DATA-DRIVEN SYSTEMIC TRANSITION IN TEXTILE SECTOR: CONNECTING SUSTAINABILITY ASSESSMENT INSTRUMENTS

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ABSTRACT

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Data-driven systemic transition in textile sector: Connecting sustainability assessment instruments

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Solving current complex sustainability issues in textile sector requires actions along the whole supply chain. Digitalization and data are important assets in enhancing systemic change. Technology enables new solutions for data collection, distribution, and integration.

This thesis studies two sustainability instruments for textiles. Shades of Green (SoG) is a consumer-targeted sustainability assessment instrument, and LCIM is a life cycle inventory management tool. The aim was to find out how data in these instruments contribute to the systemic transition in textile sector, and what challenges and opportunities are related to connecting these instruments.

The results show that SoG and LCIM enable multiple data value-creation methods, such as supporting decision-making and organizing data. Each method can contribute to solving systemic problems. Biggest challenges of connecting SoG and LCIM are related to their different data requirements, measuring systems and data privacy/openness needs. Data verification is challenging for both.

Both instruments are an important addition to Finnish textile sector. They have many potential development paths, both together and separately. EU has big impact as driving, guiding, and enabling force of the instruments' development.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT
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Outi Laakkonen

Datavetoinen systeeminen kestävyysmuutos tekstiilisektorilla: Kestävyysarviointi-instrumenttien yhteen kytkeminen

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Tekstiilisektorin nykyisten monimutkaisten kestävyysongelmien ratkaiseminen vaatii toimenpiteitä koko toimitusketjussa. Digitalisaatio ja data ovat tärkeä apu systeemisen muutoksen toteuttamisessa. Teknologia mahdollistaa uusia ratkaisuja tiedon keräämiseen, jakamiseen ja yhdistämiseen.

Tässä työssä tutkitaan kahta tekstiileille tarkoitettua kestävyysinstrumenttia. Shades of Green (SoG) on kuluttajille suunnattu kestävyysarviointi-instrumentti, ja LCIM (Life Cycle Information Management) on elinkaaritiedon hallinnan työkalu. Työn tarkoitus oli selvittää miten instrumenttien data vaikuttaa tekstiilisektorin systeemiseen muutokseen, ja mitä haasteita ja mahdollisuuksia instrumenttien yhdistämiseen liittyy.

Tulokset näyttävät, että SoG ja LCIM mahdollistavat monia keinoja tuottaa arvoa datasta, kuten päätöksenteon tukeminen ja datan järjestäminen. Jokainen keino voi auttaa systeemisten ongelmien ratkaisussa. Suurimmat haasteet SoG:n ja LCIM:n yhdistämisessä liittyvät erilaisiin datatarpeisiin, arviointitapoihin, ja tiedon yksityisyys-/avoimuustarpeisiin. Tiedon varmennus on haasteellista molemmissa.

Kumpikin instrumentti on tärkeä lisä Suomen tekstiilisektorille. Niillä on monia potentiaalisia kehityspolkuja yhdessä ja erikseen. EU:lla on suuri vaikutus instrumenttien kehitystä ajavana, ohjaavana ja mahdollistavana voimana.

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ABBREVIATIONS

SoG	Shades of Green
LCIM	Life Cycle Inventory Management
SME	Small and medium-sized enterprise
SA	Sustainability assessment
SI	Sustainability indicators
CE	Circular economy
LCA	Life cycle assessment
LCT	Life Cycle Thinking
MCI	Multi-Criteria Indicator
DPP	Digital product passport

Table of contents

APPENDICES

1. INTRODUCTION

Persistent linear production and consumption system has on its part driven humankind to suffer from complex web of grand challenges of sustainability, which threaten the planetary boundaries (George et al., 2016; Steffen et al., 2015). Global textile industry with prevailing fast-fashion paradigm is adding to these challenges by causing significant environmental impacts (European Parliament, 2021; Niinimäki et al., 2020). Also, it is known to be a nest of severe social issues including, for example, insufficient living wage, poor working conditions, and child labour (Ellen MacArthur Foundation 2017, 21).

The urgent need for systemic change is obvious in the light of these known environmental and social issues within the industry and related consumption patterns. Sustainable Development Goals of United Nations (UN, 2022), in addition to many other international and national goals, acknowledge the importance of developing more sustainable production and consumption. To enhance sustainable system transition, these goals have been turned into policies and strategies which put pressure on industrial and other sectors on promoting sustainability in their actions. Also increased sustainability awareness of the consumers is adding pressure on verifying the met requirements and pursued development (Koszewska 2015, 335; Ranasinghe & Jayasooriya, 2021).

Ecolabels are tools for informing consumers of the sustainability of products and supporting their decision-making, and they have been under a growing interest in the past decades (Koszewska 2015, 340; Wojnarowska et al., 2021). However, current ecolabels have some known issues, such as, most of them focus on only a narrow set of sustainability dimensions, the relative importance of the labels is unclear, and third-party verified labels are most likely achievable only for big companies due to the high need of resources, e.g., for acquiring the needed data (Turunen & Halme, 2021). Therefore, development in those regards is needed.

Technology as one of the current megatrends (Sitra, 2021), is playing an important role in transition toward sustainable systems, and data can be seen as an asset which brings value in transition pathways through usage, circulation, and generation (Porto de Albuquerque et al., 2021). For example, digital technologies enable more efficient collecting, integration, and analysis of data (Pagoropoulos et al., 2017), which offer new and improved opportunities for both supporting consumer decision-making and sustainability verification for companies.

Textile sector, for being both economically powerful industry and environmentally significant polluter in global scale, requires attention in sustainability research, and urgent improving actions throughout the supply and value chains. Especially, the opportunities arising from digitalization need to be investigated and utilized in development of both sustainable production and consumption.

1.1. Objective of the study

The objective of this thesis is to study the data aspects of sustainability assessment in textile sector and target is on adding understanding of data utilization towards sustainability transition. More specifically, in the centre of the research there are two sustainability assessment instruments: Shades of Green (SoG), a customer targeted sustainability assessment tool, and LCIM, a life cycle information management tool, both being developed in Finix (Sustainable textile systems: Co-creating resource-wise business for Finland in global textile network) project led by Aalto University. In this study, terms instrument and tool are used as synonyms, meaning a digitally enabled aid for helping sustainability assessment.

SoG and LCIM both aim for filling the need for the easily accessible and good quality data for sustainability assessment, and they especially focus on the needs of SMEs. Instruments are being developed separately, however, it has been identified that they have similar context, and thus the question has arisen if they could be connected and if LCIM could serve SoG as data source. Three research questions are studied:

1) How data in SoG and LCIM contribute to the transition towards sustainability?

2) What are the criteria for data and data sources of consumer targeted sustainability assessment instrument in textile sector?
3) What are the data related challenges and opportunities of connecting SoG and LCIM?

First research question investigates the instruments' data content and utilization in relation to the sustainability transition, and target is also to discuss these in the context of Finnish textile sector and its digitalization, to illustrate the realistic scenery of the instrument development work and its importance for transition. The purpose of the second question is to find the criteria framework to be used in answering the third research question, that is, evaluating the SoG and LCIM connecting in data related aspects. First and second question are answered based on literature. Third question draws from knowledge gained from the first two questions but also from the experiences of SoG and LCIM development.

All topics in this thesis have prevailing focus on data, referring to data utilized in the assessments that is performed with the instruments. Some restrictions are made: This thesis does not include any considerations of technical issues of connecting, such as technology choices or other detailed discussions of practical execution of connecting. It only evaluates the connectivity on other relevant aspects. These restrictions are justified with the specialty of the research topic. Connecting two sustainability assessment instruments is such a new research theme that it deserves full focus, and the topics that do not support that are therefore excluded. Also, the evaluation of technical issues would require first establishing the details of the implementation plan (who, how etc.) based on which the technical system would be built.

For further clarification, this thesis is not intended for finding the solutions for the possible challenges, nor is it aiming for making plans for developing and executing the found opportunities. Intention is only to add understanding of their existence.

1.2. Research structure

This thesis consists of eight chapters of theoretical and empirical study in total. In the theoretical section, first main chapter concentrates on data-driven transition in Finnish textile sector, beginning with describing the systemic challenges of global textile sector and continuing to the topic of data enhancing transition towards sustainability. Next, the current status of digitalization is presented, also including the data needs and availability. Last topic is future EU trends in digitalization towards sustainability.

Second part of the theory concentrates on the sustainability assessment of textiles, starting by presenting the sustainability assessment generally, and then continuing to the methodological aspects of assessment and the consumer targeted assessment. Last topics in this main chapter are data value creation and data quality in sustainability assessment, and sourcing data for assessment.

Methodology chapter introduces the case instruments Shades of Green and LCIM and presents the research methods used in this study. In Results, first, contribution of SoG and LCIM data on transition towards sustainability is presented. Next, the criteria for evaluating the suitability of the data source for consumer targeted assessment data are presented, which are next applied in the case of connecting SoG and LCIM. In Discussion, future speculations of the development possibilities and challenges are discussed further.

2. DATA-DRIVEN TRANSITION IN FINNISH TEXTILE SECTOR

Systemic challenges in global textile sector are complex, and many issues within the industry contain both severe environmental and social impacts. Digitalization is expected to have crucial transformational power with its effective utilization. In this chapter, these topics, and a link between them, is explained. The current status of digitalization and data use in Finnish textile sector, and the future trends on EU level, are also presented to enlighten the broader context of case study instrument development and their relationship to systemic transition.

2.1. Systemic challenges of global textile sector

Global textile industry has developed to its current state during the past 200 years, counting from the industrial revolution in Europe in the eighteenth century. Combined with other industrial, societal, and economic development, multiple factors have resulted to prevailing fast-fashion paradigm and to the environmental and social issues caused by it. Complex systemic challenges of textile sector appear on societal, industry and consumer level, and their interlinked and multifaceted problems do not have any simple and straightforward solutions. (Finix, n.d. a.)

On societal level the main problems are caused by fast fashion as a business model, with its take-make-dispose mentality. In textile sector, large companies dominate the field, and millions of actors are involved in long supply chains, where huge amounts of products for constantly changing fashion trend cycles are produced. Status quo has consisted of consumers that are used to have wide offerings of cheap clothes, and producers and suppliers having focus only on gaining fast profits in short-term. Environmentally this creates an unsustainable burden for natural resources and earth’s capacity to endure emissions. Global textile industry is significant polluter, estimated to produce 10% of the CO_2-emissions and consume 4% of freshwater (European Parliament, 2021; Niinimäki et al., 2020). Providing raw materials for textiles adds to the problems because cultivation of natural fibers require lots of arable land, water, fertilizers, and pesticides causing e.g., soil degradation. On the other hand, plastic-based fibers from non-renewable resources release microfibers during use and production. (Ellen MacArthur Foundation 2017, 38-39.) Long and complex supply chains are difficult to monitor and create space for severe social issues for workers in cheap labour countries, to where the production is much centred. Violations of human rights are not uncommon, and the almost all-female workforce suffers from insufficient wages for living, poor working conditions, and long working hours, among others, and child labour is much too usual. (Ellen MacArthur Foundation 2017, 20-21.)

On consumer level, problems relate on big part to the consumption behaviour. Consumers mostly prefer cheaper prices over other factors in their purchase decisions (European Commission 2018, 178), and also habits of buying low-quality clothes and short use times add the unsustainable burden of the textile sector. In global perspective, most of the textiles are still disposed to landfills long before their actual wear-out state. (Ellen MacArthur Foundation 2017, 19-20.) Recycling processes are being developed, but variety of fibres, mixed fabrics, and chemicals used in production make it difficult. Recent environmental awakening and raising awareness of climate change of consumers and other stakeholders has put pressure to change on the sector, as its many issues have been brought up to the knowledge of wider audience. (Finix, n.d. a.)

2.2. Data enhancing transition to sustainability

Data has a crucial role in enhancing transition to sustainability, which according to Grin et al., 2010) is

> "*a radical transformation towards a sustainable society, as a response to a number of persistent problems confronting contemporary modern societies*."

In the current era of digitalization, the aim of digitalization efforts is to harness digital technologies, thus data, to address grand challenges for tackling climate change and promoting sustainable development (George et al., 2021). For example, United Nations (n.d.

a) and World Economic Forum (Jensen, 2021) are advancing their pursues towards sustainability by emphasizing the importance of data utilization and digitalization.

Digitalization can be defined as

> "*transformation of business models as a result of fundamental changes to core internal processes, customer interfaces, products, and services, as well as the use of information and communications technologies.*" (Isensee *et al*., 2020.)

This definition reveals how thorough changes and ambitious goals are involved, and how great transformational power digitalization is expected to have. Anticipation is that digitalization enables and leads to transparency, faster and more efficient supply chains, and totally new business models embedding sustainability and circularity within (Schumann et al., 2022). Closely related term *digitization* means standardizing and redesigning previously individually carried out processes, and *digital transformation* combines the adoption of new technologies and organisational transformations for utilizing technologies in undertaking the opportunities they create (Liisberg & Heitmann, 2017). These three terms present the layout and vocabulary for data utilization towards transition in public discussions.

Another perspective to data utilization is presented by Porto de Albuquerque et al. (2021) who identify three main data-enabled transformation pathways to sustainability transformations: usage, circulation, and generation. Data usage pathway is the most common and prevalent, and it contains the use of data in informing decisions through indexing or measuring elements, that is, in referential function. In other words, data can be used to improve understanding and support decisions towards sustainability transformations. Data circulation pathway enables connection among different actors and systems with data flow and joins them for coordination and communication. It can even result to stronger engagement for sustainable development pathway though increased trust and consensus. Data generation pathway refers to the moment of data generation process itself, where actors can have social learning experiences, grow their critical awareness, and even change their perspectives and behaviours. Digital technologies enable these pathways allowing collection, integration, and analysis of massive amounts of data in various points of processes, and data-based knowledge creation for decision-making and improving actions (Porto de Albuquerque et al., 2021).

2.3. Current status of digitalization

In Finland, the interest towards developing circular textile and fashion industry has risen strongly, and data and digitalization are seen as major components in enabling its realization. Many organisations, such as Ministry of Finance (n.d.), Sitra (n.d.), and VTT (Kamppuri et al., 2021; Kauppila, 2022), have analysed the possibilities and challenges of digitalization in Finland. For example, the VTT analysis (Kauppila, 2022, 109-111) shows that opportunities lie in the wide support for the general idea of promoting data-driven circular economy, as political field is relatively united. Also, a wide set of initiatives is put forward, such as European Union promoting the twin transition and data-driven circular economy in its initiatives of EU Green Deal and the EU Taxonomy, which add the availability and quality of information, and possibility of using it in key decision-making processes. (Kauppila, 2022, 109-111.)

However, considering specifically Finnish textile sector current level of digitalization is low and possibilities are not fully utilized in companies. One reason to this is simply the lack of concrete ideas for implementing data-driven circular economy and strategies for executing such desired future, which explains the small number of companies linking digitalization and textile industry. Considering technological aspect, currently possibilities for sharing, enhancing, and using data theoretically exist but those are not still utilized to the best potential. Also, the lack of institutional arrangements is hindering the progress on data-driven circular economy, although development is on-going in this sector. (Kauppila 2022, 109-111; Kamppuri et al. 2021, 29.)

The pursued future of circular textile sector includes efficient solutions in collection, integration, and analysis of data, and this is still far ahead. Currently data collection is not filling the data needs, and the data collection methods are falling behind of what is technologically possible. (Kauppila 2022, 23-24; Kamppuri et al. 11-12) The common methods used today are variable, including surveys and questionnaires, statistics, databases (some open access), and research, whereas hyped new solutions such as blockchain, artificial intelligence (AI), BigData, and digital twins, are not among them yet, apart from perhaps some pioneering companies. There is a need for centralized circular economy data governance and cohesive data collection. The lack of standardized and systematically updated data causes decreased data quality and makes data collection very time consuming. Incohesive data also, for example, complicates making comparisons and time-series. Main issues related to effective data collection are seen to be the challenges in co-operation, ownership, and resources. (Kauppila 2022, 32-35; Kamppuri et al. 23-25.)

One of the main questions in developing digitalization considers the data sharing and the dilemma of how to share the benefits of privately owned data. Sharing and opening data could benefit companies by creating transparency to their actions and lead to gaining new opportunities for market differentiation around data, such as label or tool (Jarman et al., 2016), and other parties, such as individuals, start-ups, and other organizations, by enabling them to create new data applications and business from it (Kauppila 2022, 37-38). However, there are also several challenges that prevent or make data sharing a less interesting and hinders opening data repositories and data streams for all. Questions include such as how to protect sensitive business information, company reputation, and stakeholder relations, how to minimize or delete the possibility of incorrect data interpretation or manipulation, how to keep the anonymity of data, and how to help small manufacturing companies overcome the lack of resources in data sharing related work. (Kauppila 2022, 36-38; Kamppuri et al. 24-25.)

Both Kauppila (2022, 37) and Porto de Albuquerque et al. (2021) remind that open data alone does not necessarily lead to data utilization and sustainable transformations. There are also requirements for usability and interpretability in enabling stakeholder’s data value creation. In EU, this is addresses by introducing the FAIR principles, standing for Findability, Accessibility, Interoperability, and Reusability, which aim for enhancing wider usability of data across the countries, companies, and other stakeholders (Publications Office, 2022).

2.3.1. Data needs and availability

As presented in previous chapter, consensus of the requirement for utilizing data and digitalization towards circular textile and fashion industry seems to be clear. Also, data needs have been identified in Circular Design Network project workshop, and the list is categorized into four themes: Textile product data of origin, consumer product data, data of work clothing, and recycling and material loops data. Data of origin includes the basic information of the first phase of the product, mainly concerning raw materials and textile chemicals, for example, origin of the raw material, producer of the product, and true LCA data on raw material. Consumer product data consists of various product information, such as material, production and logistics, size, style, use and purpose, environmental impact data, and various data on renting, using, recycling and other waste management data. Work clothing data includes similar data than in the previous themes, but also data on the standards and regulations that the products and their raw materials meet. Recycling and material loops data concentrates on data for planning and executing recycling, such as, material, fibre composition, amount of textile waste, local storage information and points of return. (Kauppila 2022, 22.)

Currently, there is a big gap between the identified data needs and actually available data. For example, SYKE conducted a survey to map Finnish textile flows and noticed that even though some waste management related data is gathered, a lot of information is not collected systematically, and they claim that the same problem applies to circular textile data and information in wider sense, too. (Kauppila 2022, 24).

2.4. Future EU trends in digitalization towards sustainability

Digitalization is driven forward with on-going technological and policy development, enhancing the three data-enabled pathways towards sustainability in Finnish textile sector.

European Union has several action plans, strategies, and directives regarding both circular economy and digitalization, referred as twin-transition, and the two main strategies promoting these topics are EU Green Deal and Digital Decade. (European Commission, 2022a.)

Textiles have been identified as one of the most important area of development in EU, therefore, several actions have been targeted to textile sector directly and indirectly. EU Green Deal is addressing, among others, to the issues of product sustainability, enabling consumer awareness, and digital support for data sharing along the supply chains. Applying Ecodesign Directive to textiles too, in addition to current use cases, is discussed and targeted for proactively enhancing circularity of products guiding the more sustainable products with design choices. (European Commission, 2022a.)

EU Strategy for Sustainable and Circular Textiles is targeting for 2030 the transition to take place and European market to provide only products that are recyclable, do not include hazardous substances, have long use time, and are produced socially and environmentally respectfully (European Commission, 2022a). The objective of Product Environmental Footprint (PEF) method is to provide guidelines for calculating companies' environmental performance, based on reliable, verifiable, and comparable information, and accessibility to the results for other actors, for example, public administrations, NGOs, business partners. Guidelines will be published by the end of 2022 (European Commission, 2021b). Promotion of Digital Product Passports (DPP) aims for collecting and providing information of the product throughout its life cycle and carried with the product for improving traceability. The initiative on Empowering Consumers for the Green Transition aims at ensuring that consumer information is based on EU approved sources, such as EU Ecolabel, legislation, or third-party verification, and included information of guarantee and repair. (European Commission, 2022a).

EU's Digital Decade thrives for digital transformation of Europe by 2030. Digital Compass action plan sets actionable targets for increasing digital skills of citizens and professionals, providing good digital infrastructures, and supporting digital transformation of businesses and public services. (European Commission, 2021). For example, Gaia-X project aims to develop European data infrastructure and create a digital ecosystem for enabling availability and sharing data and services openly, transparently, and securely. Gaia-X would provide unified terms, architecture, and components for all solutions regardless of the level or sector of the application. (Federal Ministry for Economic Affairs and Energy, 2020.) EU Data Act, on the other hand, is a policy action towards comprehensive rules for data generation and utilization across EU and ensuring fair and competitive data availability and accessibility for variety of use cases and users, addressing on the legal, economic, and technical issues (European Commission, 2022b.)

3. DATA IN SUSTAINABILITY ASSESSMENT OF TEXTILES

Sustainability assessment (SA) is dependent on the data; conducting an assessment is only possible if sufficient data in decent quality is available. In this chapter, the purpose is to present different aspects of sustainability assessment and indicators affecting on the data requirements of the assessment. These dimensions include general sustainability assessment related aspects, the different methodologies for assessing, data value-creation and quality perspectives. Also, a framework for finding criteria for sustainability assessment data source is presented, and consumer targeted sustainability assessment is described for providing additional understanding of the specific requirements of that type of assessment.

3.1. Sustainability assessment instruments and indicators

Sustainability assessment is a growing field of interest as the pursues on developing more sustainable processes, services, and any kind of actions are gaining popularity. Sustainability assessment is a process that has one or several of the three aims: contributing to a better understanding of the meaning of sustainability and its contextual interpretation, integrating sustainability issues into decision-making by identifying and assessing sustainability impacts, or fostering sustainability objectives. In short, sustainability assessment rises for three challenges: interpretation, integration, and information-structuring. Sustainability assessment and its usability relies on data that can be turned into information and finally knowledge. (Waas et al., 2014.)

Sustainability assessment instruments differ in their perceptions of what are the relevant and legitimate sustainability perspectives, what and how to measure, to whom assessment is meant, and by whom the assessment is made (Gasparatos & Scolobig, 2012). Sustainability assessment is based on sustainability indicators (SI), which help in simplifying, quantifying, analysing, and communicating complex information. There are various purposes for sustainability indicators, such as, assess and evaluate the performance, provide trends, support decision-making and strategy formulation, and help communicating the achievements. (Singh et al., 2012.) The methodological options of sustainability assessment are numerous, therefore, understanding their differences and similarities should be considered and also the suitability of indicators for the certain use case should be ensured. Indicators can be classified and evaluated, for example, based on Booysen (2002) seven dimensions of classification and evaluation, which are presented in Table 1.

Table 1. Classification and evaluation of sustainability indicators (Booysen 2002).

	Dimension of classification/ evaluation	**Description**
1	Content	What aspects or facets of development are measured?
2	Technique and method	Is measuring - quantitative/qualitative - objective /subjective - cardinal/ordinal - uni-dimensional/multi-dimensional?
3	Comparative application	Is comparison of development made (a) across space (‘cross-section’) or time (‘time-series’), (b) absolute or relative manner?
4	Focus	Is measuring done in terms of input (‘means’) or output (‘ends’)?
5	Clarity and simplicity	In regards of content, purpose, method, comparative application, and focus
6	Availability	Is there readily available data on the particular indicator across time and space?
7	Flexibility	Are changes possible in content, purpose, method, comparative application, and focus?

Sustainability indicator classification and evaluation considers the content of the indicator to identify what sustainability aspects it includes. Measuring techniques and methods, and comparative application describe in more detail how the indicator results are produced and presented, and the focus informs if the measuring considers input or outputs. Clarity and simplicity dimension refer to the quality of previously mentioned three dimensions. Last two classification and evaluation dimensions are, availability and flexibility, which relate to the data availability for the indicator and possibility for changes in regard to indicator purpose, content, method etc. (Booysen, 2002.)

3.2. Assessment methodologies

Variety of methodological options exists for sustainability assessment, and the methodological choice impacts on the assessment process, results, and data needs. Three main methodologies, Life Cycle Thinking, Circular Economy, and Multi-Criteria Indicators are introduced in the following chapters.

3.2.1. Life Cycle Thinking

Life Cycle Thinking (LCT) is a methodology which aims for considering the comprehensive life cycle of the product instead of traditional focus on manufacturing processes only. In LCT, interest is in all sustainability dimensions, environmental, social, and economic, and the goal is to both reduce negative environmental impacts and improve social and economic performance, many of which can be interlinked to each other and create synergies towards sustainable development. Ulterior motive of life cycle thinking is to share responsibility of the impacts and actions for all the stakeholders along the life cycle, and thus preventing the burden shift along the value chain. Considering the resource use, emissions, and social impacts of each life cycle phase of the product allows decision-makers to make well informed actions within the system. (Life Cycle Initiative, 2022a; Mazzi, 2020.) Figure 1 illustrates the cradle-to-grave perspective, i.e., the life cycle from raw material acquisition to production, use, and finally to end-of-life phase.

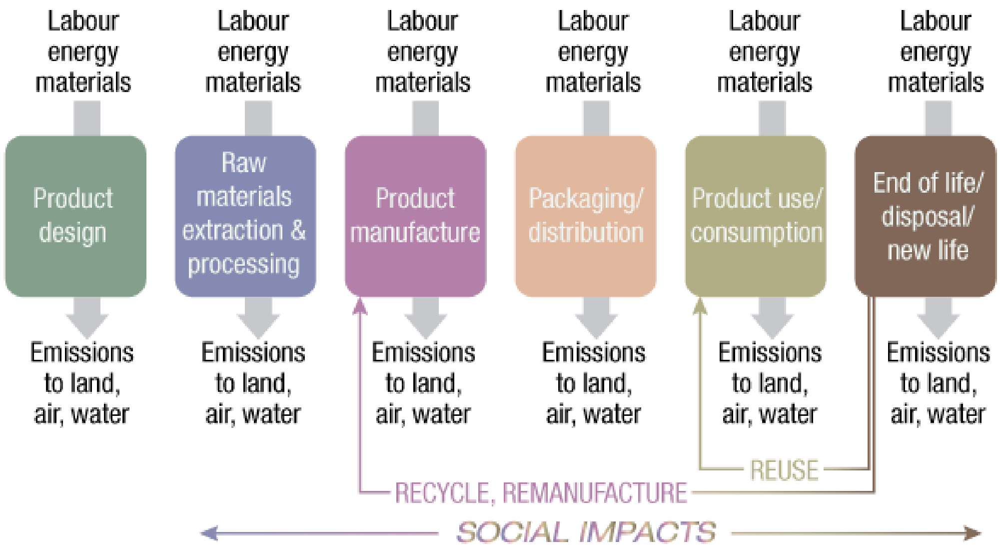

Figure 1. Life Cycle Thinking (Life Cycle Initiative, 2022b).

Life Cycle Thinking approaches benefit industries, consumers, and government decision-makers by providing information for, e.g., overall business management, multi-stakeholder dialog, and sustainability supporting initiatives and programs. (Life Cycle Initiative, 2022a). Methods using life cycle approach are potentially able to provide thorough and detailed information for many stakeholders, but their demand for advanced methodologies and a lot of data are not easily fulfilled. (Luo et al., 2021.)

One of the main methods used for textile products is Life Cycle Assessment (LCA) (Luo et al., 2021). LCA is a science-based, ISO standardized method for systematic processing and evaluation of product system to identify the main environmental impact areas and evaluating potential threats. LCA can analyse product life cycle from cradle-to-grave, but narrower scopes are also possible. *System boundaries* define the research object limits in the environment and technosphere, and *functional unit* describes "quantitative description of the benefit a product is expected to provide". Functional unit jeans could be, for example, "wearing a pair of cotton jeans daily for three years". *Unit process* is the smallest unit of production process phase, for which the inputs are allocated. (Klöpffer 2014; 2-3.)

Challenges of LCA relate especially to data and unidimensionality. In LCA, all the data for assessment are collected into an inventory in the phase of inventory analysis. Being very thorough method at its best, LCA is data-intensive and data acquisition can be very complex, requiring expertise. Using primary data, that is, the data measured and collected from actual processes, is most preferable and accurate, however, that is rarely available, and often approximations from secondary data sources such as data bases and literature are required. The challenge of pre-collected data in databases is often the inaccuracy and incompleteness of data (Luo et al., 2021) and the lack of up-to-date and geographically representative data. (Klöpffer 2014). Literature can be used as data source in certain cases, although specificity of researched products can create obstacles in applicability (Luo et al., 2021.)

LCA concentrates only on environmental aspects, and this unidimensionality is acknowledged to be insufficient for assessing comprehensive sustainability. Additional methods for assessing social and economic aspects are not yet as widely used due to lack of applicable and measurable indicators, although methods are already slowly gaining popularity. Social-LCA (S-LCA) and Life Cycle Costing (LCC) are methods targeted to fill the need for multidimensional approach, and Life Cycle Sustainability Assessment (LCSA) pursues on combining all three dimensions. (Life Cycle Initiative, 2022c; Life Cycle Initiative, 2022d.)

3.2.2. Circular Economy

Circular economy (CE) is a multidimensional concept, which emphasizes the integrated environmental strategies and management systems instead of plain mitigations actions (Calzolari et al., 2022). It aims for the system that benefits business, people, and the environment, by decoupling the economic activity from the use of natural resources and adding resilience of society. Figure 2 illustrates the action potentials towards circularity (ECERA, 2020), which aim at decreasing the amount waste and pollution to the minimum, circulating products and materials, and enhancing the nature regeneration (Ellen MacArthur Foundation, n.d.).

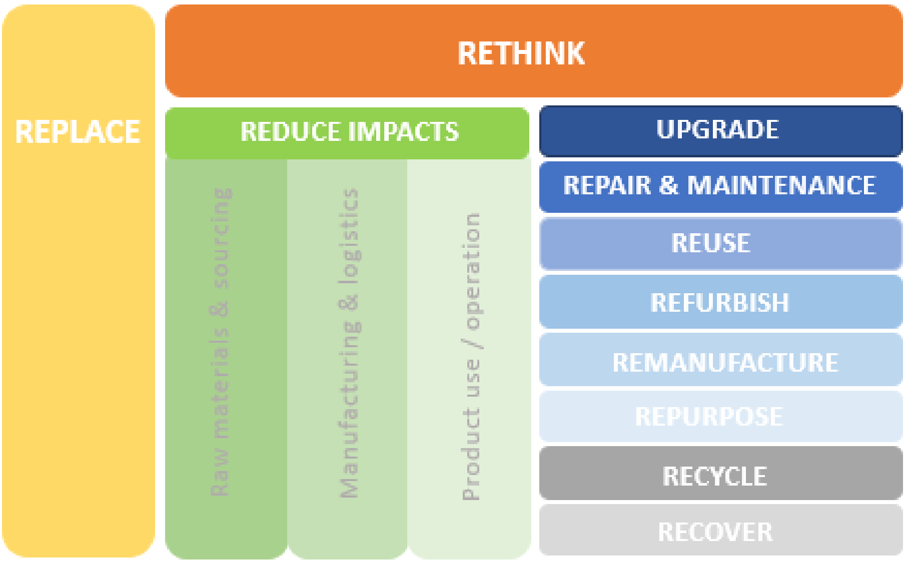

Figure 2. Circular Economy framework (adapted from ECERA, 2020).

Replacing is the starting point where design and planning are used for maximising the value delivery while minimizing the resource use. *Reducing* impacts in production phase is done through developing processes more efficient. Opposite of linear model, circular economy emphasizes the importance of end-of-life phase where the last option is to discard product, after the possibilities of *reuse*, *refurbish*, *remanufacturing*, *repurposing*, and *recycling* are applied first, if possible. *Recover* is the utilization for energy. *Rethinking* of new value delivery possibilities is applied throughout the life cycle. (ECERA, 2020.)

Although the importance of circularity and its assessment is seen important, the current difficulty is the lack of consensus of clear and unified indicators for circularity assessment (Martinho, 2021; Calzolari et al., 2022) and of the views how to implement CE strategies with real environmental benefits in practice (Mannan & Al-Ghamdi, 2022). Multidimensionality of circular economy framework complicates the focus of the analysis, can cause conflicting metrics, and complicate identifying standard indicators. (Martinho, 2021.)

3.2.3. Multi-Criteria Indicators and combined methods

Multi-Criteria Indicators and combined methods may be the future direction of sustainability assessment in textile sector. Current assessment methods do not sufficiently represent the complexity of textile industry and the trade-offs between costs and benefits that sustainability framework includes (Luo et al., 2021; Wojnarowska, 2021). Luo et al. (2021) suggest developing of hybrids on quantitative and qualitative methods also due to difficulty and costs of data collection.

Multi-Criteria Indicators are more inclusive and flexible in terms of value considerations than other types of sustainability assessments (Calzolari et al., 2022), meaning that they can consist of different combinations of sustainability dimensions. Multi-Criteria Decision Analysis (MCDA) is one type of MCI and can be seen as a term including variety of methods that combine multiple dimensions. MCDA methodologies can include multiple, even conflicting set of qualitative and quantitative criteria, which provide more holistic and balanced view for decision-making, but in case used alone, cannot provide sufficiently objective and precise answers. Therefore, reliability of impact assessment can improve with supplementation of other evaluation methods. (De Luca et al., 2017.)

Utilization of integrated methods can have multiple benefits and synergies. For example, integrated methods can be better suited to stakeholders needs and provide more comprehensive and unbiased support for decision-making while more perspectives are analysed. However, combined methods can also entail more uncertainties due to wider number of indicators and large number of information that needs to be collected. Also, methodological disagreements are more possible, and the requirement for a sensitivity analysis increases for making model relevant and plausible. (De Luca et al., 2017.)

Combining LCA and CE assessment is one proposed option with beneficial impacts on more in-depth analysis and wider understanding on sustainability. These methods could complement each other by adding up the scientific environmental assessment and strategical visions of CE. LCA can verify the less negative environmental impacts of CE closed loop processes, or help finding the possible limitations and inaccurate assumptions of CE strategies. The joint assessment can provide simultaneously both wider and more specific views for continuous development towards more sustainable processes. (Mannan & Al-Ghamdi, 2022.)

3.3. Consumer-targeted assessment

Achieving sustainable future requires changing consumption patterns towards a more sustainable level, in addition to developing more sustainable production processes. Consumer's pro-environmental behaviour is tightly connected to ecological awareness and knowledge (e.g., Dihr, 2021; European Commission 2018, 185), although myriad factors affect to final decision where price seems to be one of the most emphasized (e.g., European Commission 2018, 178). Gathering sustainability information of products is nearly impossible for individuals, even for one's with high interest and motivation, therefore easily understandable and timely support for consumers purchase decision-making is required (Turunen & Halme, 2021).

Consumer targeted assessment instruments aim for affecting purchasing decision-making and behaviour of customers towards more sustainable choices, and ecolabels are a common method for that purpose. Ecolabels are an effective solution for educating consumers of environmentally friendly products and providing information for producers about their products. Producers can utilize that information for improving their products' sustainability and presenting customers the current advantages of their products (Wojnarowska et al., 2021). Sustainability assessment gives organization a mean to communicate its sustainability objectives and advantages to stakeholders, but also, raising understanding of sustainability of public. This adds to the importance of including all the key indicators to the assessment in order to educate consumers and other audience of the dimensions of sustainability. (Waas et al., 2014.)

Current textile related ecolabels have some known issues, such as, most of them concentrate on few criteria including only a part of the sustainability dimensions and that third-party verified labels are most likely achievable only for big companies due to the high need of resources, e.g., for acquiring the needed data. On consumer side, the difficulty comes from the existence of variety of labels with different, non-comparable criteria, when choosing which label is more important compared to the other is impossible. Most importantly, the binary (yes/no) logic of current labels does not represent the process-like nature of sustainability development and gives consumers misleading messages of the textiles' sustainability. (Turunen & Halme, 2021.)

3.3.1. Requirements for effectivity

Consumer targeted sustainability assessment, such as labels, aims at informing and supporting consumer in their purchase decision making. There are a number of factors to consider in order to have effective impact with labels.

Trustworthiness is one of the most crucial factors for determining the effectivity of label (e.g., Meis-Harris et al., 2021; Gorton et al., 2021). It consists mainly of two aspects, the source and verification of the information. These aspects refer to the understanding that labels should be trustworthy and transparent, and also, that product evaluations should be accurate and reasoned with agreed criteria and methods. (Meis-Harris et al., 2021.) Label source has impact on consumers' perceived credibility, and governmental sourced are most often positively responded to over corporate sourced labels (Atkinson & Rosenthal, 2014; Meis-Harris et al., 2021).

Also, while acknowledging the importance of integrity and transparency of data verification, it is highly challenging and costly, in current operational environment of textile industry where supply chains are long and complex, and most usually not in the hands of one company. Therefore, the combination of multiple criteria and life cycle considerations should be emphasized (Koszewska 2015, 332; Meis-Harris et al., 2021), as well as the third-party verification (Gorton et al., 2021; Koszewska 2015, 332; Meis-Harris et al., 2021.)

Transparent information sharing could also enhance labels' potential power (Koszewska 2015, 341). In an optimal situation, there would be continuous data provision from the actors regarding all the processes along the product life cycle, however, in reality the resource requirements are most probably not met, and motivation is insufficient. Also, continuous dialogue among regulators, providers, and users of the data could have positive impacts on label effectiveness. (Kauppinen 2022, 85.)

In addition, there are factors not directly considering data, however important and related to the data aspect. These are presenting tangible sustainability benefits of the product choice, providing information timely and in appealing (easily understandable) form, and confirming policy conjunction (Meis-Harris et al., 2021). Also, it is important that products with labels achieve sufficient market penetration to remain sustainable and viable (Atkinson & Rosenthal, 2014; Meis-Harris et al., 2021). If applicable, involving utilization of new technologies may enhance label effectivity (Koszewska, 2015.)

3.4. Data value creation and data quality

The foundation of the data-driven transition and digitalization is the value-creation with data. Data itself does not possess transitional power, but it can be a powerful substance of various value-creation processes which in turn have transitional impacts. In classic definition of data value chain, the value is produced in linear process consisting of data creation, data transformation, data value-add, and data impact/use (Data Economy, 2022; Open Data Watch, 2022.)

Attard et al. (2016), however, illustrate data value creation happening in a data value network, where the activities do not have to follow a certain order and can also be executed simultaneously, even by multiple actors in co-production. Five data creation methods, Data Discovery, Data Curation, Data Interpretation, Data Distribution, and Data Exploitation, all include several techniques, as seen in Figure 3, the purpose of which is to make data usable and fit for its use.

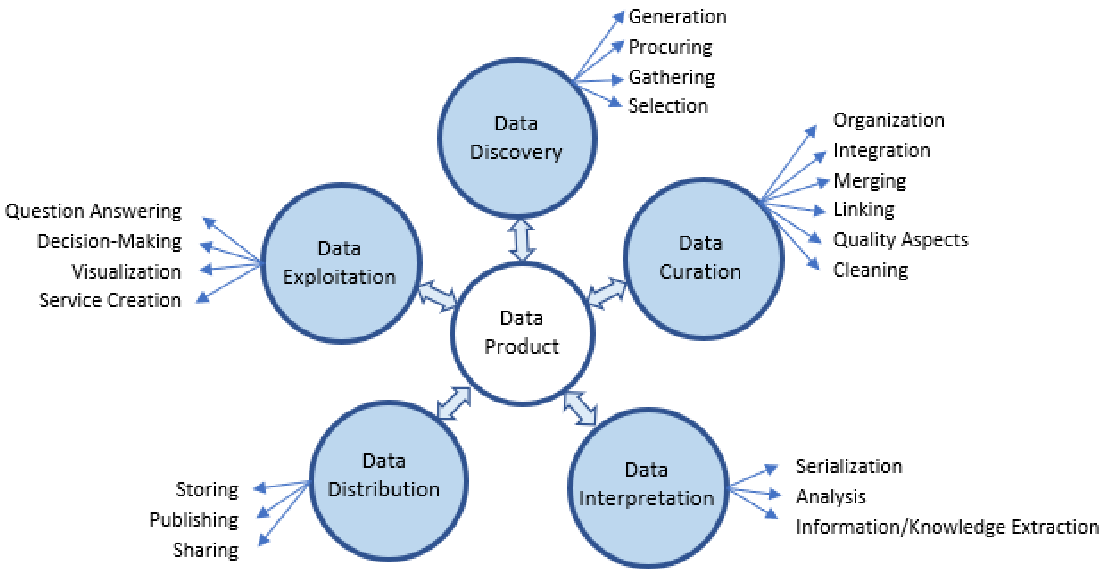

Figure 3. Data Value Network (adapted from Attard et.al., 2016).

Data discovery is the process of obtaining data, where the sources of data can be as varied, and many techniques can be applied, such as generation, procuring, gathering and selection. Data curation consists of techniques for modifying data to create more value of it. Techniques can be, for example, organization, integration, merging, linking, quality improvement, and cleaning. Data interpretation means representing data in a more understandable form, through techniques such as serialization, analysis, and/or information extraction. Data distribution turns data to a product available for others to search and discover by storing, publishing, and sharing. Data exploitation is usually considered as the goal of the Data Value Network, and it is a stage where data can be consumed, for example, in decision-making, visualization, service creation and question answering. (Attard et al., 2016.)

Data quality is a crucial factor in data value-creation and there is an abundance of approaches to the data quality in the literature. EU has also published data quality guidelines, known as FAIR principles, to improve the availability of good quality data and enhance uniform usability of data across Europe. Principles consist of four main categories, Findability, Accessibility, Interoperability, and Reusability, and their subcategories (Figure 4). (Publications Office, 2022.)

Findability	Accessibility	Interoperability	Reusability
Completeness	Accessibility/ availability	Conformity/ compliance	Timeliness
Findability		Machine readability/ processability	Consistency
		Openness	Accuracy
			Relevance
			Understandability
			Credibility

Figure 4. FAIR principles (adapted from Publications Office, 2022).

Findability refers to the humans' and computers' ability to find data sets, which can be enhanced with metadata, that is, the explanatory data of the data sets. Completeness means that data is represented as a solid entity including all the needed information. *Accessibility* of data is provided if required data can be reached and retrieved without restrictions or errors. *Interoperability* consists of conformity/compliance, machine readability/processability, and openness, which mean that data is in standardized form, automated data processing is enabled, and availability of data for utilization without, e.g., licences. *Reusability* includes the most subcategories, consisting of timeliness, consistency, accuracy, relevance, understandability, and credibility. Timely data (and metadata) is up to date, considering changes, and represents the actual and current situation. Difficulty is in understanding the content timeliness requirements automatically. Consistency refers to having no contradictions in data and is especially important factor when data is combined from multiple sources. Accuracy is the data preciseness, that is, data is correct and consistent, and gives user the correct understanding. Relevance means that data is fit for the use, containing helpful and applicable data and sufficient in amount. Understandability of data means clarity and comprehensiveness of data to the user, and credibility depends on how trustworthy the data sources, i.e., able to provide trusted and believable data. The last three dimensions, relevance, understandability, and credibility, all depend on users' perception and can be only affected to the limit. (Publications Office, 2022.)

3.5. Sourcing data for assessment

Referring to the previously identified aspects of data availability, value-creation, and quality, it is clear that data sources used in sustainability assessment have an important role. Questions arise, how can we identify relevant data source and how can we perform a quality-based assessment of that data source? Sourcing data from a destination and combining it with other data in another target, is an action of data integration, which Gartner (2022) defines as

> "*architectural techniques and tools for achieving the consistent access and delivery of data across the spectrum of data subject areas and data structure types in the enterprise to meet the data consumption requirements of all applications and business processes*".

Due to the limitation in the focus of this study, that is, the exclusion of technical issues, the data source assessment is bound to be narrower than without this limitation. Excluding techniques and tools from the equation only the data consumption requirements are left.

One method for defining requirements for data source is a requirement analysis, which is a comprehensive method often used in system engineering and software engineering for determining the needs or conditions to meet the new or altered needs of product or project. Requirement analysis is critical to the success or failure of a system or software project, and it considers the possibly conflicting requirements of the various stakeholders, and includes analyzing, documenting, validating, and managing the requirements. The requirements should be documentable, actionable, measurable, testable, traceable, and related to identified business needs or opportunities, as well as defined to a level of detail sufficient for system design. (Simplylearn, 2022.) There are number of strategies (e.g., Grady 2014, 792-793), tools, and techniques (Simplylearn, 2022) to perform requirement analysis for a system but here is presented one general framework for requirement analysis.

Requirement analysis consists of five steps, that are identifying the key stakeholders and end-users, capturing requirements, categorizing requirements, then interpreting and recording requirements, and finally, signing off. First step, identifying key stakeholders and end-users is crucial for understanding all the requirements, and both groups should have an impact on the project results. Capturing requirements in second step can be done by interviewing stakeholders and end-users both individually and in groups, introducing different use cases and building prototypes to get a clearer picture of products functionalities and analysing its possible feasibility issues and problems. Next step, third, is categorizing the requirements by their type to avoid confusion, and then, in fourth step, requirements are defined, prioritized, and analysed further to ensure that requirements are correctly understood, feasible, and their importance is identified. Last step, sign-off, is to get final signed agreement on the requirements. (Simplylearn, 2022.)

4. METHODOLOGY

In this chapter, the case instruments Shades of Green and LCIM are introduced, concentrating on their purpose and structure. Also, the research methods are explained.

4.1. Case study instruments

Importance of data has been widely understood regarding the sustainable system transition in textile industry. Finix project has taken up the challenge, and two separate tools are being developed with the aim to enhance sustainable system transition by providing supportive instruments for sustainability assessment. Both instruments aim for serving easily accessible and usable information for assessing company's level of sustainability in their actions and offerings. In addition, SoG's primary purpose is to provide customers sustainability information of the products in a form that it is easily understandable and turned into actions. In the following subchapters, these two instruments are introduced in more detail.

4.1.1. Shades of Green

The development of SoG has raised from the understanding that there remains a frustrative gap between sustainability information provided for customers and the impact it has on the purchasing behaviour of customers even when the awareness and knowledge about the sustainability has risen. Given sustainability information has not proven to be actionable. (Turunen & Halme, 2021).

Shades of Green instrument has been designed based on the definition of sustainability and the knowledge gained of the identified needs of improvement on sustainability labels. It is an instrument for assessing the both ecological and social sustainability, and its purpose is two-fold:

1) Provide actionable information for customers and enable them to make more sustainable purchase choices.
2) Provide SME sustainability criteria for assessing their offerings and developing it according to the criteria. (Turunen & Halme, 2021.)

SoG aims for addressing customers' need for having simple and easily understandable information for their decision-making regarding textile purchases. Information given with the instrument needs to be informative, simple, and actionable to effectively impact on choices, and include wide scope on the sustainability indicators to provide comprehensive result. The structure of SoG instrument includes an embedded idea of the continuous improvements instead of an on-off evaluation of the sustainability, which is more common among certifications. SoG instrument has three-levels that represent the integration level of the sustainability actions in the company. The levels are:

1) Minimum integration of sustainability
2) Advanced integration
3) Sustainability innovation (Turunen & Halme, 2021).

These levels are visualized as a staircase with different shades of green (Figure 5). Below the three steps, there is a brown level indicating the products that do not qualify and reach the lowest level in the scale. (Turunen & Halme, 2021.)

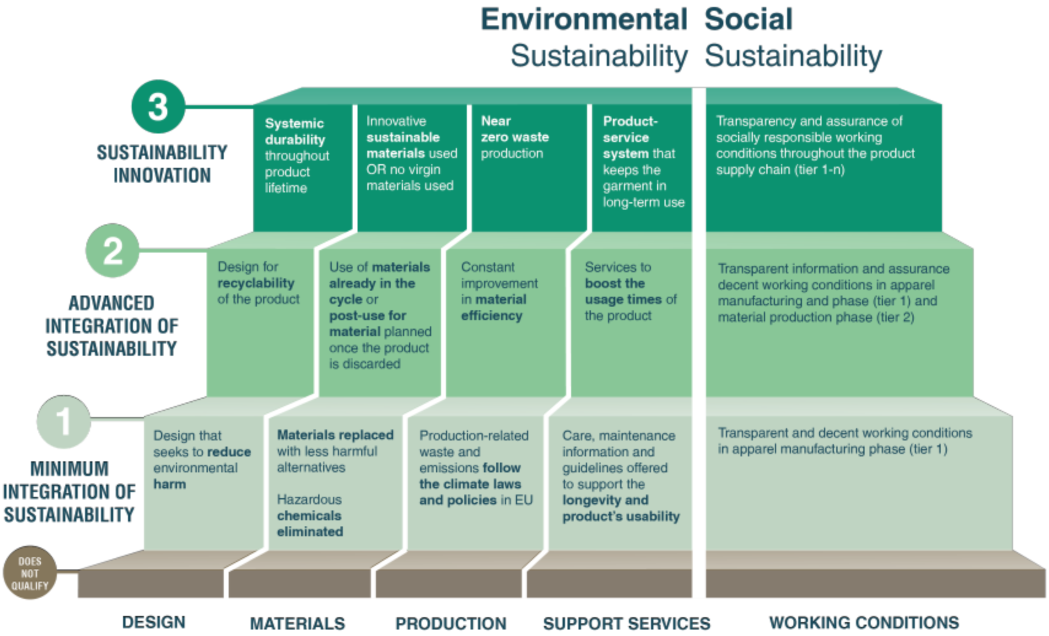

Figure 5. Shades of Green instrument (Turunen & Halme, 2021).

Instrument considers sustainability from environmental and social aspects, which both have separate indicators on each of the three levels. Also, an important factor in the instrument is that it takes the life cycle of the product into consideration, including phases from gradle to use. The four phases in environmental sustainability section are design, material, production, and support services. The two main prevailing ideas are to emphasize the longevity of the textile and ensuring the consistency with circular economy model. (Turunen & Halme, 2021.)

Shades of Green instrument is still being further developed and there are considerations of removing the separate Design phase and having it embedded into other categories, for instance. Also, the distinction of Materials and Products is under evaluation, where one possible idea is to comprehend Materials to include all the process phases before the complete consumer product, and, respectively, Production referring to consumer product. (Turunen, online interview 4 May 2022.)

4.1.2. LCIM

Life Cycle Information Management (LCIM) tool is being developed for collecting and storing data of fibres, fabrics, and apparel products into a single database. LCIM tool is based on the idea of life cycle assessment (LCA), that is, a method for assessing the environmental impacts of a product or service during the life cycle. The longer-term objective of the tool is to become a go-to on-line tool for small and medium sized enterprises for assessing the impacts of their products and to get the LCA results from this tool automatically. The idea is that companies input their own actual data into LCIM, that is, the intention is to collect primary data, which is assumably the most accurate data of the processes for the calculations. In case this primary data is not available, secondary data is used, which is collected from databases, such as EcoInvent and GaBi, and other sources. In the future, target is that LCIM would store and manage exhaustive life cycle information of textiles. (Uunimäki & Jain, n.d.)

In the LCIM tool, different production flows for a product are defined, and the data is input for each process separately (Figure 6). LCIM hierarchy contains fibers, components (yarn), materials (fabric), assemblies, and products, which each can include one or several production steps, for instance, fiber production, knitting, dyeing, spinning, and finishing. (Uunimäki & Jain, n.d.)

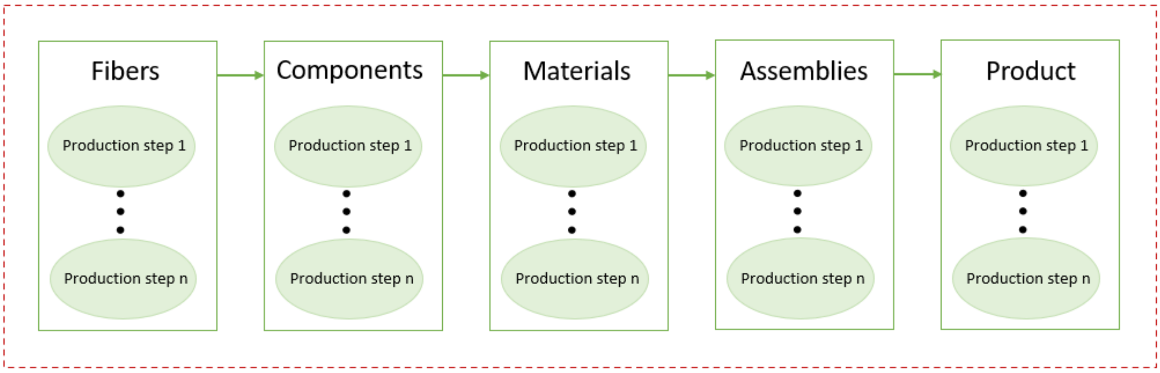

Figure 6. Simplified structure of LCIM.

Figure 7 presents an example of data input sheet, where first some general information (name, fiber, company) is filled and then related steps are added. Data is intended to be input from fibers onwards, similarly to actual production process, and compile the next phase from previous ones. For example, one or several fibers form a component, components belong to materials, materials to assemblies and finally these all together form a structure of the product.

Figure 7. New Fiber data input sheet in LCIM (Finix n.d. c).

According to current scope, the focus of LCIM tool life cycle assessment is on environmental emissions from energy consumption and direct water footprint of the product. Data accessibility is one major reason for these limitations, and also the usability of the tool is prioritized over level of details. Already the energy data input can be quite complex, and the more inclusive and detailed data is required to input, the more difficult it is for companies be able to achieve. For example, energy consumption is presented in kW/h per kg of fiber/yarn/fabric, and for that, the energy consumption of the production plant and yearly production amount of fiber/yarn/fabric are needed to be able to calculate the input result. These data preferably come directly from the producer, but in case not available, average numbers are taken from secondary sources. (Uunimäki & Jain, n.d.)

Direct water footprint is similarly preferably based on actual water consumption in the production plant per time, but secondary data can also be used. In the future, the ecotoxicity of colouring and printing might be added, for instance. The target in applying the LCA logic in LCIM tool is, at least, to get results for climate change impacts quantified in CO_2-equivalents. (Uunimäki & Jain, n.d.)

4.2. Research methods

This study is a combination of literature review, thematic interviews, and utilization of analytical methods. Foundation of this study is in the literature, where the information for theoretical part was gathered. Case study draws from the founding of literature and was complemented with instrument developer interviews. Requirement analysis method was utilized as assisting framework for finding the main criteria for evaluating instruments' connecting.

The co-developer of Shades of Green, Linda Turunen, gave thorough information of both the structure and content of the instrument, and of the development process and the future aspects for it. Kirsti Cura, Mirka Uunimäki, and Patrik Koskinen, were interviewed from the LCIM development group. Kirsti Cura enlightened especially reasons for starting the LCIM development and early steps of it. Mirka introduced the practical side of LCIM, including contents and use of the tool, as well as explained the development process at hand. Patrik Koskinen gave additional information of the current LCIM development phase and future. All interviewees also participated to the discussion of the potential use cases and speculations of the future.

5. RESULTS

In this chapter, the answers to the three research questions are presented with the main focus on the current status of the instruments. Further speculations and future aspects are handled more in chapter 6. Discussions. First research question of this study is, how data in SoG and LCIM contribute to the transition towards sustainability. The answer is drawn from the understanding that data-driven transition is expected to combine sustainable system transition needs and data utilization. The connection between the tools and transition is presented by using data value-creation actions and data-enabled transformation pathways as mediums.

Investigating the possibilities and challenges of connecting SoG and LCIM is the second main theme of this study, and it is divided into two research questions: first, identifying the criteria for evaluating connecting, and second, making the actual evaluation and interpreting the results. Answering these two latter research questions begins with establishing the relationship of the instruments, where the planned purpose and use create the foundation. The criteria for evaluation are found using requirement analysis framework, where main stakeholders' needs are identified, defined, and prioritized. Based on these, the evaluation of connecting is performed reflecting each criteria separately.

5.1. Contribution of SoG and LCIM data on transition towards sustainability

Data can enhance transition through three data-enabled transformation pathways, usage, circulation, and generation, and therefore, data can be seen as an asset towards more sustainable future. However, data only provides an opportunity, not a solution, unless some value is gained from data, that is, if data value-creation actions are carried out to unleash the potential of the asset. Data products such as SoG and LCIM have potential to increase the value of data as they enable and operate a number of data value-creation action. Also, specifically as sustainability assessment instruments, SoG and LCIM are designed for enhancing the systemic change and therefore they are even more likely to enable positive effects.

In this study, data value-creation actions are presented as practical applications to realize data-driven pathways and these two elements create the connection between data in the case study instruments, SoG and LCIM, and the systemic transition in textile sector. Table 2 combines these elements and shows each method of data value-creation allocated to one of the data-enabled transformation pathways. For example, question-answering and decision-making clearly represent data use, thus, those actions are connected to data usage pathway.

Further, the systemic development needs are organized in relation to the pathways, and, for example, decreasing environmental impacts requires data usage (e.g., information extraction and decision-making). The linkages and allocations presented here are not exhaustive or thoroughly studied but compiled to present the main frame of the connections that are needed to understand the contribution of the instruments data.

Table 2. SoG and LCIMs data value-creation actions and contribution to systemic transition in textile sector through data-enabled transformation pathways.

Data value-creation SoG	LCIM	Method	Data-enabled transformation pathways	*Systemic development needs*
x	x	Question answering	*Usage*	• Supply chain reorganization • Circular materials • Emission decrease • Consumers' sustainable purchase decisions • Environmental impact decrease
x	x	Decision-making		
x		Visualization		
		Serialisation		
x	x	Analysis		
x	x	Information/knowledge extraction		
	x	Storing	*Circulation*	• Providing data platforms for sustainability development work
x	x	Publishing		
x	x	Sharing		
x	x	Organisation		
x	x	Integration		
x	x	Merging		
	x	Linking		
x	x	Generation	*Generation*	• Educating companies & consumers
x	x	Gathering		
x	x	Selection		

Systemic transition

SoG and LCIM execute various data value-creation actions, as seen in Table 2, and both of them contribute through all three pathways. Related to usage pathway, SoG performs question answering (how sustainable product is on given scale), decision making (indicates comparable sustainability information), visualization (criteria and results are presented illustrated), analysis (sustainability indication based on measures), and information/knowledge extraction (transforms data into compiled results). LCIM creates similar value of data, excluding visualization. Contribution to systemic development through usage pathway can be, for example, realized in company's ability to make better informed decisions about more sustainable materials and supply chain actors, or identify the most critical points of environmental burden along the product life cycle. Enabling consumers to make more sustainable purchase choices has obviously potential to effect on systemic change, but the result depends also on consumers' decisions.

Considering the circulation pathway, LCIM has more related activities than SoG due to the purpose of the tool. As a data inventory, it is targeted for storing, organising, merging, linking, and integrating data. Optimally it could also provide an open data sharing point, but within the current scope sharing and publishing are only performed among LCIM provider and companies. SoG functions as a melting pot for various type of data and provides results as a multi-criteria indicator. In data circulation pathway, SoG's impact is raising from merging, integrating, and organizing data, but also by sharing and publishing, as the assessment is aimed to be visible by the consumer products.

Regarding generation pathway, LCIM impacts through data generation, gathering and, selection. Data is collected, and simultaneously selected, from companies and secondary data sources. Companies' personnel may need to find or trace the required data, and this can be viewed as data generation, since the data has not been known before. Similar actions are required for SoG, and both instruments can impact on transition through generation pathway also by educating both data collectors and end-users, for example, of the dimensions and impacting factors of sustainability, data needs and improvement areas for companies' actions.

5.2. Identifying criteria for data source evaluation

Evaluation of connecting the two case study instruments depends on the potential relationship between them, meaning, there must assumingly be either one-way or mutual benefits of the connection. Based on the purposes of the instruments, one beneficial type of relationship is clear: LCIM, as an inventory tool, could serve as a data source for SoG, which as a sustainability assessment tool provides a method for presenting the result of assessment but does not necessarily contain the data. The results here are based on this relational assumption, and other possibilities are speculated in Discussion.

5.2.1. Requirement analysis results

The criteria for evaluating LCIM suitability for SoG data source was performed with utilizing requirement analysis, which, based on the literature (chapter 3.5), is suitable method for establishing and agreeing on the targets for system development process. Here, it is used for understanding and choosing three most critical requirements for determining the suitability of connection between SoG and LCIM. In this study's requirement analysis, the aim was to identify what needs SoG as a consumer targeted sustainability assessment instrument must fulfil and what needs it brings to this connection. Many of the identified requirements are in the background and impact indirectly as needs towards the data source. Requirement analysis was only considered as an assisting tool for providing analytical framework to follow, and it was performed mainly based on the literature collected for this study but combined with the information gained from the instrument developer interviews.

According to the framework, first, the key stakeholders and end users where listed, then the requirements of each of them were identified, and third, the requirements were categorized to understand more comprehensively what kinds of requirements there are. The compilation of results is presented Table 3. The key stakeholders and end users are society, consumers, companies, and developers. Three requirement categories, use case, functional, and system, were chosen purely based on what was considered descriptive. Use case requirements refer to SoG being a consumer targeted sustainability assessment instrument, which implies certain aspects, such as considering consumer needs and communicational issues, and the target of impacting on sustainable development. Functional requirements relate to the question how instrument should work, considering, for example, what results it is expected to provide and who uses it. System requirements have a wider meaning compared to functionalities, including bigger picture of the parts and actors around the connection.

Table 3. SoG related key stakeholders and end users, requirements, and requirement categories.

Key stakeholders and end users	Requirements	Category
1. Society Sustainable development	Data quality / FAIR principles	Use case
	Alignment with EU policies and guidelines	Use case
	Value creation efficiency	Use case
	Multidimensionality	Use case
	Flexibility for changes in assessment	Use case
2. Consumers Actionable information for purchase decisions	Trustworthiness	Use case
	Timeliness	Use case
	Tangible benefits	Use case
	Clarity and simplicity	Use case
	Informational	System/functional
	Appealing	Use case
	Utilization of new technologies	Functional/system
3. Companies Information for improving own processes and for providing information to consumers	Value-creation ability	Use case/system
	Information for sustainability actions	Use case
	Data content	Functional/system
	Trustworthiness of instrument	System
	Data quality	System
	Resource-wise achievable	System
4. Developers/ providers Guidelines for development of the instrument and rules for data processing	Data quality / FAIR principles	Functional
	Compatibility of data content and measuring logic	Functional
	Flexibility for changes in technical system	Functional
	Co-operation possibilities	System
	Functional system	System

The requirements from society provide a wider background for instrument development, and they all relate to enhancing sustainability, thus are derived, and can be seen as use case related. Instrument needs to create value for the society effectively, that is, turn data into information and be part of the knowledge creation as well. Multidimensionality is considered more beneficial for decision making than unidimensional methods, and flexibility for changes is required for being able to adjust assessment according to best knowledge available. Aligning EU policies, which are here related to the Green Deal and Digital Decade, is an important societal requirement as they are jointly agreed wider goals; policies guide and rule the cohesive development of data utilization and sustainability work in EU area. Instrument development must therefore, at least, fill the minimum requirements of policies, and even anticipate ahead, if possible, to gain momentum. EUs FAIR principles came up in literature in relation to advancing digitalization and data use, as well as improving the effectivity of sustainability assessment, and therefore those are requirements from behalf all the stakeholders.

Consumers are the targeted end user group of the SoG instrument, expected to receive actionable information for decision-making. Also, it may add their knowledge on the sustainability and what matters impacts on the sustainability level of a product. Consumer requirements are related to the effectiveness aspects of the assessment, most importantly, trustworthiness, ability to provide information, and timeliness. Other requirements, clarity and simplicity, tangible benefits, ability to appeal, and use of technology, are more related on how the information is provided in the instrument. Main part of the consumer requirements is derived from use case, only ‘informational’ and ‘utilization of new technologies’ belong to functional and system requirements, as they relate to serving information from the instrument.

Companies have twofold role: They both provide data for SoG and receive information from it. The location in the middle of the system is displayed in company requirements. Data content and quality are related to companies role as data provider. Receiver role sets requirements for the ability to create value, provide information for sustainability actions, trustworthiness and being achievable in resource-wise. Companies want SoG to bring them value by supporting their sustainability actions and potentially gaining them competitive edge for openly presenting their sustainability assessment results. Also, during the assessment process, also companies potentially have a learning experience and increase their knowledge of the sustainability efforts needed. This all is enabled with sufficient data content, and trust enhances commitment of all the stakeholders.

Developers/providers refer here to the party that is developing, implementing, and maintaining the instrument, although they might not be the one and same. Their interest is in implementing a system that creates most value and functions according to the users’ needs, therefore, requirements are related to system and functionalities. Important factors are also the co-operational potentials and practical realization between the developers/providers of data source and data use. Developing is guided by the FAIR principles, and compatibility of data and measuring systems is enabling factor for the connection between instruments. Flexibility for changes in technical systems improves the usability of the instrument and simplifies the development work.

Requirement analysis gave a wide setting of the needs and prerequisites, from many angles, that a consumer targeted sustainability assessment has. However, in relation to selection of data source, the main requirement is quite obvious, the data content. It enables the use of the source in the first place. Based on the literature (chapter 3.4.), data quality is critical for decision-making and other value-creation methods also. In the requirement list, data quality was presented as separate requirement, but it is also embedded in trustworthiness, which was mentioned more than once. FAIR principles as EU's data quality guidelines are therefore selected as the second criteria. Third criterion is not so directly from the requirement list, but more derived based on the understanding of sustainability assessments and their data needs built during the study. Methodological choices on the other hand are raised from the valuations and the target of the assessment, and on the other hand impact to the assessment data needs. At society level, the requirement for multidimensionality was listed, and this is prioritized, based on the purpose of the instrument, that, is, enhancing the sustainability and systemic transition. These three criteria are explained in more detail in the next chapter.

5.2.2. Evaluation criteria

The suitability of LCIM as SoG data source is evaluated based on the criteria drawn from the previously presented requirement analysis. These criteria are:

1. Data content
2. Methodological compatibility
3. FAIR principles.

Criteria is listed in order in which they are evaluated in following chapter. Prioritizing data content as the most important factor is quite obvious; connection to a data source is pointless if it cannot offer the data that is needed. Therefore, the primary objective is to analyse the data content first, and based on that, determine if the proposed data source is worth further investigation. Data content refers here only to identification of whether data is found or not in the data source, and not to the form, processing rules, accessibility, or other such factors. Also, distinct from data availability and relevance, data content evaluation does not consider the accessibility aspect or the amounts of data (abundant or low). Important aspect of this criteria is to evaluate what are the possibilities of adding the missing data into data source. If all the data is not already in the source, but is easily included, it might be still potentially useful.

Second criterion is methodological compatibility, which refers to the aspects of underlying valuation perspective and its derived impacts on data. Methodology defines the target of the assessment and gives frames to what is actually assessed and how, and furthermore, what changes and development efforts it enables and verifies.

Third criteria are FAIR principles which give framework for data quality and sharing objectives. These aspects are important from point of view of, for example, data value-creation, consumers' and companies' decision-making ability, and EUs pursue of data-driven transition. FAIR principles combine several of the identified requirements, for instance, trustworthy data, alignment with EU policies, and open data sharing possibility (from technical perspective). FAIR principles include data content evaluation (relevance), which was already considered as first criteria, but provides also much wider perspective, as was presented in chapter 3.5.

5.3. Evaluation of connecting SoG and LCIM

Connecting SoG and LCIM as data source and target are examined in this chapter. Results of the evaluation are based on the three main criteria identified in requirement analysis in chapter 5.2.2.

5.3.1. Data content comparison

Data content comparison is based on the comparison of full mapping of LCIM data content and SoG data needs (Appendix 2). SoG indicators and measures (Appendix 1) were analysed for defining the actual data need behind the measure. For instance, on minimum integration level the indicator in Materials phase of SoG includes statement “*Hazardous chemicals removed”.* This can be indicated with data that tells what chemicals are used or with a certification that proofs that no hazardous chemicals are used. Therefore, the actual data need here is “chemical [name]” or “certification”. Results of mapping are presented in Table 4, categorized to each SoG indicator category (green = match, yellow = partly match, red = no equivalent).

Comparison of data content of LCIM and the needs of SOG revealed that there is currently a big gap. The most representative data in LCIM are data related to Materials and Production phase indicators in environmental assessment section of SoG, whereas data for support services and social working condition indicators were almost non-existent. Information for some measures could conditionally be derived from LCIM, for instance, the length of the supply chain can possibly be determined by counting the number of companies related to the product. Some measures give multiple options for data and those are partly found. For instance, ‘verification of sustainability’ in Materials phase includes options of CO_2 emissions, water footprint or other, where at least the two first mentioned are included in LCIM currently. Regarding chemical use, LCIM input sheet includes dye and printing chemicals and certifications.

Table 4. Data content comparison.

Environmental - materials	Environmental - production	Environmental - support services	Social - working conditions
Material	Product	Product	Supply chain actor country
Country of the material	Product source (assembly)	Information on product care and maintenance	Supply chain actor address
Source of material	Certificate or qualitative report of waste and emission reduction efforts in main production facilities	Information on product repair	Supply chain actor name
Composition of material	Waste amounts / time (reduction efforts)	Information of spare parts or products available	Trade relation start date
CO2 emissions / water footprint / other verification of sustainability	Production method (e.g., production from order / optimized production etc.)	Maintenance & care service information	Verification of Code of Conduct
Chemicals used or certification of non-hazard chemical use	Number of unsold products	Repair service information	Third-party auditing
Waste-water purification information	Handling method for unsold products	Extended product warranty information	Factory visit proof
Air purification information	Cutting waste handling method	Information of mass-customization actions /custom fit services	Employee living wage verification
Product testing results, e.g., abrasion resistance, wash, or usage times, other	Chemicals used in finishing or certification	Additional product-service system information	Employee workload verification
Tests, footprints, length of supply chain etc. verification of the exceptional sustainability		Information of services to boost reuse	Employee working hour verification
		Information of services to circulate materials / repurpose the product	Employee work contract existence
		Information of taking care of the whole lifecycle of the product	

At this point, data equivalents are presented here only on a principle of availability/non-availability. Also, some of the identified data needs are on a robust level, e.g., ‘Additional product-service system information’. In this study purpose, it is not necessary to specify the actual data in more detail here (could be, for example, just a tick in a box “yes” or a link to a webpage where information is given) but just to acknowledge that this sort of data is missing altogether. Also, both instruments are still under development and changes are likely, and on the other hand, LCIM data model is developed to be flexible for data additions. Therefore, it is not meaningful for this study to concentrate on too specific details.

The result of the data content evaluation also showed that LCIM contains additional data that is not needed for the current indicators of SoG. These data are important to identify for analysing the potentials of LCIM data offerings. The results of this second data mapping are presented in Appendix 3. Some of the unmatched data is descriptive, such as names of the materials (company given), product brand and season, which have no direct purpose for the assessment but gives additional information and specification. Part of the data is collected for enabling more accurate selection of secondary data for LCA calculation, e.g., dyeing method, finishing method, and component type. Overall, these additional data do not seem to add important value from SoG perspective.

An important data issue that should be considered in connecting SoG and LCIM is the possible need for tracking the improvements. If there is a need to communicate the improvements of performance in SoG assessment, that also requires saving historical data. Currently, however, there are no such plans for SoG.

5.3.2. Methodological comparison

The main reason for the data content differences established in the previous chapter is instruments' methodological backgrounds: LCIM processes quantified environmental data related to the production of textiles, and SoG has wider perspective to sustainability assessment. Methodological choices impact on what is assessed and how, therefore, these aspects were compared, and the results are presented here. This evaluation is grounded on the identification of LCIM being based on LCA concept and SoG has strong circular economy framing combined with social dimension. The object of the assessment is same in both instruments, that is, the sustainability of a textile product, but, put in LCA terminology, the goal and scope differ, which results to inevitable differences.

First, the life cycle phases included are different. LCIM concentrates only on the production, from fibers to complete product ready for consumer use, and it considers end-of-life phase in terms of recyclability (gives option to choose from: biological, chemical, mechanical, pyrolysis, thermal and not known). SoG considers those same production phases but starts from product design and continues assessment to the product use phase and end-of-life (Figure 8). In both cases, packaging and distribution are excluded. SoG consciously emphasizes the circularity, and especially longevity of product utilization, which is seen in high representation of indicators related to support services, but also others, such as product durability. LCIM cannot support SoG with these data, according to the current scope of the tool.

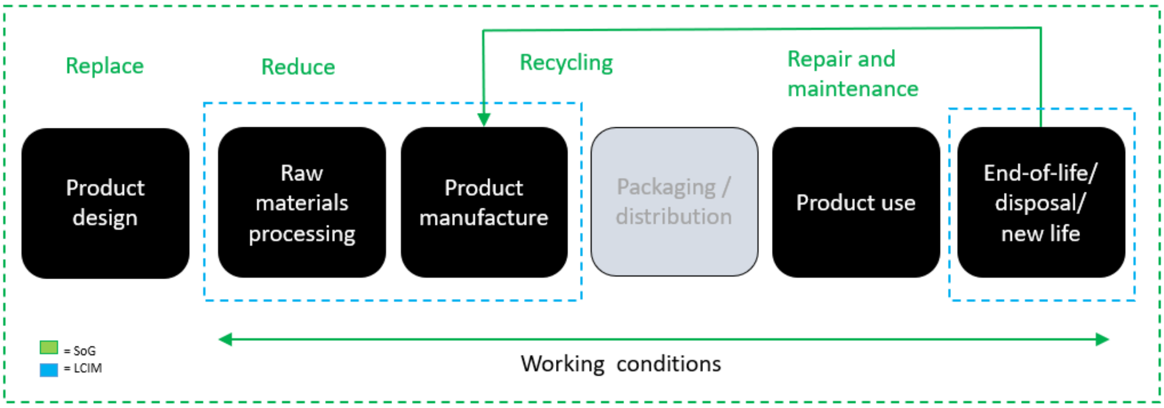

Figure 8. Methodological comparison and system boundaries of SoG and LCIM from life cycle perspective (adapted from Life Cycle Initiative, 2022b).

Second profound difference between SoG and LCIM is the use of qualitative and quantitive data. LCIM processes data and gives results quantitatively. Qualitative data is also collected, such as, type of fiber, dyeing method and finishing method, but the purpose of those is mainly to guide the selection of applicable secondary data for the calculations, and not to assess based on them directly. In SoG, however, there are a number of qualitative indicators and measures with different qualification systems, such as yes/no and choosing the better option, which demands ranking and rules for determining preferable option. For example, material selection is one case where better option is to be indicated. In SoG, at this point of development, this is considered as a moving target, where current material determines the better option, thus, not all the existing material possibilities are ranked to one list, but, for instance, organic cotton would be better choice that traditional cotton. However, implementing a ranking list is not completely ruled out; in the future it could possibly be done, and then “preferred” materials could be pointed out.

Regarding quantitative measuring, CO_2-emissions and water footprints are the similarity between the assessments, and those could create a natural and beneficial join for co-use of the instruments. In SoG, on the sustainability innovation level in Materials category, there is an indicator ‘*Innovative sustainable materials used OR no virgin materials used’* for which the intended measure is ‘*Material production has minimal negative environmental impacts’*. According to plan, company could verify this by disclosing qualitative/quantitative data on how the material choice reduce environmental impact. This data could contain, for example, the amount CO_2-emissions, water footprint or some other relevant information. LCIM, on the other hand, in the current scope, is aiming for calculating the CO_2-emissions and water footprint for the product, therefore, there could be a possible join between the tools in utilizing LCIM calculations for SoG verification. Estimated based on this study, this join seems possible, considering data content and form, and the methodological similarities in regard to production phase. This kind of co-use was presented beneficial in the literature (chapter 3.2.3), combining scientific LCA and strategic CE, where LCA can help verifying the positive impacts of CE strategies.

5.3.3. Considerations on FAIR principles

Following FAIR principles ensures that quality of data in the instruments is good and enables uniform usability of data in EU area. Each principle was evaluated separately, and the main points are collected to Table 5, considering LCIM from SoG needs perspective. Completeness was not evaluated, because the essential part of it is the metadata that is explanatory data for the actual data and is not in the scope of this study.

Table 5. LCIM suitability evaluated based on FAIR principles.

FAIR principles	Evaluation
Findability	
Completeness	Metadata evaluation in not in the scope of the study
Findability	Data privacy requirements effect on findability
Accessibility	
Accessibility/availability	Data privacy requirements effect on availability, case specific access
Interoperability	
Conformity/compliance	Clear data input instructions needed
Machine readability/processability	Clear data input instructions needed
Openness	Data privacy requirements may prohibit the openness
Reusability	
Timeliness	Depends on companies activity and secondary data updates
Consistency	Careful planning of joining data and clear instructions on data inputs
Accuracy	Human error risk high
Relevance	Data content evaluation results: low but development possible
Understandability	Important focus area for further development
Credibility	Impartial data source developer/provider is beneficial

Three main aspects can be drawn from evaluation of FAIR principles for more critical consideration. First, data privacy issues of LCIM contradict the preferred data source openness and findability of SoG. Due to LCIM data collection method, data of individual companies can be recognizable in the inventory, at least in the starting period when the collected data masses are not big yet. From SoG point of view, according to the findings from literature (presented in chapter 3.3.1), openness of data increases trust for the assessment, but companies' perspective might be different. It is probable that companies, if not all but many, object the openness of data in LCIM inventory for wider audience, where they themselves have restricted views only to their own data, too, for protecting their privacy. The data availability is one of the big questions that has been discussed in the SoG workshops with practitioners, and it has been concluded that publicly disclosed data would be preferable in some cases, but the future host (not known at this point) will make the decisions about whether the data (and which data) need to be publicly disclosed.

Second critical point is also related to the data collection, namely, the risk of false or incorrect data, that can result from multiple reasons from human error to deliberate embellishment. Of FAIR principles, conformity/compliance, machine readability/processability, consistency, and especially accuracy, are at risk due to human data input. Some of the risk can be diminished with very clear and specific instructions for data input, but data verification imposes a big challenge regarding LCIM use. Similar risks are related to SoG use, too, in case it is used as self-reporting tool by companies, which is most likely option in the early phase of instrument implementation. Thirdly, the utilization processes must be clearly defined, compatible, and agreed, to avoid problems related to data updates, data utilization (data and calculation definitions), or change handling, for instance.

Currently, as the development of LCIM is still in the early phase, the evaluation of given instructions and usability of the tool is not appropriate, and those are not addressed at this point. Instead, those are only raised here to acknowledge their importance. Considering the LCIM data collection method, which was just presented as somewhat unreliable, there is a positive side too. It is self-determined, and data collection can be changed according to observed needs, which gives flexibility to the utilization of the tool. Also, consumers are likely to perceive LCIM as more trustworthy source due to it being developed by impartial organization, compared to commercial one.

5.3.4. Actions improving compatibility

The three-criteria evaluation of connecting LCIM to SoG, in the capacity of data source, revealed that there are actions needed for increasing their compatibility. In short, the first steps needed are:

- Adding more SoG relevant data content to LCIM.
- Defining data processing rules of measures especially related to qualitative indicators.
- Dealing with the data privacy dilemma and agreeing on the solution.
- Taking actions to improve the reliability of data (data verification).

The first mentioned would require changing the scope of LCIM but would not prevent implementing the original functionalities too. Data inventory would only be wider. Data privacy and verification are assumably the most complicated ones to solve.

6. DISCUSSION

In Discussions, aspects related to the connecting of instruments are first elaborated. Second, the current situation of instrument development is presented, and then the speculation of the possible development paths for SoG and LCIM, both individually and together. Closing theme for this study is the discussion of the importance and utilization trends of sustainability assessment instrument in the bigger picture.

6.1. Additional aspects to connecting SoG and LCIM

Connecting SoG and LCIM includes challenges, as seen in the chapter 5, but it also has potential benefits. In addition to those presented previously, several other considerations of the challenges and possibilities can be drawn from connecting variety of aspects presented in this study.

In a wide sense, on societal level, SoG and LCIM have same prevailing target, to enhance transition towards sustainability in textile sector, and they are guided by the same EU policies. These aspects support the connecting and co-use, as the common aims and similar challenges could benefit from sharing knowledge and resources. Co-development and use of the instruments could bring synergies in resource use, and thus enhance development of data-driven sustainability transition more effectively, in comparison to two totally separate instruments. For example, the data collection could be the common ground to start co-developing. Data content was not a big match yet, but adding data that SoG needs, could enable new use cases for LCIM, thus, be beneficial for both in that way too. Connecting data collection could benefit the companies using the instruments also. Assumingly, the potential SME users are same for both instruments, and therefore connecting would bring them benefits in making their work easier; one data input place for two instruments could provide more support for their sustainability development efforts with less work. Also, consumers would get more information with one combined assessment.

Co-use of these two assessment instruments can also be beneficial from the methodological perspective. The current trend in sustainability assessment development is towards combining methods, which enable more comprehensive understanding of the sustainability level of the product and allow better informed decision-making. Therefore, combined, SoG and LCIM could be interesting and advanced type of assessment. Also, developing of hybrids on quantitative and qualitative methods was suggested in literature (chapter 3.2.3) due to difficulty and costs of data collection. Those could be proponents for co-development in this case too. However, a careful plan should be made, including technical issues of connecting, before advancing. Although joint data collection can be cost effective, it might also include some issues, too, if not planned well.

6.2. Instruments’ future potentials in enabling systemic transition

First, there is a short glimpse to the instruments’ current situation, presented to lay ground for the next chapter, where the possible future development paths are speculated.

6.2.1. Current situation of instrument development

Both Shades of Green and LCIM are still being developed and there are likely to be changes to what has been presented here as their present content. Instruments are only taking their early steps, and future is somewhat open.

Considering SoG, development work continues with three steps. Firstly, preparation of clear instructions for companies on how to answer the measure questions is on the list. Secondly, instrument needs more testing and both larger amount and variety of different kinds of companies for creating wider understanding of the instrument in use. In the early testing the companies have mostly been Finnish and sustainably well-performing, and as development goes on, more heterogenous testing is in scope. Thirdly, the information of what is learned, and knowledge gained during the SoG development is provided for the cases similar to SoG. In addition to these three steps, discussions about the indicators, measures and their operationalizing continue, since it is not easy or straightforward to define them in practical level or draw lines, for instance, between advanced integration and sustainability innovation level. Also, searching of a host for taking over the instrument is going on. However, one option is that SoG works as a self-reporting tool for companies and assist independent internal assessment and development work. (Turunen, online interview 4 May 2022).

LCIM is also in the middle of development still and the future is open at the moment. Currently the data model is being remodelled by an outsider company. Target is to create more flexible and changeable structure that allows easier development in the future. After that, the next step would be developing the actual tool out of this "proof-of-concept" version. Possibilities for collaborative opportunities with other organizations are being planned but still open and realization is unsure. Participating EU data infrastructure project GAIA-X as an example of use-case and collaboration with Finnish Textile and Fashion related to digital product passports are some options (Koskinen, online interview 10 May 2022).

6.2.2. Potential future development paths

Both Shades of Green and LCIM have a lot of potential to become an essential and complementary part of Finnish textile sector. There is certainly a need for both of them, and drivers supporting their development exist, but there are also challenges that may endanger their growing to their potentials.

LCIM is definitely on a potential path towards becoming an important addition to fulfilling the data needs in Finnish textile sector. Currently its data collection scope includes some part of the three (out of four) categories of data needs listed by VTT (chapter 2.3.1), including the data of origin, consumer product data, and recycling and material loops data. In the future, very advantageous development direction would be including more of those data needs into this same inventory, to strengthen its position as a single data storage and source for various purposes. Assumingly, concentrated data storage would be both resource efficient to build and easier for enabling the conformity and consistency of data. Larger variety of data would also enable wider data utilization possibilities, thus, enable more value-creation options and have more potential to impact on systemic transition.

However, this kind of future would require solving the data privacy issue for companies, especially. Among EU policies presented in this study (chapter 2.4), there was EU Data Act, which might bring some solutions, as it aims at creating comprehensive rules for data generation and utilization across EU with target of ensuring fair and competitive data availability and accessibility for variety of use cases and users. As one detail, Data Act also considers the negotiation power of SMEs and preventing risks of anyone taking advantage of them. This is important aspect for LCIM, where the targeted company users are SMEs.

Another opportunity for LCIM is to include Digital Product Passport (DPP) to the scope. The content of DPP is still open regarding textiles, but speculatively, it will provide an important tool for information transfer between the stakeholders along the textile supply chains, which is currently lacking, and enable improved assessing of textiles' sustainability. If these data could be stored and utilized in LCIM, instruments assessing capability would increase. Simultaneously other possibilities for data utilization could also increase along the larger variety of data, and potentially even new co-use opportunities for SoG and LCIM, with improved data openness and verification.

For SoG separately, the potential future paths are fewer in sense of functionalities, as it is more specifically targeted instrument, and, currently, with no known host. The future host plays a big role in determining the development paths. For instance, specifying the final structure and measures are at the hands of the host. Also, the decisions regarding the implementation determine what kinds of potential paths instrument have. It might be anything from a self-reporting tool for companies to an internationally used assessment instrument. One possibility is that SoG will carry on in the work of other organizations through the information and knowledge shared of its development process.

Currently, there seems to be no similar consumer-targeted sustainability assessment instrument, with focus on product level and filling the needs of SMEs. For example, Good On You, claiming to be "the source for fashion's most trusted sustainability ratings", considers the impacts for the whole life cycle, evaluates 500-plus data points across more than 100 key issues, but the rating (on a scale from We avoid to Great) is at brand level

(Good On You, 2022). Also, Re-Make (2017), which is an Australian non-governmental organisation, performs brand level rankings. They score brands based on six categories, which are traceability, wages and wellbeing, commercial practices, raw materials, environmental justice and climate change, and last, governance, diversity and inclusion. Re-Make also ranks SMEs.

7. SUMMARY

In the centre of this study was two sustainability assessment instruments, Shades of Green and LCIM. Shades of Green is a consumer targeted sustainability assessment instrument with environmental and social dimensions, where emphasis is on circular economy and longevity of a product. LCIM is a life cycle inventory management tool, which has target of collecting and storing comprehensive data of textiles into a single database and enable easily achievable environmental assessment for SMEs.

Textile sectors environmental and social issues demand for systemic solutions in order to enhance the sustainable development targets. Digitalization and data utilization enable sustainable transition though the data-enabled transformation pathways of usage, circulation, and generation, and that are realized with data value-creation actions. Shades of Green and LCIM both enable multiple data value-creation methods, which realize the data-enabled transformation pathways of usage, circulation, and generation, and help in solving known systemic issues. Therefore, instruments have potential power to impact on systemic change in textile sector.

The most important criteria regarding connecting SoG and LCIM, considering LCIM as a data source to SoG, were identified with requirement analysis and are the compatibility of data content, the compatibility of methodology, and application of FAIR principles. Based on the evaluation, LCIM data content is only partly relevant, mainly due to methodological differences. Methodological differences effect on considering different life cycle phases in the assessment, and difference in accepting qualitative and quantitative indicators, but also common ground for joining instruments was found in both having CO_2 emissions and water footprints included. This could enable LCIM use for SoG indicator verification. Considering FAIR principles, main issues relate to varying perspectives of data privacy and openness of SoG and LCIM, data verification issue, and having agreement on data management.

There are many potential development paths for the instruments, both separately and jointly, as especially combined methods are growing interest. EU policies, such as Data Act, Digital Product Passport, and Green Deal, can be significant drivers, guiders, and enablers of development.

8. CONCLUSIONS

Sustainability assessment has grown interest in past years and that tendency seems to continue. Current sustainability assessment methods have their shortages, but the importance of sustainability assessments is clear. We need organized and verifiable means for assisting informed decision-making regarding both the development of sustainable production and consumption. New digital technologies create constantly new possibilities to improve the accuracy of assessments, and methodologies improve in their ability to represent the reality in understandable and concise ways. Also, the amount of data has increased over the decades dramatically, yet there are shortages for some, and the data flows are not directed efficiently to their use points. The data collection and sharing methods are being developed intensely by many actors as the joint understanding exists of the need for it, but many challenges are still to overcome, especially in ensuring fair and competitive data utilization for various users.

The current era of digitalization demands for more knowledge of the potentials of data and ways in which it impacts. This study added to the understanding of systemic transition with data. One of the main targets was to establish how data of the case sustainability assessment instruments enhance the systemic transition, and the connection was found. The impact on transition depends on what and how much value from data can be created and turned into actions assisting in systemic needs. Data-enabled transformation pathways are at the background of the transition. This theoretical interpretation could support in establishing the importance of different data products and in finding alternative ways to add that potential, but further study is required, as the scope of this thesis was not in performing a deep analysis on the topic.

Creating solutions to complex systemic problems requires innovative solutions and efficient resource use. From these viewpoints, connecting SoG and LCIM would be highly desirable, and although the result of this study implied big challenges there, it also gave a direction for the next research path, that is, to investigate more closely on the development of combined assessment. CE based method and LCA together could present wider view on the sustainability of products, than each of the methods separately, and generating implementation of such method would benefit the target of Finland becoming world leading in sustainable textile production.

In conclusion, in this overwhelming crossfire of urgent messages regarding current and future sustainability hazards, we must concentrate on utilizing the assets and means we now have, in the best possible way, while innovating new and improved solutions. Even the instruments presented in this study have many challenges to solve, going forward is more important than perfection. There are no easy answers to systemic problems, and perfect solutions are neither realistic nor achievable, therefore, improvements to what has been done are always a small win and a way to right direction.

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Shades of Green indicators and measures

Environmental: Materials (draft version from fall 2021)

Phase	Indicator	Measure
Minimum integration	Materials replaced with less harmful alternatives	
	Material production in low-risk countries	*(if relevant – please, justify)*
	If material production is not in EU area…	Activities for wastewater purification for main production facilities has been applied Activities for air purification for main production facilities has been applied
	Material does not contain hazardous chemicals	*(choose all that apply)* Material has Öko Tex certification No hazardous chemicals used in material production No hazardous chemicals used in finishing stage of the production
Advanced integration	Use of materials already in the cycle or post-use for material planned once the product is discarded	Substantial use of recycled fabrics / fibers in the product Substantial use of leftover fabrics / fibers in the product
	If made of virgin material, the environmental aspects of the material are exceptionally sustainable	Specify why the material is regarded exceptionally sustainable, e.g. tests, footprints, length of supply chain…
Sustainability innovation	Innovative sustainable materials used OR no virgin materials used	Material production has minimal negative environmental impacts (The company discloses qualitative /quantitative data on how the material choice reduce environmental impact (CO_2, water footprint, etc.)
	Long-term quality and durability of the material is justified	Information on the expected lifetime in the relevant use context available, e.g. abrasion resistance / product testing results / wash or usage times The end of life has been taken into account

Environmental: Production (draft version from fall 2021)

Phase	Indicator	Measure
Minimum integration	Production-related waste and emissions follow the climate laws and policies in EU	• The product is made in EU • If production is not in EU area, the production related waste and emissions are examined and actions for reduction in main production facilities has been applied (certificate / qualitative report)
Advanced integration	Constant improvement in material efficiency (choose all that apply)	Information that details waste minimization during production is provided (material efficiency in terms of this product)
	Material production -related (tier 2) pollution, emissions and waste follow the climate laws and policies in EU	• The material is produced in EU area • If material production is not in EU area, the production related emissions (to air, water & soil) as well as waste are examined and actions for reduction in main production facilities have been applied (certificate / qualitative report)
Sustainability innovation	Near zero waste production	• No over-production (e.g., production from order / optimized production etc.) • Unsold products will be recycled / remanufactured / repurposed • No cutting waste (or cutting waste will be recycled / remanufactured / repurposed)

Environmental: Support services (draft version from fall 2021)

Phase	Indicator	Measure
Minimum integration	Care and maintenance information and guidelines offered to support the longevity and product's usability	• Availability of information or guidelines on product care and maintenance • Availability of information or guidelines on product repair • Spare parts or products available that enable easy repair and/or care
Advanced integration	Services to extend the lifecycle and/or to boost the usage times of the product (Combination of 1-5)	• Maintenance & care services • Repair services • Extended product warranty • Mass-customization actions /custom fit services
Sustainability innovation	Product-service system that keeps the garment in long-term use / cycle (Choose all that apply)	• Full-fledge set of the services, such as leasing/renting, take-back or the like • Services to boost the reuse by new customers (e.g., second-hand) • Services to circulate the material / repurposing the product at the end of its lifecycle • Company takes care of the whole lifecycle of the product

Social: Working conditions (draft version from fall 2021)

Phase	Indicator	Measure
Minimum integration	Transparent and decent working conditions in apparel manufacturing phase (tier 1)	• Address of the direct (tier 1) supplier publicly disclosed • Long-term trade relations preferred. Specify when the trade relation started. • Information of the supplier (factory name, address) is offered in product-specific manner. • Manufacturing / garment production in low-risk country • Code of Conduct & third-party auditing OR factory self-visited • Human rights performance across its tier 1 suppliers has been actively monitored. No human rights violations: supplier Code of Conduct to ensure all basic standards & workers' rights* in the manufacturing phase. • The regional living wages of the manufacturing phase have been examined and compared to local living standard • The workloads and working hour distribution have been examined and compared to local standards. No constant and excessive overwork. • The company requires supplier to offer workers formal contracts, including when subcontracting to homeworkers
Advanced integration	Transparent information and assurance of decent working conditions in the manufacturing phase (tier 1) and main material production phase (tier 2).	• Producer and production location and information in terms of fabric manufacturing (name, address, country, starting year of trade relation) exist. Information is product specific. • Material production in low-risk country • Code of Conduct & third-party auditing OR self-visited material production factory (/factories if multiple materials in the product) • Human rights performance across its tier 2 suppliers has been actively monitored. No human rights violations: supplier Code of Conduct to ensure all basic standards & workers' rights* in the material production phase. • Wages in the material production phase comply to the regional living wages standard • The workloads and working hour distribution are in line with the local standards. The material production phase, no constant and excessive overwork.
Sustainability innovation	Transparency and assurance of socially responsible working conditions throughout the product supply chain (tier 1-n)	• Names & addresses of the suppliers throughout the product's supply chain reported (from field/lab to finalized product) • Decent working conditions ensured throughout the supply chain

*No child labor, no bonded labor, no forced labor, safe workplace, freedom for association, right to collective bargaining.

Data content comparison of SoG data requirements and LCIM equivalents

	SoG data needs	LCIM equivalent
E	Material (/ fiber / component)	Fiber / component / material
E, S	Country of the material (/fiber/component)	Company location
E	Source of materials / fibers	Fiber: Fiber source OR component: Source of recycled input
E	Composition of material	Percentage (of fibers or components)
E	CO2 emissions / water footprint / other verification of sustainability, both current & trend	CO2 emissions Water consumption Energy consumption
E	Chemicals used	Material level: Dye stuff, printing stuff Component / material level: certification
E	Certifications	Certification (component or material level)
E	End-of-life / recyclability information	Product: recycling method
E	Production method	*not available*
E	Handling method for unsold products	*not available*
E	Waste amounts / time (development trend) during production	*not available*
E	Waste handling method	*not available*
E	Waste-water purification information	wastewater treatment as "open box"
E	Air purification information	*not available*
E	Abrasion resistance / product testing results / wash or usage times / other	*not available*
S	Trade relation start date	*not available*
S	Verification of Code of Conduct	*not available*
S	Third-party auditing	*not available*
S	Factory visit proof	*not available*
S	Employee living wage verification	*not available*
S	Employee workload verification	*not available*
S	Employee working hour verification	*not available*
S	Employee work contract existence verification	*not available*
E, S	Supply chain actors' country	Company location
S	Supply chain actors' address	*not available*
E, S	Supply chain actors' name	Company
E, C	Information on product care and maintenance	*not available*
E, C	Information on product repair	*not available*
E, C	Information of spare parts or products available	*not available*
E, C	Maintenance & care service information	*not available*
E, C	Repair service information	*not available*
E, C	Extended product warranty information	*not available*
E, C	Information of mass-customization actions /custom fit services	*not available*
E, C	Additional product-service system information	*not available*
E, C	Information of services to boost reuse	*not available*
E, C	Information of services to circulate materials / repurpose the product	*not available*
E, C	Information of taking care of the whole lifecycle of the product	*not available*

E = environmental, S = social, C = circular economy. ID's are for grasping a rough idea of the data in different dimensions, and it is acknowledged here, that some of the data could be included in other dimensions, too.

Identifying additional data content potentials of LCIM for SoG

LCIM	SoG Environmental: Materials	SoG Environmental: Production	SoG Environmental: Support services	SoG Social: Working conditions
Fibers				
Fiber name				
Fiber material	x			
Production company name				
Production company location	x			x
Percentage (amount of fiber in component)	x			
Components				
Component name				
Production company name				
Production company location	x			x
Component type (knit/woven/non-woven)				
Is recycled (don't know/yes/no)	x			
Source of recycled input	x			
Source of fiber	x			
Certification	x			
Percentage (amount of fiber in component)	x			
Materials				
Material name				
Material trade name				
Production company				
Production company location	x			x
Material weight				
Material description				
Structure				
Colour				
Colour code				
Pattern				
Dyed (yes/no)				
Dyeing method				
Dyeing stuff	x			
Printed (yes/no)				
Printing method				
Printing stuff	x			
Finishing	x			
Certification	x			
Percentage (amount of component in material)	x			

LCIM	SoG Environmental Materials	 Production	 Support services	SoG Social Working conditions
Assemblies				
Name				
Products				
Name				
Brand				
Company name				
Company location	x			x
SKU				
GTIN				
Season				
Product category (accessories/clothing/footwear/workwear)				
Product type				
Product weight [g]	x	x		
Finishing	x	x		
Recyclable	x	x		
Production steps *(in each product phase: fiber/ component/ material/assembly/ product)*				
Production step company				
Production step location	x	x		x
Production date				
Means of produced energy	x	x		
Energy consumption [kW/h]	x	x		
Water consumption [l]	x	x		
Water waste-treatment	x	x		
CO2 emissions [t/CO2 eq.]	x	x		

In the table columns Production and Support service are coloured grey to indicate that data regarding fibers, components, materials, and assemblies do not relate to these categories, and only the consumer products are related.