT, the Technical Research Centre of Finland Ltd., with representatives of Finnish Textile & Fashion (Suomen Tekstiili & Muoti), Chemical Industry Federation of Finland (Kemianteollisuus ry) and Service Sector Employers (PALTA ry). Figure 1 documents the project organisation, where the Confederation of Finnish Industries (Elinkeinoelämän keskusliitto) was also represented.

Project manager:	Leila Saari
Project members:	Jukka Kääriäinen Satu-Marja Mäkelä Tuija Rantala Ella Hatara Laura Kojo
Project's steering group:	Emilia Gädda, Finnish Textile & Fashion Marja-Liisa Niinikoski, Finnish Textile & Fashion, chair Mika Tuuliainen, Confederation of Finnish Industries Jari Konttinen, Service Sector Employers Anni Siltanen, Chemical Industry Federation of Finland Tuija Rantala, VTT Technical Research Centre of Finland Ltd Leila Saari, VTT Technical Research Centre of Finland Ltd, secretary

Figure 1. Project organisation

2. Methods

This chapter reports the research framework applied in this research. Generally, a research framework refers to the overall structure, approach and theoretical underpinnings that guide a research study. It is a systematic way of organising and conceptualising the research process, including the research question, data collection methods, analysis techniques and interpretation of findings. Figure 2 presents the research framework applied in this study.

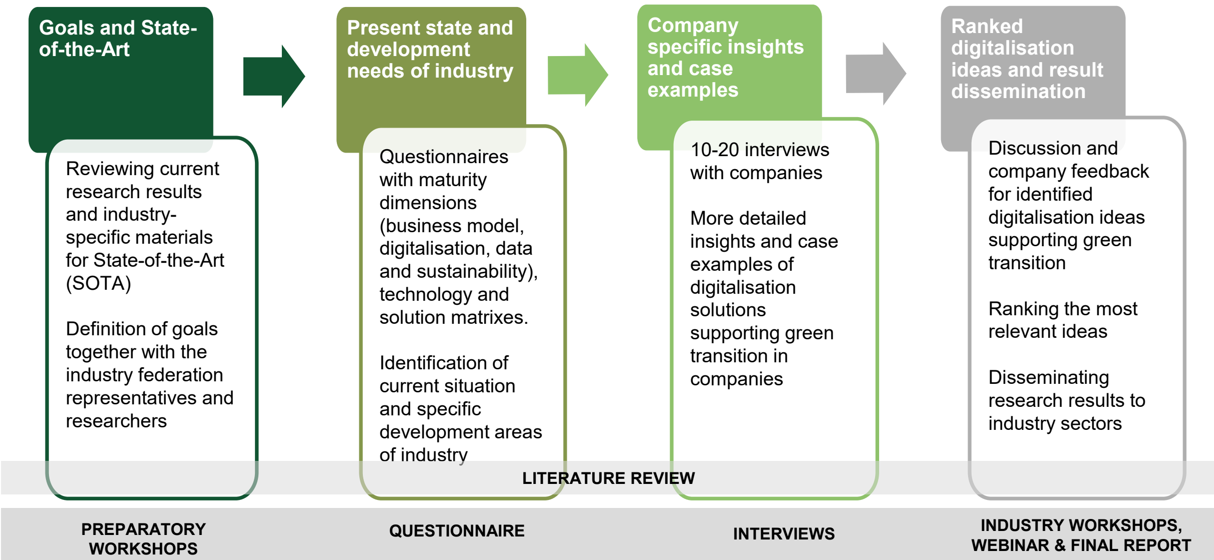

Figure 2. The applied research framework

The exploited methods were: i) questionnaires, ii) interviews, iii) literature review and iv) workshops. Table 1 summarises the method applied in those three industry sectors. The comprehensive analysis of the textile industry included a questionnaire and interviews. The logistics and chemical industry were handled with questionnaires and workshops. The logistics and the chemical industry questionnaires received a low number of responses and therefore they are not reported to secure the anonymity of companies. The low input from companies was supplemented by a preliminary list of digital ideas from the existing surveys for the logistics and chemical industry workshops.

Table 1. Applied research methods

Method	Clothing manufacturing value chain	Logistics	Chemical industry
Questionnaire	N=18	N=2	N=4
Interviews	N=10	not planned	not planned
Workshop	not planned	YES	YES
Literature review	major	minor to support the workshop	minor to support the workshop

Questionnaires

Three questionnaires were conducted, one for each industrial domain: i) clothing manufacturing value chain, ii) logistics and iii) the chemical industry. The questionnaire for the clothing manufacturing value chain included three types of questions: maturity-level questions, matrixes and open questions and background questions. The maturity-level questions were based on the Open Smart Manufacturing Ecosystem (OSME) maturity tool [1] and the Circular Economy (CE) matrix [2] (see maturity levels in Figure 12 and Figure 13 in Appendices). In addition, two new questions were generated: warehouse automation and data for environmental impact.

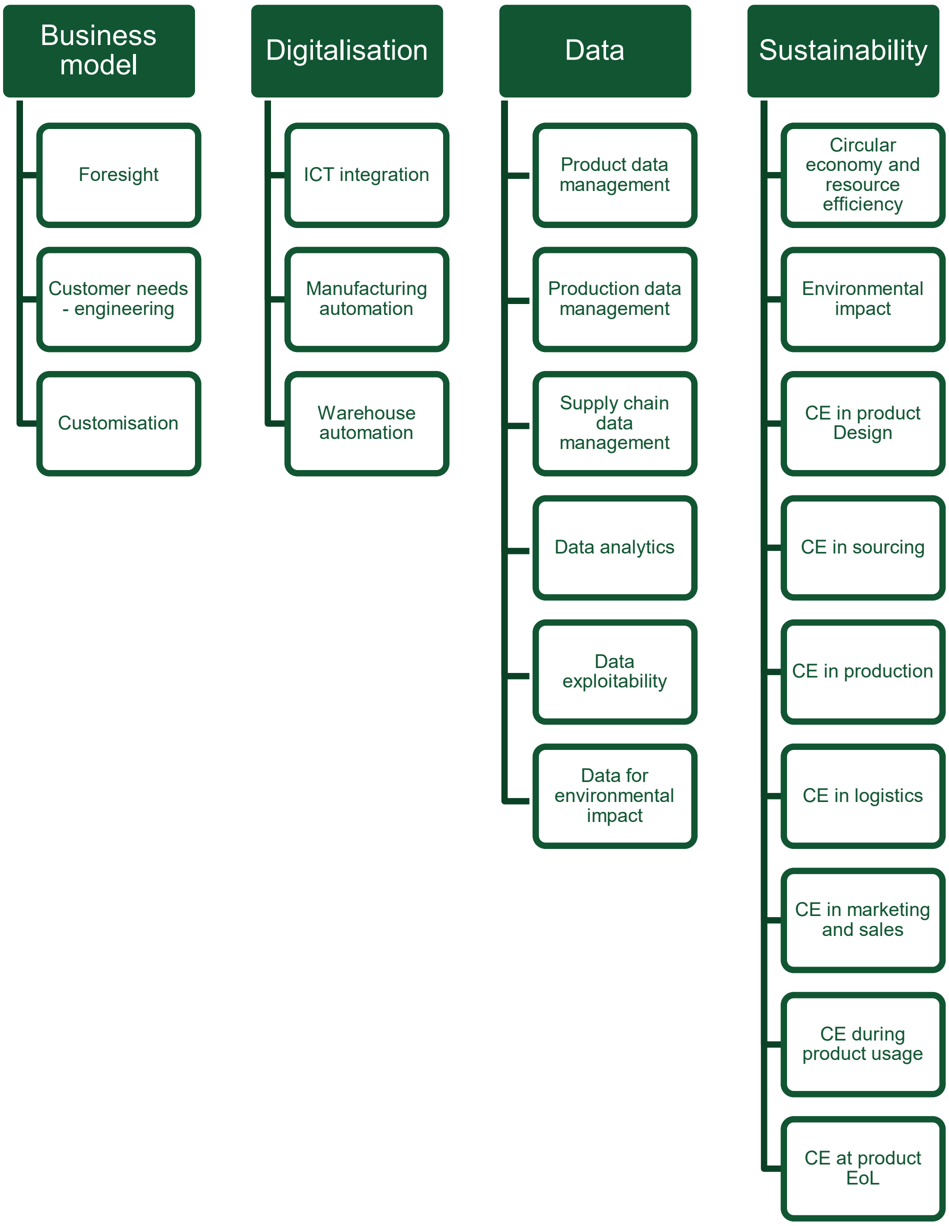

Figure 3. The maturity dimensions and question areas for the clothing manufacturing value chain

[1] https://cris.vtt.fi/en/publications/building-the-maturity-model-for-a-sustainable-collaborative-manuf
[2] https://cris.vtt.fi/en/publications/towards-sustainable-manufacturing-through-collaborative-circular-

Figure 3 displays the maturity dimensions and question areas implemented in the questionnaire dedicated to the clothing manufacturing value chain. Currently, both background tools are available at VTT's twin transition landing page, https://twintransition.fi/ .

In addition to the maturity-level questions, with five optional prewritten responses to choose from, the questionnaire included the technology and digital solution matrixes (see Figure 10 and Figure 11 in Appendices) and a few open ended questions. The questionnaire was implemented in Finnish; thus, the questions are presented in a separate document (in Finnish).

The questionnaire was implemented by Questback[3] and launched in August. The textile questionnaire gathered 18 (N=18) responses from the clothing manufacturing value chain. The main product of the respondents was either clothes and accessories or protective and workwear. The respondents were mainly senior level managers (N=15). Most of the companies were small or medium sized; eight companies had fewer than 10 persons (Figure 4). Figure 5 presents the annual turnover of the companies.

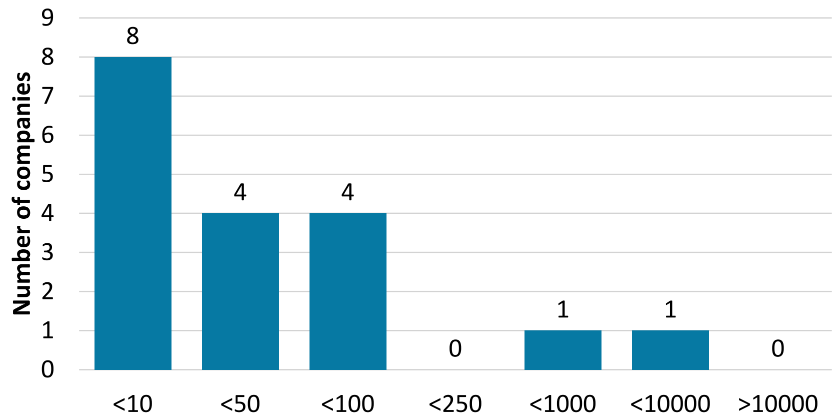

Figure 4. Number of personnel

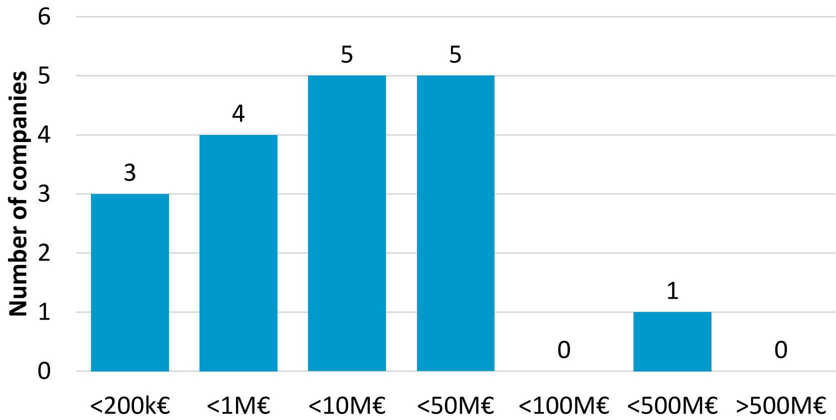

Figure 5. Turnover of companies

Unfortunately, the number of responses remained low in both logistics (N=2) and the chemical industry (N=4), and the results of those questionnaires cannot be reported here, because the anonymity of companies cannot be ensured.

[3] https://www.questback.com/

Interviews

Semi-structured interviews with 10 clothing manufacturing value chain companies took place in October–December 2023. Table 2 characterises the companies interviewed.

Table 2. Interviewed clothing manufacturing companies

Company ID	Interview date	Main product	Persons	Annual turnover
A	17th Oct	Other, spinning machines	<10000	>500M€
B	23rd Oct	Clothes and accessories	<50	<50M€
C	23rd Oct	Protective and work clothes	<250	<50M€
D	23rd Oct	Sports and outdoor products	<100	<50M€
E	16th Nov	Materials, bio-based fibres	<100	<1M€
F	17th Nov	Protective and work clothes as a service	<50	<50M€
G	28th Nov	Clothes and accessories	<50	<200k€
H	28th Nov	Protective and work clothes	<50	<10M€
I	8th Dec	Other, B2B SaaS: digital showroom	<50	<10M€
J	15th Dec	Materials, bio-based fibres	<10000	>500M€

The interviews were organised remotely and recorded via MS Teams. The opinions were also documented online via the interview form implemented by Questback. In particular, the technology matrix and the functionality matrix from the textile questionnaire were reused in the interviews (Figure 10 and Figure 11 in Appendices).

Workshops

Table 3 lists the workshops organised during the research. The first four workshops modified the questionnaires for each industry. The fifth and sixth workshops discovered digitalisation ideas with company representatives.

Table 3. Workshops

Workshop topic	Attendees	Date
Reviewing the questions of the clothing manufacturing industry questionnaire	Project steering group and researchers from VTT	22nd June
Second review of the clothing manufacturing industry questionnaire	Project steering group and researchers from VTT	14th August
Preparing the questions for logistics questionnaire	Representatives of the Service Sector Employers and the Confederation of Finnish Industries and researchers from VTT	12th October
Preparing the questions for the chemical industry	Representatives from the Chemical Industry Federation of Finland and researchers from VTT	13th October
Digitalisation ideas supporting the green transition of logistics	Two company representatives, four representatives of alliances and four researchers	15th January 2024
Digitalisation ideas supporting the green transition of the chemical industry	Four company representatives, three representatives of alliances and five researchers	7th February 2024

3. Results

The results were obtained using four methods (questionnaires, interviews, literature review and workshops). The results are organised according to these methods, starting with the questionnaires.

Questionnaires

The questionnaire for clothing manufacturing value chain received 18 responses. Next, the results of the questionnaire conducted within the textile industry are discovered. Figure 6 displays the averages of each maturity question.

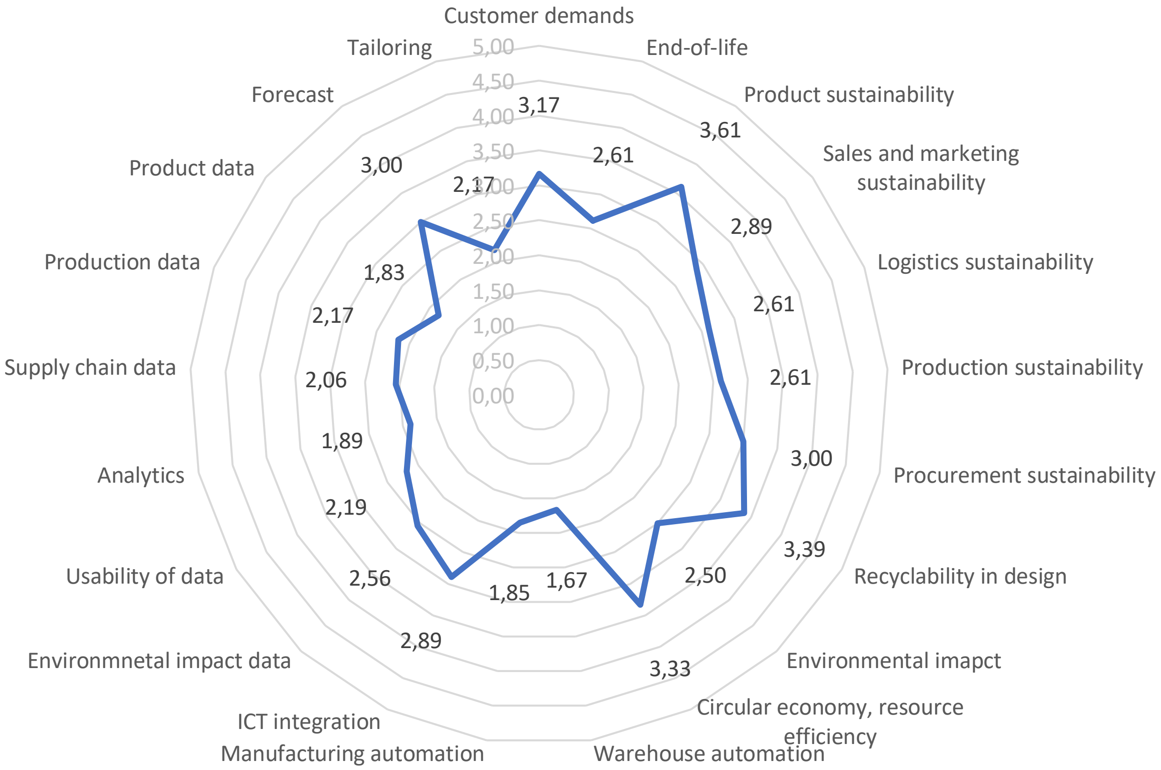

Figure 6. The averages of each maturity question (N=18) in the textile questionnaire

The results show that the **sustainability of products and extending the life cycle of textiles have been goals** for a while. Circularity aspects such as resource efficiency (3,33) and recyclability in design (3,39) are at the higher level. Product sustainability (3,61) and circularity aspects are seen to be at a higher level than the sustainability aspect of procurement (3,00), production (2,61), logistics (2,61), and sales and marketing (2,89).

The collection of data about the product (1,83), supply chain (2,06) and production (2,17) are at different levels. For example, there are **higher scores for production and supply chain information but not for the product itself**. The level of analytics (1,89) is also low compared with the higher score from the usability of data (2,19) and the understanding of how much data and information is available about the supply chain, production and environmental impact (2,50).

Further, there is a higher score for customer demands (3,17), meaning that customers' feedback is mostly considered in product and service design. However, there is also room for improvement in manufacturing and warehouse automation, but the overall ICT integration is seen to be at a good level based on the higher score.

Figure 7 displays the results of the technology matrix. The colour bars indicate how many companies considered the technology (rows) to be actively used and applied, partially used, usable in the future, studied and piloted, not in use, unknown technology or not needed (for this digital technology).

Basic programmes are well used, as could have been expected based on the high score of overall ICT integration (maturity question). Basic programs that include various general - such as Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM) - and industry-specific (such as patternmaking) tools/information systems are actively or partially used. Integrated digital product design can be digital materials, 3D designing and digital patternmaking via different programs.

The most unknown digital technology was the utilisation of digital twins. Digital twins can be physical devices modelled on a computer, e.g. for simulations and remote control. In addition, the digital identification of products is already in use in eight companies. Digital identification of products includes identification methods such as RFID, QR codes and GS1.

Another actively used digitalisation aspect is wireless data transfers, which were already actively or partially used in 16 companies. Wireless data transfer is the digitalisation of offices and working spaces, including getting rid of cables and providing access with portable devices to systems and networks from anywhere. Other forms of wireless data transfer include WLAN and 5G. The green share of wireless communication does not correlate with IoT.

Technologies that particularly affect shopping experiences are the utilisation of chatbots and augmented reality or virtual reality (AR/VR). Utilising chatbots, e.g. on the company's website, is a virtual version of customer service in the shops, and they imitate human dialogue. It was not actively used, but four companies stated that it would be applied in the future. In this context, AR/VR refers to avatars or the virtual fitting of clothing. It was actively used in one company and partially used in two.

The analysis and utilisation of data are still evolving, although the digital identification of products is barely half used. Data analytics, IoT, machine vision and software robots (robotic process automation, RPA) were identified as topics that should be studied or piloted. IoT sensors enable measuring processes and locating materials and goods. In addition, machine vision can be used to identify materials and product quality characteristics from an image or video. Robotic process automation is a computer programme that handles routine data transfers from one system or table to another.

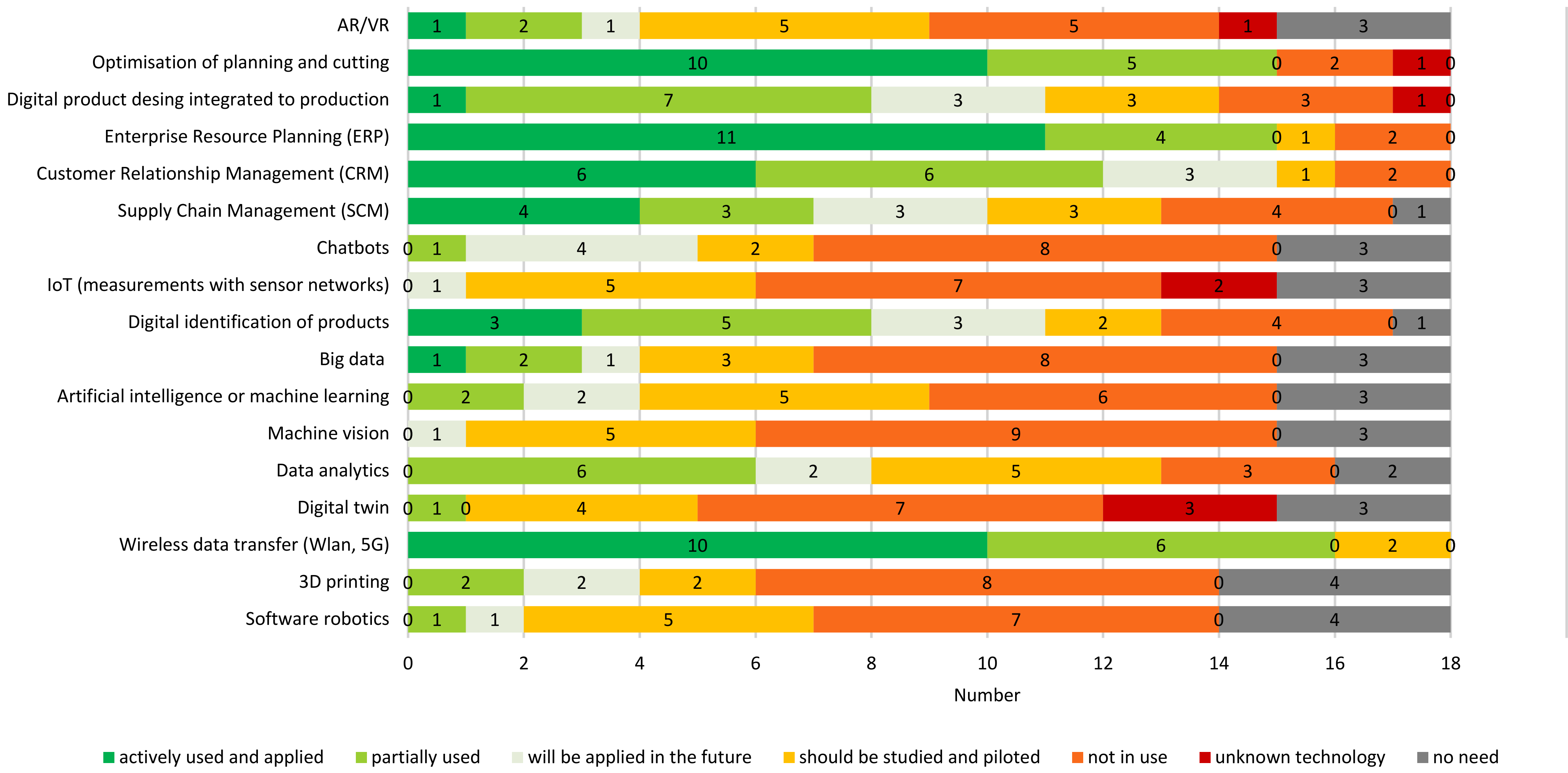

Figure 7. The results of the technology matrix in the textile questionnaire (N=18)

Interviews

The summary of interviews can be expressed within two main topics: data and digital product passport (DPP) and future investments. First, the textile industry is transforming **towards a data ecosystem**. Understanding and forming it requires support and time. DPP is perceived as a powerful means of increasing responsibility, transparency and traceability and is recognised as a future activity. Each actor in the value chain is responsible for its own information. SMEs are worried about the costs related to the deployment of DPP. There is a requirement for a common technological solution at the EU level. The practical experiences and piloting related to DPP should be openly shared within the textile industry. Analytics and artificial intelligence functionalities should be used to support data utilisation for decision-making. Standardisation for data-based functions is considered essential regarding, for example, sustainability calculations and DPP implementations.

In 2022, the European Union (EU) introduced the concept of a DPP, which should store and share all relevant information throughout the entire product lifecycle. The objectives of the EU DPP are to support sustainable production, enable the transition to a CE, provide new business opportunities to economic actors, support consumers in making sustainable choices and allow authorities to verify compliance with legal obligations [4]. The CIPRASS project paves the way for textile, battery and electronics DPPs [5].

All data management-related and other measures regarding future legislation will cost a lot. There are also **uncertainties about the investments that regulation and legislation will require**. It is easier to make investments if the future scenario is fixed at 15 years. Investment subsidies should be fixed at the EU or state level. It would secure investment subsidies at the more local level, for example, compared with the case where green transition subsidies in the USA have overthrown investments in Finland related to the battery industry. SMEs have very limited resources and the burden of DPP can be fateful for them.

In addition to these main topics, the interviews indicate that the transition towards CE is in progress. The textile industry is moving towards a closed material loop. The closed material loop is improved by developing the middle-of-life (MoL) and end-of-life (EoL) phases. Progress is also required within logistics. Transportation optimisation and warehousing will move towards demand-based production. Another goal is to improve the transparency of logistics.

Case examples of digital solutions boosting green transition

The case examples where digital solutions boost green transition are split into two tables. Table 4 lists the digital solutions in the design and manufacturing phases, beginning-of-life (BoL). Table 5 lists a few digital solutions for sales being part of the MoL phase.

[4] https://cris.vtt.fi/en/publications/digital-product-passport-promotes-sustainable-manufacturing-white
[5] https://cirpassproject.eu/wp-content/uploads/2024/03/CIRPASS_Cross-sector_and_sector-specific_DPP_roadmaps_1.1.pdf

Table 4. Digital solutions in the design and manufacturing phase

Life cycle phase	Digital solution	User company	Provider company	Contribution to sustainability
Design	The digital printing process allows such precision and accuracy that a fabric can be crafted with an exact logo, design, pattern or colour variation.		6	Reduces water and energy. Less colours needed and more white fabric to be reused
	Continuous motif and pattern design by AI	7, 8		AI supports human designer and thus releases time for creativity and increases human occupational wellbeing and efficiency. The AI should be exploited to create positive sustainability impacts for all pillars: economic, ecological and social.
	3D design, patternmaking and virtual prototyping	9	10	Enables products to be designed using 3D software, which helps us to significantly reduce the amount of textile waste, emissions from logistics and the use of natural material. Less time and resources needed.
Manufacturing	Sensing elements, e.g. quality control of spinning machines		11	Reduces energy consumption of the machines, increasing efficiency as well as quality of the output (e.g. yarn).
	AR/VR, remote maintenance of spinning machines		12	Less down time, fast expert availability for maintenance, enhanced safety and quality of operations.
	Autonomic cutting of fabric		13, 14	Optimised cutting minimises material waste and cutting errors and increases efficiency in production.
	Automated sewing of garments by sewing bots	15	16	Enables on-demand manufacturing and reduces human labour, trade-off between ethical issues.
	Factory digitalisation	17	18	Reduces energy consumption, reduces GHG emissions and increases quality, optimisation of material and resource usage, transparency and traceability of process.

[6] https://www.printscorpio.fi/en/
https://printscorpio01.vilkas.fi/img/cms/VTT-CR-04462-14.pdf
[7] myth-ai.com
[8] https://ellenmacarthurfoundation.org/topics/fashion/examples
[9] https://halti.com/pages/our-responsibilities
[10] https://browzwear.com/success-stories/halti
[11] https://saurer.com/en/products/machines/spinning/air-spinning/autoairo
[12] https://www.textiletechnology.net/fibers/news/saurer--india-itme-spinning-solutions-from-bale-to-yarn-33068
[13] https://www.lectra.com/en/products/vector-furniture
[14] https://www.gerbertechnology.com/technical-textiles/cutting/gerbercutter-dcs-1500/
[15] https://www.innovationintextiles.com/automated-sewbot-to-make-800000-adidas-tshirts-daily/
[16] https://softwearautomation.com/sewbots/
[17] https://apparelresources.com/technology-news/manufacturing-tech/look-inside-hugo-boss-smart-factory/
[18] https://www.worldfashionexchange.com/

The focus of this research was set to the BoL phase of the textile, literally the clothing manufacturing value chain. Still, Table 5 highlights some solutions in the sales and resales phase.

Table 5. Digital solutions in the sales phase

Life cycle phase	Digital solution	User company	Provider company	Contribution to sustainability
Sales	B2B platforms to matchmake brands, factories and suppliers		19, 20, 21	In best cases, could decrease GHG emission and increase sustainability awareness, i.e. provide matchmaking based on sustainability values.
	Blockchain solutions for supply chain transparency		22, 23, 24	Verify, trace and share the supply chain actions, including used materials, chemicals and manufacturing information. Ensure compliance with sustainability standards, allow responsible sourcing practices, and increase consumer trust and consumer sustainability awareness
	Digital platforms for customisation and make to order	25, 26	27	Minimises the risk of errors and manages the information of unique customised products. When the customer can customise the product to suit their needs, less product returns and higher customer satisfaction are expected.
	Sustainable marketplace (B2C)	28, 29		Creates marketplaces that select brands based on how well they meet the sustainability criteria defined by the marketplace operator. Matchmakes brands and sustainability-aware consumers.
	Digital/virtual fitting (3D)	30, 31		Finds clothes that fit the user's measurements and thus reduces unnecessary product returns.

Logistics workshop

The project organised a workshop to identify which digital solutions facilitate the green transition in the field of logistics. The workshop focused on freight transport. The workshop started with a task identifying where digitalisation could contribute to the green transition in the logistics sector.

[19] https://sqetch.co/
[20] https://www.bizvibe.com/
[21] https://www.findsourcing.com/
[22] https://www.fibretrace.io/
[23] https://everledger.io/
[24] https://auraconsortium.com/
[25] https://www.unmade.com/case-studies/castelli-custom
[26] https://www.unmade.com/case-studies/sportful-custom
[27] https://www.unmade.com/platform
[28] https://fi.ivalo.com/
[29] https://www.eco-stylist.com
[30] https://imagewear.fi/pages/esovitus
[31] https://www.sizey.ai/

A preliminary list was used to facilitate the discussion. This list was compiled based on existing reports[32, 33, 34], supplemented based on the workshop discussion and further prioritised by highlighting the most important digitalisation targets.

Based on prioritisation, the most important target is for digital solutions to help in emission calculation and thereby facilitate sustainable logistics choices. The workshop also highlighted Scope 3 calculation and reporting (Figure 14. in Appendices on page 27).

Big companies shall report greenhouse gas emissions that are **the result of activities from assets not owned or controlled by the reporting organisation but that the organisation indirectly affects its value chain** (Scope 3). These emissions are divided into 15 categories, each with its own calculation methods, data requirements and data collection guidance[35]. **Upstream activity emissions** can include purchased goods and services, distribution, waste generation in operations and employee commuting. **Downstream activity emissions** can include distribution, processing of sold products, use of sold products, EoL treatment, franchises and investments. The data collected can be primary (on-site collected data), secondary (based on industry or product-specific averages) or a mix of both. Often, Scope 3 emissions, or even one particular category of Scope 3, make up a large proportion of a company's total emissions; hence, calculating Scope 3 emissions is an important step towards a company's carbon neutrality or decarbonisation strategies.

Up and downstream emission reporting is not possible if there are no means to reliably measure, calculate, combine and report these emissions. In this context, logistics companies play a very important role and must be able to reliably report emissions to cargo owners who report to the authors. However, workshop participants also stated that logistics chains are complex and multimodal (e.g. land, sea, air and hub operations); therefore, collecting emissions data is cumbersome. Easy-to-use, reliable and transparent platforms can help in gathering this data.

The second and third prioritised targets relate to the optimisation and consolidation of freight and routes. These were also specified as "low-hanging fruits" for companies since their implementation in the initial phase does not necessarily mean investments in digital tools. These activities can already be initially practised when the company's operating processes and operating culture are improved. Therefore, these could lead to quick savings (both money and environment) but on a larger scale need digital solutions. This has also been highlighted by the International Transport Forum (ITF)[36]. They argue that using digital technology to improve truck utilisation in the road transport sector through higher asset sharing has one of the most significant individual impacts on CO2 emissions. Another is smart steaming (optimising port call operations in the maritime sector).

It was also discussed that systems that assist the driver in economical driving are another "low-hanging fruit" since these kinds of systems are already common in modern vehicles and thus can quickly provide emission reductions and cost-savings. After the workshop, VTT classified how the ideas related to the three different pillars of sustainability: economic, ecological and social (Table 6).

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[32] https://www.aut.fi/files/2196/Liikenteen_tiekartta_Tiivistelmaraportti_2022.pdf
[33] https://www.palta.fi/wp-content/uploads/2020/12/Tie-vahahiiliseen-liikenteeseen_Liikenteen-ja-logistiikan-tiekartta_Loppuraportti_062020.pdf
[34] https://skal.fi/wp-content/uploads/2022/12/SKAL_tavoiteohjelma_2023-2027.pdf
[35] https://ghgprotocol.org/corporate-value-chain-scope-3-standard
[36] https://www.itf-oecd.org/digitally-driven-operational-improvements-freight-emissions-reduction

Table 6. How digitalisation ideas (of logistics) contribute to sustainability pillars

Digitalisation ideas	Economic	Ecological	Social
Digital solutions that help in emission calculation		X	
Freight consolidation	X	X	
Route optimisation	X	X	
Digital order and delivery systems	X		
Load factor improvement	X	X	
Supply chain data management, utilisation and sharing	X		
Planning of reverse logistics	X	X	
Use of electronic freight transport information	X		X
Systems that assist the driver in economical driving	X	X	X
Virtual arrival, estimated time of arrival in shipping	X	X	
Traceability, positioning and identification	X	X	X
Proactive preparation of the fleet (e.g. optimal preheating)	X	X	
Preventive maintenance (fleet)	X	X	
Electric battery charging control	X	X	
Networking of vehicles enabling platooning	X	X	

It was also mentioned in the workshop that the EU is working with the methodology for the measurement of greenhouse gas emissions from freight and passenger transport. The European Commission proposes uniform procedures to define the future greenhouse gas emissions of passenger and freight transport and related hubs such as ports and terminals (CountEmissionsEU [37]). The definitions consider international standards and data collection methods already in use by companies. The methodology used builds on the international standard ISO 14038:2023 [38]. Uniform procedures increase the usability of data and make the emission effects of different services comparable. This promotes the possibilities for end customers, both industry and consumers, to make informed choices about transport and delivery options. The Global Logistics Emissions Council (GLEC) has developed the GLEC Framework [39] to support the implementation of ISO 14083. This harmonises the calculation and reporting of logistics GHG emissions across multimodal supply chains and can be implemented by shippers, carriers and logistics service providers. This development and its effects on the logistics sector should be monitored in Finland.

Chemical industry workshop

The project organised a workshop to identify which digitalisation solutions facilitate a green transition in the chemical industry. The workshop started with a task identifying solutions where

[37] https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/757562/EPRS_BRI(2023)757562_EN.pdf
[38] https://www.iso.org/standard/78864.html
[39] https://www.smartfreightcentre.org/en/our-programs/global-logistics-emissions-council/calculate-report-glec-framework/

digitalisation could contribute to the green transition in the chemical industry. A preliminary list was used to facilitate the discussion. This list was compiled based on existing reports [40, 41, 42], supplemented based on the workshop discussion and further prioritised by highlighting the most important digitalisation targets.

The four digitalisation targets prioritised as the most important ones (bolded in Table 7) can be divided into two themes. The first theme is related to process and production efficiency, optimisation and utilisation of digital twins, which promotes resource and energy efficiency during production and asset management. The second theme is related to the traceability of materials and products as well as supporting sustainability assessment and reporting with digital solutions. This result is in line with the Cefic (2023) report[40]. In their analysis, they were seen as the most important sustainability priorities for implementing digital technologies as process design and production for climate and circular objectives, sustainability assessment and enabling materials and chemical circularity through tracking and tracing.

In the workshop, it was pointed out that logistics emissions – which belong to the Scope 3 [43] category – are also an important part of life-cycle emissions in the chemical industry. Scope 3 reporting capability should already be considered in the tendering phase of transport companies. The challenge here is that logistical chains can be complex, including different modes of transport (rail, truck and sea) and different hub functions (port/land terminals). The geopolitical situation may also require that the use of traditional transport routes is impossible and alternative transport routes must be sought. Therefore, the calculation of emissions from a turbulent operational environment is complicated. However, as stated in the previous section, regulations, standards and calculation guidelines such as CountEmissionsEU[37], ISO 14038:2023[38] and GLEC[39] are anticipated to help with this.

It was further pointed out that significant value comes from optimising the entire value chain process using digital solutions. Here, companies should first start by improving the efficiency of individual phases and their own processes and then move on to optimising the entire value chain. On the other hand, the challenge here is the existence of many heterogeneous legacy IT systems and their integration. Furthermore, collecting data requires planning and resources and is also an investment. Therefore, it is essential to know what data should be collected and for what reason – for instance, in the workshop, it was stated that data could be utilised for artificial intelligence and simulations in product and process development to support sustainable decisions. After the workshop, VTT classified how the ideas relate to the three viewpoints of sustainability (Table 7). The bold digitalisation ideas on the top of the table were prioritised in the workshop.

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[40] https://cefic.org/app/uploads/2023/04/ADL_CEFIC_Digital_technologies_for_sustainability_2023.pdf
[41] https://kemianteollisuus.studio.crasman.fi/file/dl/i/_eW2nw/ZzUnkeuHZwGyL1evAfWWrA/Teknologiaselvitysvaihe1tiivistelm.pdf
[42] Ikonen, Kallela, Pietilä, Suonsivu, 2021, Strategic capabilities for carbon neutrality in the chemical industry, Kemianteollisuus ry, Aalto yliopisto, March 2021
[43] https://ghgprotocol.org/corporate-value-chain-scope-3-standard

Table 7. How digitalisation ideas contribute to sustainability viewpoints

Digitalisation ide	Economic	Ecological	Social
Process design and optimisation in production	X	X	
Digital solutions for traceability of relevant material and products, including DPP		X	X
Making production and product development more effective with digital twin technology (e.g. optimisation and predictive maintenance)	X	X	
Digital solutions to support sustainable development assessment and reporting in the value chain (e.g. carbon footprint calculation)		X	X
Utilisation of (real-time) data from physical devices/machines (e.g. identify where energy or resource efficiency could be achieved)	X	X	
Data modelling and simulation techniques	X		
Digital tools for production employees	X		X
Data sharing tools in the value chain / ecosystem of the chemical industry	X		X
Smart and sustainable supply chains utilising artificial intelligence: solutions supporting the supply chain (network) based on shared data. Especially supporting decision-making, not automatic decision-making	X	X	X
Sustainability assessment tools for the early stage of R&D activities, such as toxicity assessment		X	X
Modelling and simulation during experimental work (laboratories)	X		X
IoT solutions and transparency for monitoring transport conditions	X	X	
AI-driven predictive toxicology		X	X
Autonomous robotics in experimental work in laboratories	X		X
Digital simulation / modelling: digital modelling of investments, process changes, etc. before implementation (digital twin thinking)	X		
Transportation monitoring and reporting	X	X	X
Real-time monitoring and reporting of energy consumption of parts of the supply chain (e.g. to support Scope 3 reporting): to support reporting, especially when logistics is often outsourced		X	
Logistics chains as a whole and their optimisation (Scopes 1–3)	X	X	

4. Conclusions

In this study, the current state of practices and future perspectives of companies working in textile, chemistry and logistics domains were discovered. The main emphasis in the study was on digital solutions to the textile industry's green and digital transition, especially in the clothing manufacturing value chain. According to our study, the current digital solutions in the Finnish textile industry focus on the design phase of textile products (design, 3D-modelling and pattern making). The digitalisation level of production is low although automatic cutters are in use. In general, the production of clothes and textiles in Finland is small-scale and this might influence the results showing a lack of digitalisation in production. There are already commercial IoT solutions for different phases of the textile production, but investments are high for small actors even if they could bring considerable process savings.

As digitalisation progresses, the textile industry transfers from solely handling the physical product towards managing of data. Understanding, managing and utilising vast amounts of data is important and challenging. The needed change can be hard for the textile industry and requires cooperation with many (new) types of actors, as well as a change in mindset.

Digitalisation also requires investments, but the company sector is hesitating because different EU-level regulations and reporting requests (DPP, Scope 3, ESPR, EPR and other reporting requirements) are pending. As many upcoming regulations require new types of reporting and data management, the companies wish for common lightweight and inexpensive solutions to support the upcoming changes. For example, DPP is seen as too expensive an investment in the SME sector that could drive companies into severe financial situations.

New disruptive manufacturing technologies, such as 3D printing and casting of fibres, that directly form the end product will change the traditional way of producing textiles by leaving phases such as spinning, weaving and sewing obsolete. These technologies can also enable personated, on-demand and even local production in which digital tools are essential. A pioneering example is Simplyfiber[44], which injects bio-based fibres for moulds to create shoes. When transforming towards closed material loops the overall sustainability (economic, ecological and social) impact e.g. the GHG emissions from transportation must be considered. Thus, the opportunities of local (closed loops) production have to be explored.

Sustainability is central to the textile industry. Current activities focus on circular economy[8], especially textile recycling. In Finland, ecological manufacturing methods are neglected as only a few companies spin and dye yarn, weave fabric and sew clothes. It is widely acknowledged that digitalisation has great potential in providing sensor-based identification material and supporting the automation of the sorting process. In future, the DPP can play a key role in providing accurate digital information, e.g. enabling more efficient material flows from resales to recycling.

Many of the business models in the circular economy are based on digitalisation and data, such as marketplaces and the sharing economy. They strongly rely on digital platforms and would benefit from traceable and transparent data on textile products.

Figure 8 submits the road map towards the green and digital transformation. Although the focus is on the textile industry, the focus areas can be generalised to other industrial domains. Further, the findings from the industry surveys and interview results following recommendations and actions for achieving the green and digital transformation for innovation support, employer's associations and companies are highlighted in Figure 9.

[44] https://www.simplifyber.com/

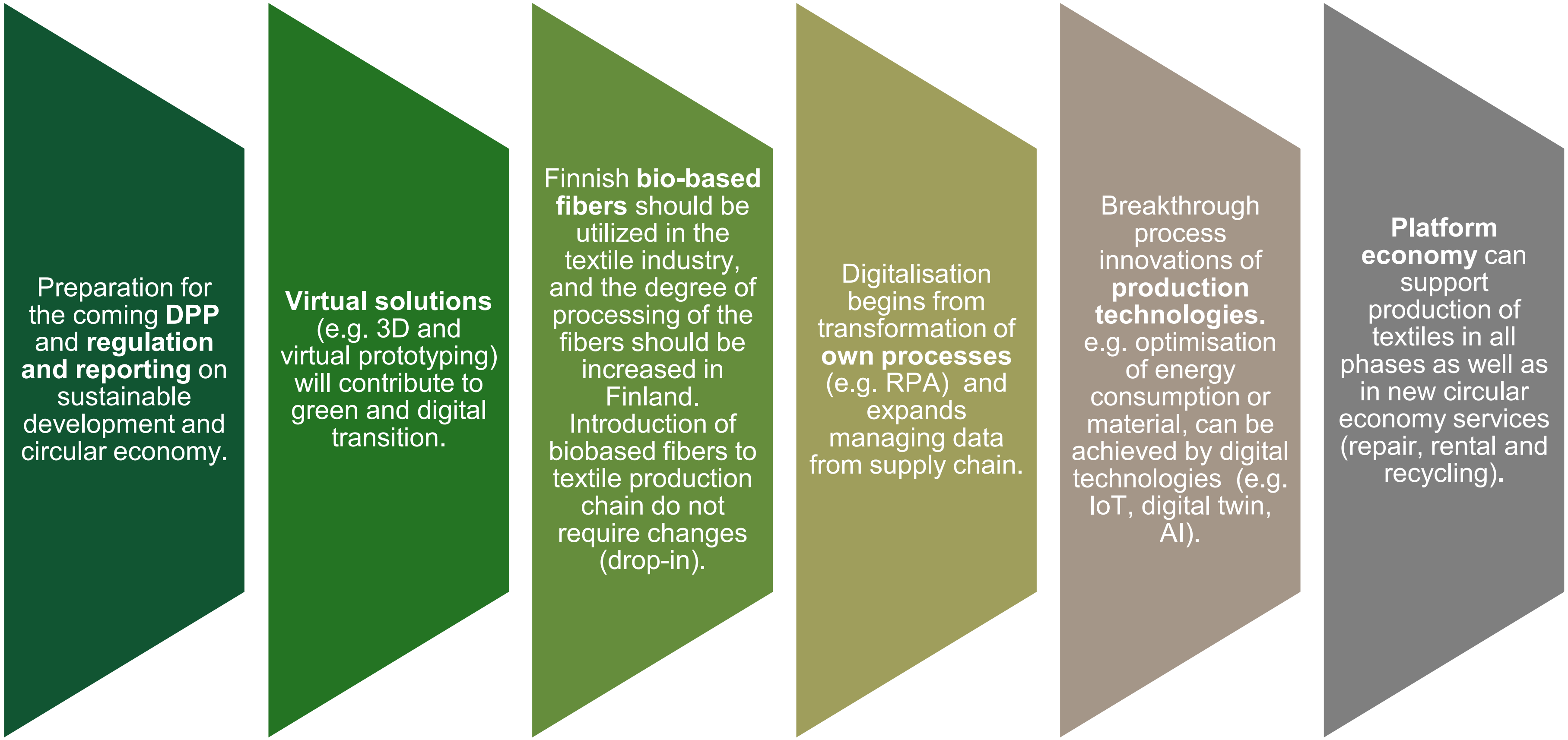

Figure 8. The road map of textile industry for green and digital transformation

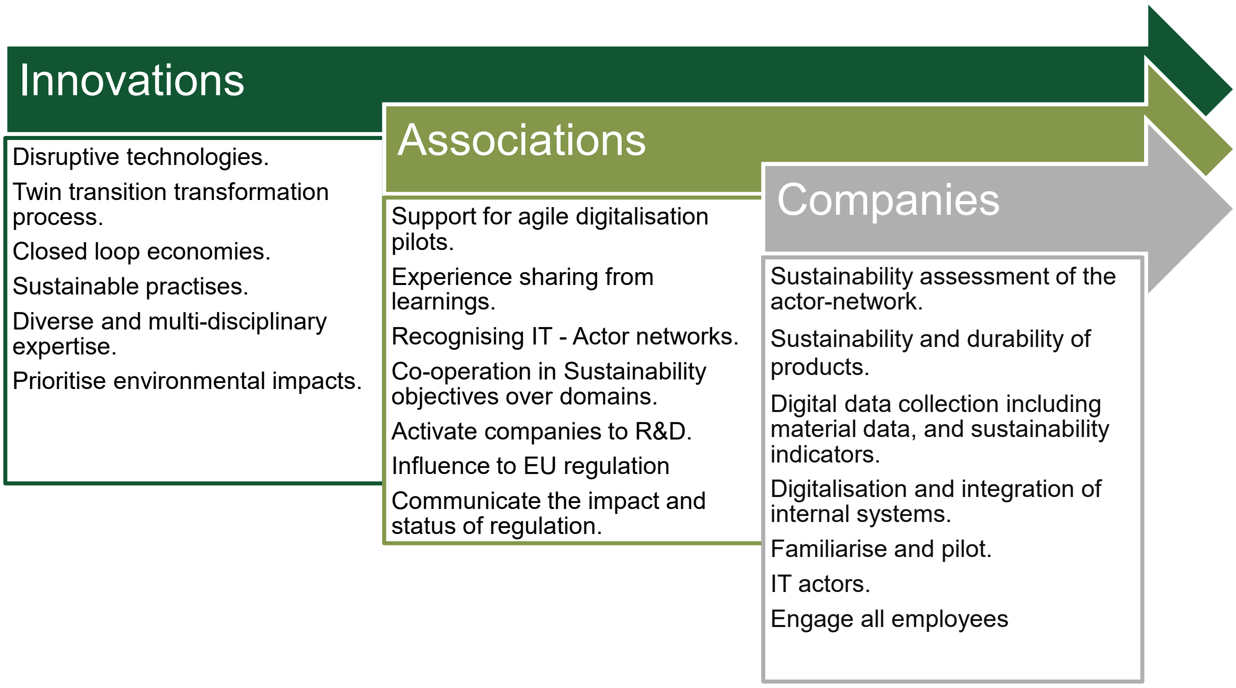

Figure 9. Recommendations for innovation support, associations and companies

Moving towards a green and digital world needs investments and support for new innovations. Innovation support is provided by multiple sources, including government agencies, non-profit organisations, educational institutions and private companies. The textile industry is globally highly competitive and profit margins have traditionally been very small compared to many other industrial sectors. Therefore, companies' ability to invest significantly in research, development, and innovation in the short term is limited. VTT has earlier emphasised the importance of development of circular economy and digitalisation together[45]. Additionally, consumer purchasing behavior does not fully support market-driven renewal in companies within the sector.

EU has recently announced new partnership programs that will be at the heart of the Horizon Europe Strategic Plan 2025-2027. One of the partnerships, “Textiles of the Future”, is targeted to boost sustainability, circularity and digitalisation of textile industry[46]. Multiple funding instruments exist at the national and EU levels that can provide funding for different types of R&D activities that should be deployed. The innovation support for green and digital technologies should take into account the following:

- Development and creation of new ecological bio-based materials that can disrupt the way products are produced. These could provide totally new opportunities for apparel production, but they require long-term support and commitment from R&D activities.
- Industries are moving towards closed-loop principles for sustainable and resilient business models that benefit both the environment and society. These actions need to be supported.
- Not only do sustainable technologies need support, but different sustainable and circular practices also need incentives throughout society (e.g. reduced taxation of repairing services). Although some pilots have already been conducted, incentives related to sustainability,

[45] https://cris.vtt.fi/en/publications/finland-as-a-forerunner-in-sustainable-and-knowledge-based-textil
[46] https://research-and-innovation.ec.europa.eu/system/files/2023-07/ec_rtd_candidate-list-european-partnerships.pdf

especially, should be increased. These types of initiatives should also be studied and experimented with.

- The change process for twin transition is a long-term activity. Innovation support needs to provide tools from piloting to deployment. The transition also requires diverse know-how and training, including new materials, chemistry, digitalisation and business models.
- Domestic innovation support should also take account of impacts in employment, tax accumulation and environmental aspects to contribute to the three sustainability pillars (economic, ecological and social).
- Consumers' consciousness of sustainability issues is rising and driving the consumer behaviour transformation. DPP supporting transparency and traceability together with AI solutions [47]can fasten the change towards a more sustainable textile industry.

Employer's associations can have a large role in compiling digitalisation pilot projects in business collaboration, e.g. around product passports and sustainability regulation requirements. Enabling rapid agile pilots will accumulate know-how. Sharing the experiences from pioneering companies' digitalisation trials will benefit all and the best practices can be adopted. Identifying an IT actor–network (s) to support digitalisation trials will lower the threshold to start collaboration. Emission calculations will become a unifying factor across sectors, as emissions from the supply chain must also be reported in the future (Scope 3). Activating multiple companies in R&D activities will enhance innovation. When R&D activities are carried out in collaboration, the benefits of diverse expertise can be fostered and the pace of innovation accelerated. The role of active lobbying on EU regulations, domestic R&D and investment policies has been clear for the associations. As multiple legislative actions are ongoing in the EU regarding sustainability and new reporting practices, clear information about the progress of regulations and their impacts on businesses is needed.

Companies should initiate the assessment of the sustainability of their actor–network. This work leads to increased transparency and facilitates sustainability management and further reporting. Companies that do not do so already should invest in collecting and managing data from used materials in processes of calculating indicators, e.g. for sustainability reporting. The data required for different processes are often in different internal systems. To improve data (automatic) utilisation, the level of system integration should be increased, e.g. by using RPA. Data management needs are versatile for complex business data and require special attention. Piloting helps to get familiarised with new technologies and provides opportunities to evaluate the usefulness of the new technology.

Several new technologies still have relatively low adoption rates (in the textile industry). Augmented or virtual reality (AR/VR) can be exploited in, for example, digital prototyping and virtual fitting. Internet of Things (IoT), sensor networks and cloud solutions help with process and product quality control and the localisation of products and materials. Artificial intelligence (AI) and data analytics enable toxicity prediction and predictive maintenance of equipment, among others. Machine vision integrated with AI can ensure quality control online. Also, digital twins for process development, remote control or monitoring of production equipment could have remarkable benefits for green and digital transformation.

Identifying IT actors to partner with and support digitalisation (pilots) can fasten the twin transition. Companies should further develop the sustainability of products to support a circular economy (e.g. utilise redesign fashion principles). Advancing green transition cannot be the responsibility

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[47] https://www.europarl.europa.eu/RegData/etudes/STUD/2021/662906/IPOL_STU(2021)662906_EN.pdf

of one person/department but requires the strategic commitment of the company that is implemented throughout the organisation.

In the 2023 Digibarometer[48], in which 22 countries were compared, Finland ranked first. Of the different sectors (companies, citizens and public sector), Finland performed best in the public sector area. Finland's ranking improved, especially in the comparison of companies. In terms of companies, Finland is now in second place, i.e. up four places. The perceptions of company managers have been strengthened in that the ICT technology available in Finland meets the needs of companies and improves their competitiveness. The special theme of the 2023 Digibarometer examines the impact of big data on companies and describes its development from the perspective of the Finnish business sector. Based on a company-level review, the analysis finds that the majority of Finnish companies (especially large companies) utilise data to some extent but that only about one per cent have actual big data business models. The number of companies using big data has also grown quite slowly – especially if you compare the development with the increase in the amount of data.

This result is in line with our findings in the textile sector. Basic programmes (e.g. ERP and CRM) are well used in the textile industry and seem to support the needs of companies, while the analysis and utilisation of data are still evolving. As digitalisation progresses, the textile industry is anticipated to transition from solely handling physical products towards managing data. Understanding, managing and utilising vast amounts of data are challenging and require cooperation with many new types of actors as well as a change in mindset.

This study was unable to find the "golden nugget" from digital solutions that would make the textile industry radically sustainable. A large share of the environmental footprint comes from materials. To decrease the footprint of materials, multidisciplinary competences of materials, chemistry, digitalisation and business are required. Digitalisation is an enabler, but it can have big economic and environmental impacts on process improvement and optimisation (IoT, AI and digital twins). A recent study of the German SME textile and clothing industry also reveals that so far, digitalisation has not been the catalyst for sustainability[49]. Furthermore, the need for compliance with requirements and customers' new perceptions of sustainability promotes the adoption of CE activities. Digital technologies have their own important role in facilitating the sustainability transformation balancing with the three sustainability pillars (economic, ecological and social). Still, the evolution of digital technologies remains an ongoing issue, demanding continuing development, piloting and innovations. Currently, sustainability management over the value chains supporting all aspects of sustainability is capturing more attention. To achieve this, efficient tools for data sharing and AI are needed.

[48] https://www.etla.fi/julkaisut/muut-julkaisut/digibarometri-2023-data-tekoaly-ja-talouskasvu/
[49] Wiegand, T., & Wynn, M. (2023). Sustainability, the circular economy and digitalisation in the German textile and clothing industry. *Sustainability*, *15*(11), 9111.

5. Appendices

9) * Which digital technologies are applied in your company?

	actively used/applied	partially used	will be applied in the future	should be studied and piloted	not in use	unknown technology	no need
Artificial or virtual reality (AR/VR, virtual fitting of clothes, avatar)	○	○	○	○	○	○	○
Optimization of planning and cutting with planning programs (such as Lectra or Gerber)	○	○	○	○	○	○	○
Digital product design has been integrated to production (digital materials, 3D design and planning)	○	○	○	○	○	○	○
Enterprise Resource Planning (ERP) system	○	○	○	○	○	○	○
Supply Chain Management (SCM) system	○	○	○	○	○	○	○
Customer Relationship Management (CRM) system	○	○	○	○	○	○	○
Chatbots (a software application or web interface that aims to mimic human conversation through text or voice interactions)	○	○	○	○	○	○	○
Internet of Things (various types of measurements with IoT sensor networks that provide for example the view of the exact location of materials and goods)	○	○	○	○	○	○	○
Digital identification of products (e.g. RFID, QR code, GS1)	○	○	○	○	○	○	○
Big data (utilization of large data masses)	○	○	○	○	○	○	○
Artificial intelligence, machine learning (learning algorithms)	○	○	○	○	○	○	○
Machine vision (identifying, for example, materials and product quality characteristics from a picture or video)	○	○	○	○	○	○	○
Data analytics (turning raw data into useful information)	○	○	○	○	○	○	○
Digital twin (physical devices or products are modeled on a computer for simulation, optimisation or remote control)	○	○	○	○	○	○	○
Wireless data transfer (get rid of cables, access systems and the network from anywhere with portable devices. Wlan, 5G)	○	○	○	○	○	○	○
3D printing (3D printing or additive manufacturing is the construction of a three-dimensional object from a CAD model or a digital 3D model)	○	○	○	○	○	○	○
Software robotics (Robotic process automation (RPA) is a software technology that makes it easy to build, deploy, and manage software robots that emulate humans actions interacting with digital systems and software)	○	○	○	○	○	○	○

Figure 10. Technology matrix (in textile questionnaire)

11) * For which activities have digital solutions been utilized in your company?

	actively used/applied	partially used	will be applied in the future	should be studied and piloted	not in use	no need	cannot say
Product design	○	○	○	○	○	○	○
Sourcing	○	○	○	○	○	○	○
Production	○	○	○	○	○	○	○
Logistics	○	○	○	○	○	○	○
Sales and marketing	○	○	○	○	○	○	○
Product use and maintenance	○	○	○	○	○	○	○
End of product life cycle	○	○	○	○	○	○	○

Figure 11. Solution matrix for the (textile) questionnaire

Figure 12. CE maturity levels[2]

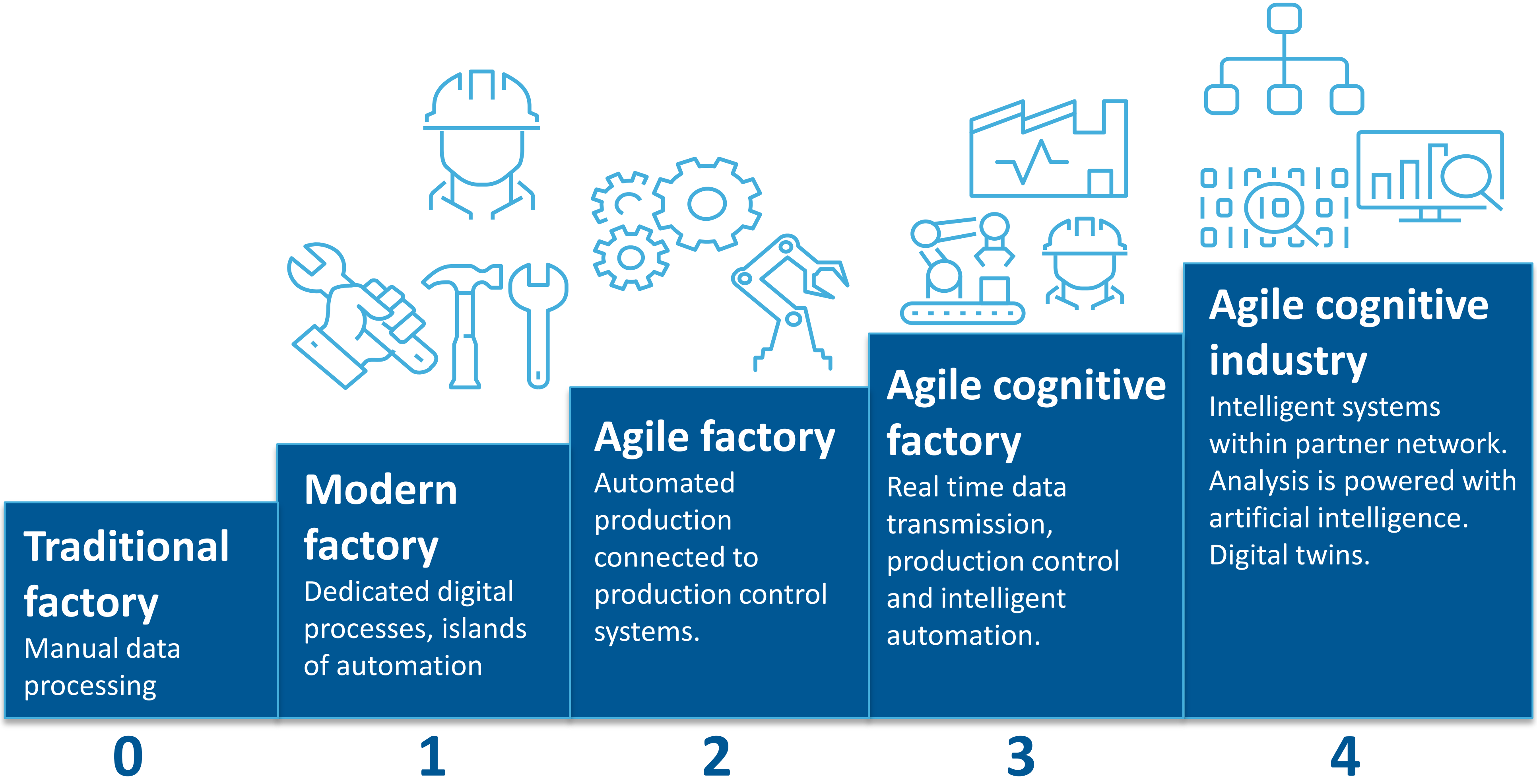

Figure 13. The digitalisation stairs of the manufacturing industry[1]

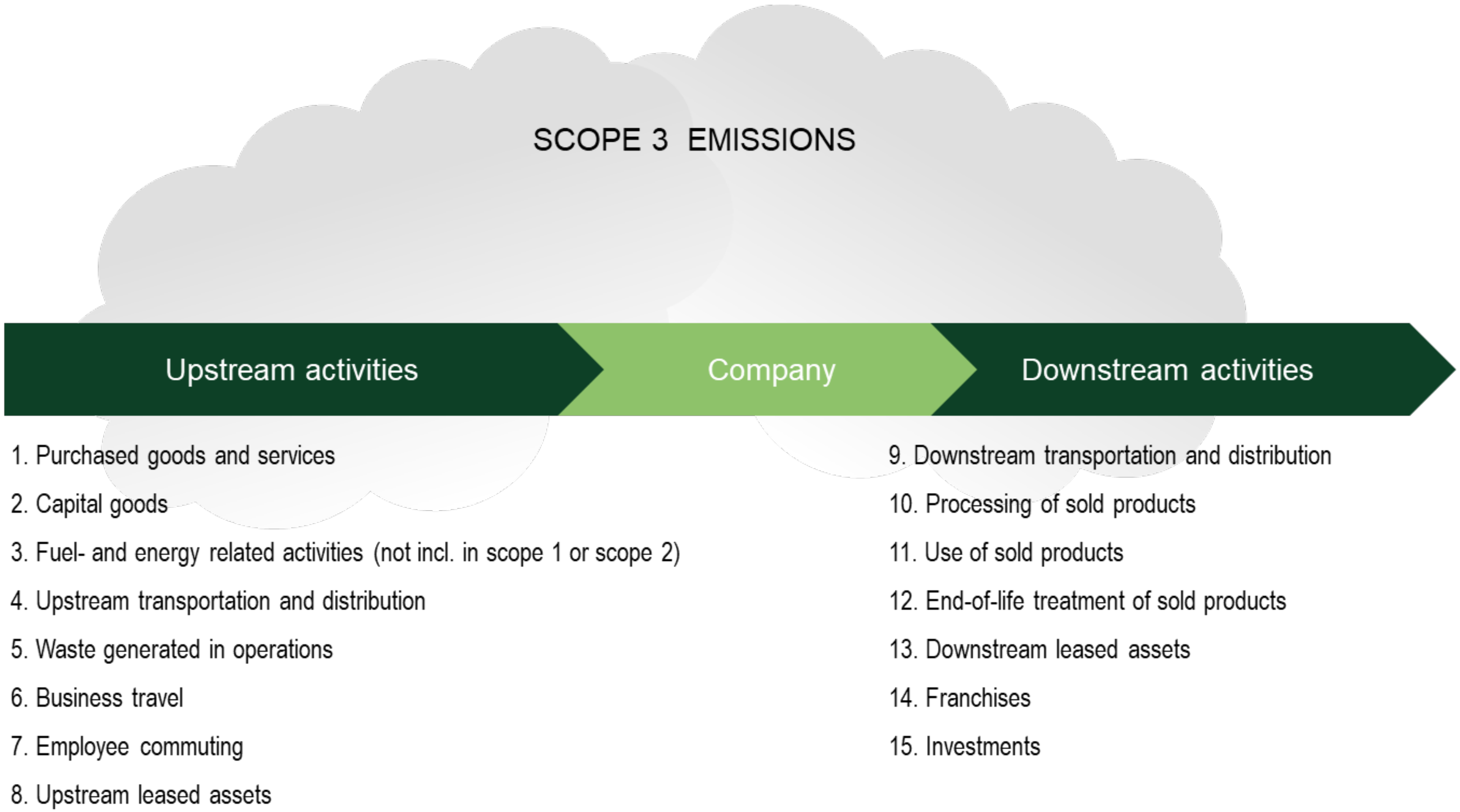

Figure 14. Scope 3 emission categories from upstream and downstream activities.
Adopted from Greenhouse Gas Protocol. "The Greenhouse Gas Protocol: Corporate Standard, Revised Edition." World Business Council for Sustainable Development, World Resources Institute, 2024. https://ghgprotocol.org/corporate-standard, accessed March 12, 2024.

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