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Measuring sustainability in manufacturing value chain

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Summary

Sustainability is a key driver and challenge for the manufacturing industry in the 21st century. Manufacturing companies face increasing demands and expectations from various stakeholders, such as customers, investors, regulators and society, to improve their sustainability performance and contribute to the global sustainable development goals. Sustainability encompasses the environmental, social and economic dimensions of the impacts and benefits of manufacturing activities, products and services.

Sustainability management requires a holistic and systemic approach that considers the entire value chain, from raw material sourcing to end-of-life management, and interactions among the actors and stakeholders involved.

To effectively manage and improve sustainability, manufacturing companies need to measure and monitor their sustainability performance and value. These functions require the identification, collection and analysis of relevant data and information on sustainability impacts and benefits, as well as the use of appropriate indicators and metrics to communicate and report them. However, measuring and reporting sustainability are not straightforward tasks. Many challenges and gaps hinder the availability, reliability, comparability and usability of sustainability data and indicators. Examples include the lack of clear and consistent sustainability definitions and frameworks, standardised and comparable indicators and metrics of sustainability performance and value, and adequate methods for measuring sustainability. Additionally, there are difficulties in integrating and aligning sustainability goals and indicators across all value-chain actors.

This white paper aims to address these challenges and gaps and to provide an understanding of and guidance for measuring sustainability in the manufacturing value chain. This paper is based on the research findings and publications of the projects Towards Transparent and Sustainable Value Chains (GG_Sustis2023, funded by VTT Technical Research Centre of Finland), Sustainable Data-Based Business for Manufacturing Industry (DataAsset, funded by VTT Technical Research Centre of Finland and Business Finland), Prestudy for Optimization for Extended Sustainability Requirements (PreOptimi, funded by the Finnish Innovation Fund Sitra) and Kestävän kehityksen Nyrkki (Sustainability First) workshops. This paper focuses on the research findings on the wood-fibre-based value chain, obtained from a literature review, stakeholder interviews and workshops, covering the following topics:

- the background of and drivers for measuring sustainability in the manufacturing industry, focusing on the wood-fibre-based value chain;
- the sustainability data in the value chain;
- the sustainability key performance indicators (KPIs) in the value chain;
- the Scope 3 emission calculation as a more detailed example of a sustainability KPI; and
- the conclusion and future research topics on measuring sustainability in the manufacturing value chain.

This white paper is intended for manufacturing companies that want to improve their sustainability management and reporting, as well as for researchers, policymakers and other stakeholders interested in the topic of sustainability measurement. The paper provides practical information, examples and models for measuring sustainability, as well as insights for future research and development.

The authors thank all parties behind the GG_Sustis2023, DataAsset, PreOptimi and Kestävän kehityksen nyrkki projects, the company representatives participating in the discussions and the researchers involved in the previous joint publications (Rantala et al., 2022, 2023, 2024) under these projects.

Tampere, Wednesday, 24 April 2024

The Authors

Content

I. Introduction

This white paper aims to provide insights and guidance on measuring sustainability in the manufacturing industry, using the wood-fibre-based value chain as an example. It is based on several research projects and publications and reflects the researchers' expertise on the topic of sustainability measurement.

The paper consists of the following chapters:

- I. Introduction – describes the paper's content and chapters
- II. Background – explains the drivers and challenges of measuring sustainability, especially in the wood-fibre-based value chain, and describes the main processes and actors involved
- III. Sustainability data in the value chain – discusses the types, sources and uses of sustainability data (e.g., Scope 3 and Life Cycle Assessment [LCA] data)
- IV. Sustainability KPIs in the value chain – presents the key performance indicators (KPIs) that are relevant for measuring and monitoring sustainability, from both supplier and customer perspectives, and analyses their benefits and challenges
- V. Scope 3 emission calculation – provides a detailed example of a sustainability KPI, namely the Scope 3 emissions, which cover the indirect emissions from the upstream and downstream activities of a company
- VI. Conclusion – summarises this paper's main findings and messages and highlights some future research topics and directions for enhancing sustainability measurement

II. Background – why measure sustainability

Drivers for measuring sustainability

Companies are adapting different goals related to the three pillars of sustainability – environmental, social and economic. Sustainability and corporate responsibility efforts consider biodiversity and natural capital, climate change aims, risk management and overall social responsibility. Measuring and reporting them is driven by multiple factors, such as third-party reporting certifiers, investors and other stakeholders, and directives set by the European Commission. Two examples of the European Commission's directives are the Corporate Sustainability Reporting Directive (CSRD) and the upcoming Corporate Sustainability Due Diligence Directive (CSDDD).

External pressure on companies to pursue sustainability is driven by investors, customers, stakeholders, certifications and the European Commission. Companies can also face internal pressure from their own goals and strategies towards sustainability.

Sustainability reporting is a form of transparent communication from companies to their stakeholders. The CSRD aims to strengthen companies' sustainability reporting based on European Sustainability Reporting Standards (ESRS). One aspect of the reporting is a third-party verification by an accredited certifier who assesses the materiality and reliability of the reported data. The digital reporting model aims to enhance the usability of sustainability data. It improves the accessibility and practical utility and ensures the accuracy of sustainability data. The CSRD incorporates the concept of double materiality, which involves integrating both financial targets and societal impacts. Companies are not only required to report how sustainability issues may pose financial risks but also to disclose their own impacts on people and the environment. This dual perspective emphasises a comprehensive approach to sustainability reporting that considers both the company's vulnerabilities and its contributions to broader societal wellbeing and environmental sustainability (European Union [EU], 2022a).

The CSDDD concerns large companies' aims to develop their responsibility to include human rights and environmental considerations in corporate governance and operations. It includes rules on companies' obligations to take appropriate measures to minimise their value-chain activities' actual and potential adverse impacts on the environment and human rights. It covers the companies' upstream business partners and partially, the possible downstream activities, such as distribution or recycling (EU, 2022b).

The EU Taxonomy Regulation is a classification system that sets four-step criteria that an economic activity must comply with to be qualified as environmentally sustainable. In the criteria, one of the environmental objectives must be met, and the activity must not cause harm to the other objectives. The objectives are climate change mitigation, climate change adoption, sustainable use and protection of water and marine resources, transition to circular economy, pollution prevention and control, and protection and restoration of biodiversity and ecosystems (EU, 2020). The EU Taxonomy is a tool for making contributions to the mentioned objectives. The European Commission has published delegated acts under the EU Taxonomy to list actual environmentally sustainable activities. Such examples are the Climate Delegated Act in 2021 and the Environmental Delegated Act in 2023 (EU, 2023a, 2023b). The taxonomy also encourages companies to meet the defined criteria in new projects. Investors can access more comparable and reliable sustainability information by utilising the taxonomy (EU, 2020).

The sustainability assessment framework selection, which can be considered one point of view for selecting the sustainability metrics, is identified as one key challenge in the study conducted by Hanski et al. (2024). The study focused on how sustainability was considered and how it affected the product design in manufacturing companies. The case companies acknowledged the

relevance of considering sustainability aspects (e.g., customer needs, material savings, possible extensions of the product lifecycle, and recyclability) as early as the design stage. The relevant aspects define the metrics and KPIs that have to be used in the sustainability assessment and then in the sustainability reporting. Product design can also be supported by sustainability reports and rating services, which create more comprehensive consideration for sustainability.

According to Korin (2024), manufacturing companies currently utilise their sustainability ratings and certificates mainly for communication purposes, such as enhancing their reputation, attracting customers and investors and meeting stakeholder expectations. However, some companies also use them for internal purposes, such as identifying improvement areas, benchmarking their performance and integrating sustainability into their strategies and operations. Some companies also face challenges in selecting and comparing different ratings and certificates due to the lack of transparency, consistency and comparability of the available tools. Sustainability ratings and certificates can support decision-making and incorporating sustainability into business development by providing valuable information, feedback and recognition of the companies' sustainability efforts. They can also help the companies improve their sustainability performance, enhance their competitive advantage, foster innovation and contribute to the global sustainability goals. However, some companies encounter barriers and difficulties in utilising these tools effectively, such as resource constraints, resistance to change, lack of training and knowledge, and insufficient stakeholder awareness and engagement (Korin, 2024).

Environmental and social sustainability in the company context can be referred to as corporate responsibility or corporate social responsibility. Environmental sustainability considers the use of raw materials and resources, such as energy and water, waste production, recycling and emissions. Corporate social responsibility often covers the topics of employment and wellbeing, ethics, working conditions, and social responsibility of the supply chain and other stakeholders. The economic dimension of sustainability is often overlooked when discussing sustainability. A positive economic sustainability impact can be created by resource savings and risk management. Sustainable operations consume less energy, water and other raw materials. Operational conditions and continuity of organisations can be established by risk management, which can include the avoidance of disturbances and accidents, as well as the prevention of numerous complaints linked to the firms' operations and financial risk management (Rantala et al., 2022, 2024).

Figure 1 presents sustainability and its dimensions as a nested model, where environmental sustainability covers the aspects of social sustainability and economic sustainability, which are both inside it. The different coloured circles illustrate how sustainability measures cannot be strictly divided into categories.

Sustainability measures for each dimension – environmental, social and economic – can overlap and are often related to each other in one way or another.

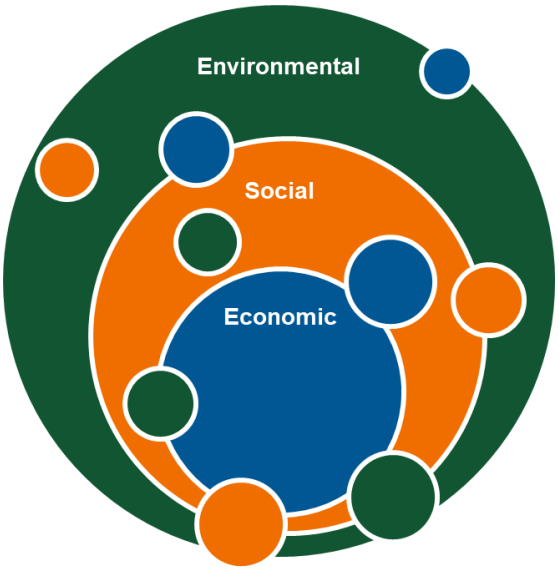


Figure 1. Sustainability dimensions as a nested mode.

The starting point for measuring sustainability is choosing the right indicators based on the selected sustainability criteria. The most influential and relevant indicators are identified by comprehensively examining the entire process. In practice, this selection process occurs in the context of the materiality analysis applied to industrial processes. In the same way, sustainability cannot be considered as a single aspect but as a whole, taking into account its environmental, social and economic dimensions, as well as sustainability KPIs. It has been suggested that sustainability KPIs encompass internal processes, learning and growth, customers, and environmental, social and economic aspects.

According to Neri et al. (2020), financial KPIs focus primarily on metrics related to investment returns and sales and assets returns, while internal processes may concentrate on activities such as recycling, certification and supply chain cycle time. In terms of learning and growth, the emphasis extends to labour efficiency and the use of new technology, among other things. Customer-related aspects include elements such as market share, customer satisfaction, product quality and delivery reliability. Environmental KPIs cover metrics related to energy consumption, water use, material use and overall environmental impacts. Finally, social indicators shed light on aspects such as community relations, employee satisfaction and safety measures, providing a holistic framework for evaluating sustainability (Neri et al. 2020).

In addition to drivers of sustainability, there are other possibly contradicting external and internal pressures or interests. These conflicting interests cause tensions, which may disturb operations and hinder the achievement of any goal (see, e.g., Schad et al., 2016; Smith & Lewis, 2011). Since the function of KPIs is to cover all the different key performance areas of an organisation, they inevitably include contradictions; improvement in one indicator may be related to reduction in another. To cite a simple example, actions to improve environmental performance may incur costs, which cuts profitability. Of course, such actions may also promote increased sales and thus, higher profits. When setting and using KPIs, it is important to understand their connections and contradictions in different actions. Such understanding enables a truly balanced management. The following quotation from an interview with a company representative clarifies the sustainability-related connections and contradictions from a corporate perspective:

> **"Our Own operations are constantly optimised. Costs are a good driver, because, in principle, waste and materials are reduced. But sustainability also brings a new perspective to this. For example, you can reduce the weight of a product if steel is replaced with aluminium, but the environmental impact of aluminium is worse than that of steel. In other words, even if the product is heavy, it can still be better for the environment."**

Sustainability in wood-fibre-based value chain

Sustainability management in the manufacturing value chain involves not only the manufacturing processes but also the upstream and downstream activities, such as material sourcing, logistics, distribution and end-of-life management. Therefore, manufacturing companies need to collaborate with their suppliers, customers and other stakeholders to address the sustainability issues and opportunities along the entire value chain. For example, they can adopt sustainable procurement practices, such as selecting suppliers based on environmental and social criteria, using renewable or recycled materials and reducing packaging and transportation. They can also implement eco-design principles, such as designing products that are durable, repairable, reusable and recyclable and have minimal environmental impacts throughout their lifecycles. Furthermore, they can offer circular services, such as product leasing, sharing, refurbishing and remanufacturing, and facilitate the collection and recycling of used products. By integrating sustainability into the value chain, manufacturing companies can create value for themselves and their stakeholders, while contributing to the global sustainable development goals.

An increasing number of consumers and investors are becoming environmentally conscious or aware about sustainability issues and how to minimise their own impact through informed consumption decisions. Such awareness creates pressure for companies in addition to those from legislation and transforming industries. Manufacturing companies face several challenges in pursuing sustainability goals. There are difficulties in obtaining data from the value chain, the data may have poor quality, and interoperability issues exist. These aspects may prevent effective data management and integration across the value chain. Measuring and quantifying sustainability are challenging as well.

The forest-based sector has changed significantly in the 21st century, contesting the traditional term 'forest industry', which covers the pulp and paper industry, the wood products industry and forestry (Näyhä et al., 2015). New technologies and innovations have enabled the production of novel products and services from forest biomass, such as bioenergy, textiles, nanomaterials and biocomposites, which have applications in various industries and sectors. Sustainability has long played a significant role in the operations of the Finnish forest sector. For over 100 years, Finland has followed the development of forest resources. The National Forest Inventories (NFI) collects and measures a wealth of qualitative and quantitative data on forests, biodiversity and vitality (Finnish Forest Association, 2021).

> **In this white paper, the authors use the term 'wood-fibre-based value chain' to refer to the production of goods made of wood-fibre raw materials, from forest to consumer products, and including the main processes involved, such as harvesting, pulping, paper/board manufacturing and converting wood fibres into various finished products.**

The wood-fibre industry has been chosen because responsibility and biodiversity are very important and topical aspects for the interviewed representatives of the case companies. Renewable materials, deforestation and carbon sinks feed the debate in the field. The wood-fibre industry is under pressure to use renewable raw materials and implement sustainable processes and operations, making it an extremely attractive sector.

This white paper utilises findings (Rantala, 2022, 2023, 2024) from altogether 20 interviews with representatives of 11 companies from the wood-fibre-based value chain (Table 1). Four representatives of four companies were interviewed especially from the Scope 3 emission management perspective. The other interviews went beyond sustainability measurement and sustainability data perspectives to thoroughly understand the case companies' businesses and viewpoints on sustainability. The interviews included questions about the value of sustainability, the reasons for wanting to achieve its goals, and the measures that companies wish to take to attain these objectives. The interviewers also asked about who defined sustainability indicators in the com-

pany and how different actors in the value chain perceived the indicators of sustainable development. Additionally, several questions related to value-chain aspects, monitoring, measuring, tracing and optimising sustainability-related activities.

Table 1. Interviewed representatives of case companies, their main products and services, as well as the number of interviewees.

Company	Main products and services	Number of interviewees
A	Machinery, lifting business	3
B	Machinery, paper making and automation systems	1
C	Machinery, valves	2
D	Retailer A	1
E	Software	1
F	Chemical industry	3
G	Forest industry	2
H	Forest industry, bio-based materials	2
I	Forest industry, harvesting machinery	2
J	Digital consulting	2
K	Retailer B	1

The findings have been refined in several discussions with other researchers and in a workshop in which the company and researcher representatives participated to analyse the interview findings. The second workshop, aimed at collecting KPIs in the value chain, was held with 14 participants from 6 companies and 3 research organisations.

III. Sustainability data in value chain

Measuring sustainability and defining the levels of sustainability in different value-chain operations require data. The term 'sustainability-related data' is not always straightforward since many sustainability-related aspects are difficult to measure or do so with exact values. In some cases, especially regarding social sustainability and ethics, there is no definitive threshold for something to be sustainable, and in the end, there is always a human being who defines whether something is sustainable or unsustainable. Qualitative and even quantitative sustainability data create a multidimensional information pool for companies, and the accurate and efficient use of data is a multifaceted problem.This chapter clarifies different types of sustainability data along the value chain and how they can be utilised.

> **"Sustainability data can be defined as any data enabling sustainable innovations, improved sustainability performance, or indicates the existence of sustainability in companies."** (Rantala et al., 2023, p. 3)

Sustainability data are collected along the value chain from upstream and downstream activities and can be divided into active and static data, depending on their use. Active data enable improved sustainability performance and sustainable innovations. For example, carbon dioxide (CO_2) emission data from the value chain could be utilised in developing the transparency of the chain and in planning emission reduction measures. Static data refer to those that display or monitor sustainability performance, such as in annual reports and in corporate sustainability reports (Rantala et al., 2023, 2024).

Sustainability data collection does not only benefit reporting or help fulfil legislation requirements. It contributes to the collection of important data related to a company's own sustainability activities and helps upgrade the firm's sustainability performance, which often results in improving overall business development, decision-making and industrial processes. Materiality analysis can be used for identifying the impacts of sustainability actions. Analysis is key to identifying indicators and helping in gathering data on the indicators. It can facilitate the perception of the collected data as sustainable data. Issues related to data are often the unavailability of the data or the lack of understanding about which data are needed. Other issues can be associated with low quality and the lack of transparency (Rantala et al., 2024).

Hanski et al. (2024) have identified some improvements in the data management process, tailored to support the design for sustainability and sustainability assessment early in the design phase. The design can be applied to all processes, from collection, analysis and utilisation to reporting. Data availability is one aspect of the product design phase that can affect how sustainability can be considered.

The sustainability data funnel (Figure 2) visualises different levels of sustainability data – material, product, company, value chain and industry levels. In practice, several side streams should be considered, especially in Scope 3 calculations. Sustainability-related impacts are expanding at the higher levels of the sustainability data funnel. Taking or not taking appropriate measures can either have negative effects or contribute to sustainable development. In other words, smaller changes in product design and manufacturing that lead to emission reductions accumulate towards the industrial level, minimising emissions on a larger scale. Similarly, ignorance can cause emissions at the material or the production level and accumulate on a larger scale.

It is important to distinguish among different purposes of using data and to identify where relevant data can be collected. The purpose of use determines what data can and cannot be utilised. For example, when calculating emissions from a production stage or a factory unit, the impacts on the surrounding community and public health do not affect the calculation. Instead, qualitative data influence conclusions about overall sustainability. Data collected from different value-chain operations can be used for multiple purposes with different motives. For instance, onsite emissions from a specific manufacturing process can be utilised as site-specific data in Scope 3 emission calculations, but the same data can also be used to calculate product-specific emissions with LCA. All sustainability-related measurements can utilise the same data and datasets, but the scope of the data utilisation differs.

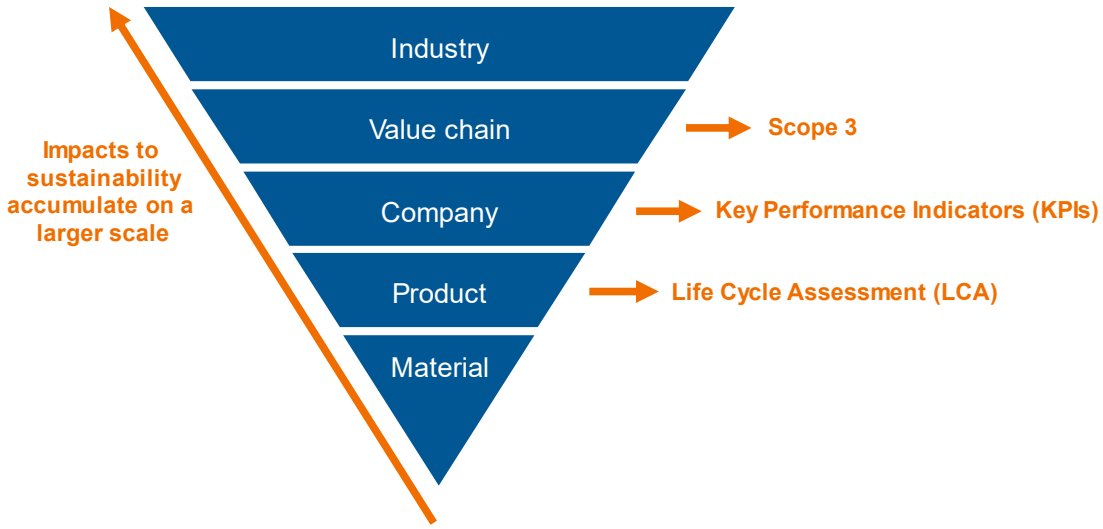


Figure 2. Sustainability data funnel — different levels of sustainability data, from material to industry level.

Data and measurements are also used for different purposes, such as LCA to improve a specific product, as well as means of communication to the end user of a product, while Scope 3 emissions can showcase the entire company's operations. The following quotation from an interviewed company representative describes the situation of sustainability data utilisation. The information is not sufficient in itself; rather, it should be utilised and guide the design process as well.

> **"Information alone (awareness) does not yet guide operations. Only the utilisation of information leads towards 'handprint' and impact. Sustainability data will be included in the designing process, where the costs of alternatives are calculated as part of the life cycle calculations. Life Cycle Assessment (LCA) calculations will be integrated into design software for mirroring the environmental impact."**

Scope 3 calculation applies to the entire company and its indirect emissions generated from upstream and downstream activities of the value chain. Scope 3 calculations are based on a categorised framework, and the output comprises the company's total emissions. LCA is product specific and assesses the lifecycle of the product from its production to the end-of-life activities. Sustainability KPIs measure a company's sustainability performance from the perspectives of the three sustainability dimensions: ecological, social and economic (Figure 1). Carbon footprint refers to the measurement of CO_2 emissions and other greenhouse gas emissions as CO_2 equivalents. Carbon footprint can be calculated at the organisational, product or individual level. However, carbon footprint calculations may slowly be replaced by Scope 3 at the organisational level and by LCA at the product level due to more comprehensive calculations and uniformity. Meanwhile, carbon handprint calculation is a method of assessing the positive impacts that a company or a product could create.

The major drivers of data collection and sharing area the regulations and the growing need for transparency and reliability. Related to reporting, the emphasis should be on automation of reporting, management of higher data quality and utilisation of data from the network (Rantala et al., 2024). Data collection is dependent of the final application, and the responsibility for gathering data is often divided within the company. One driver of comprehensive and accurate data collection is the EU's Digital Product Passport (DPP), which promotes the transparency of the product's manufacturing, origin and sustainability impact (Saari et al., 2022).

IV. Sustainability-related KPIs in value chain

KPIs related to sustainability often cover the three pillars of sustainability, comprising environment, social and economic aspects. Sustainability KPIs can also be part of the bigger picture, encompassing activities and measurements related to circular economy and corporate governance. KPIs are ways to measure sustainability in different parts of a company and its value chain. Constant utilisation of KPIs enables tackling the development of sustainability actions and can also serve as means of communication with multiple stakeholder groups and help with the overall sustainability reporting and emission calculations. KPIs can set requirements for the product design and value-chain operations. Many sustainability metrics in the whole value chain are strongly linked to the product and upstream activities, and such aspects can already be considered in the product design.

Upstream suppliers contribute to a company's overall sustainability performance and can affect how the sustainability targets are achieved. Govindan et al. (2021) suggest collaborating with suppliers and value-chain members who already share the same values and sustainability goals as those of the company. However, it is not always possible due to the limited number of suppliers within a certain distance range. This issue could also create a paradox: Is it worth chasing sustainable and high-quality data-providing suppliers if the transportation distances for delivering supplies are long, which at the same time increase the CO_2 and other greenhouse gas emissions? Hettler and Graf-Vlachy (2023) have identified pressure from buyers and negotiation powers as key drivers of primary data collection in the buyer-supplier collaboration.

Using KPIs from different sources can be beneficial and can help integrate sustainability. However, the number of different KPIs and their names can cause confusion. An often-recognised problem is the lack of consistency among sustainability KPIs. Comparing organisations and companies is more difficult when the metrics and their names are not uniform. Ibáñez-Forés et al. (2022) suggest that companies provide stakeholders more information and clear communication about the used metrics and sustainability strategies. It would be beneficial to discuss the utilisation of different sustainability KPIs in collaboration with the supply chain partners due to the challenges related to the identification of production-relevant indicators, such as the lack of understanding about measuring sustainability (Rantala et al., 2024).

Based on the interviews with the case company representatives (Rantala et al., 2024), the measured environmental performance was often done using traditional metrics, such as heating and energy consumption, water usage, recycling and transportation. The interviewees calculated the emissions themselves, both directly and indirectly, by using LCA and calculating carbon footprints, other greenhouse gas emissions or doing so based on Scopes 1, 2 and 3. In a study (Neri et al., 2020), the environmental indicators included waste and material use, in addition to the above-mentioned metrics.

From the interviews held by Rantala et al. (2024), the identified social sustainability indicators were related to safety and wellbeing in the working community. Social responsibility was also recognised, including aspects such as gender distribution, age average, tax policies, ethics and human rights, usage of child labour and product safety. The social sustainability indicators that Neri et al. (2020) identified focused more on aspects such as stakeholder relationships, philanthropic investments, occupational health and safety and labour turnover. Economic sustainability indicators concentrated on costs and supply-chain performance. In the interviews held by Rantala et al. (2024), the indicators related to economic sustainability emphasised strategy, self-sufficiency, anti-corruption, costs, monitoring the conditions, and innovations.

Based on the mentioned results, other relevant sources and the interview findings, the KPIs are divided into two tables: supplier perspective (Table 2) and customer perspective (Table 3). The KPIs are broken down into both the value-chain stage (horizontal rows) and the sustainability dimension (vertical columns). The stages of the value chain (horizontal rows) can be found in the tables as raw material supply, raw material processing, production and further conversion, brand owner, retailer and consumer. The vertical columns contain the sustainability dimensions – environment, social, and economic & governance.

The same division between the supplier perspective and the customer perspective is made in Figure 3. It presents the value chain and data sharing, as well as how the pressure for measuring sustainability is formed. The figure highlights the brand owner, who is often responsible for pursuing the overall sustainability of the value chain, collecting the sustainability data and communicating information about KPIs with different stakeholder groups. The pressure to measure and implement sustainable practices comes from legislation, market and industrial changes, customers and other stakeholders. The brand owner accordingly puts pressure on the upstream value chain to collect accurate data and encourages the parties involved to contribute to upholding the same sustainable values held by the brand.

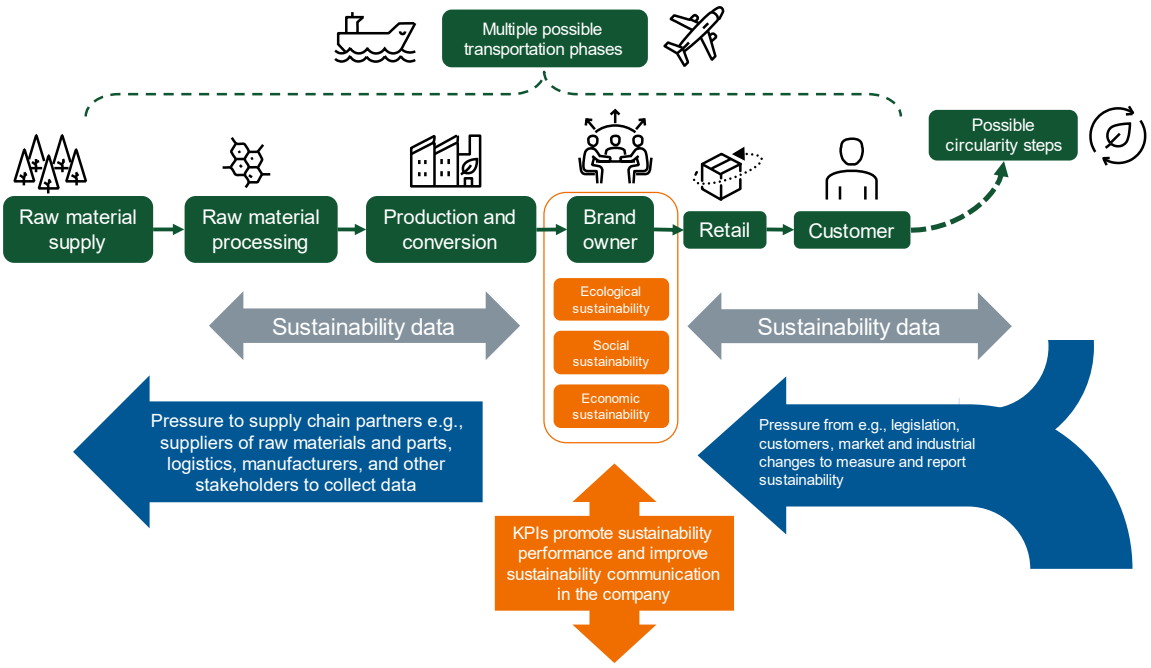
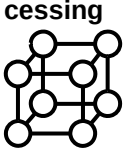


Figure 3. Wood-fibre-based, value-chain stages, data sharing and pressure to measure sustainability with key performance indicators (KPIs).

The most important indicators and KPIs in the value chain that have been identified in the studies (Rantala et al., 2022, 2023, 2024) are presented in Table 2 from the supplier's perspective. When looking at the supply-chain perspective, the aims are to reduce biodiversity impacts, decrease emissions and improve production ethics. Other significant impacts arise from the uses of water, materials and energy, as well as waste generation. KPIs can measure supply-chain material usage and process efficiency, as well as help improve them toward a more ecologically sustainable supply chain. The most significant social sustainability issues in the supply chain are related to equality, human rights and safety. Measuring social sustainability is more difficult because most indicators require data that cannot be collected automatically or measured numerically at all. Social sustainability KPIs that can be measured by percentages include diversity and ethical compliance from suppliers. Labour conditions can be measured, for example, by calculating work temperatures, work hours and absences. Economic sustainability KPIs are related to costs, turnover, efficiency of bio-based products, and so on, which are measurable indicators. They are also valuable indicators from a company's financial perspective.

Table 2. Most important indicators and KPIs in the value chain – supplier perspective.

	Environment	Social	Economic & Governance
Supplier perspective			
Raw material supply  	Origin of raw materials Amount of bio-based raw materials Share of recyclable inorganic raw materials Use of recycled parts or materials Share of wood from certified forests Meeting sustainability criteria Thinning intensity and density of remaining trees Land use Impact on biodiversity Carbon emissions Carbon footprint Transportation emissions Share of renewable fuels	Country of origin (conflicts) Rights of indigenous people Ethical compliance Human rights Percentage of women in workforce Minimum wage issues included in company targets Occupational safety Number of absences Inclusion and diversity Use of child labour Labour conditions	Change in turnover of bi-obased products Fuel consumption costs Anti-corruption
Raw material processing 	Water usage Waste water Energy use Effects on local water bodies Water quality Efficiency (time, raw material, production, loss) Reduction of energy and water usage External impacts from production (chemical and water emissions) Utilisation of product side streams Transportation emissions	Attractiveness and retention Work motivation Occupational safety Social acceptancy Labour conditions Product safety (e.g., chemical surplus) Meaningfulness of work	Logistics cost Cost of teaching machinery usage Working efficiency
Production & further conversion 	Traceability Efficiency (lead time, operational control, energy usage, material, production, waste) Material balance (in/out) Waste water Lost material Reduction of waste Recycling degree and level Final disposal of waste Heating and ventilation Resilience to extreme phenomena Transportation distances VOC emissions Direct and indirect GHG emissions Carbon footprint and handprint	Human rights Employee safety Occupational safety Absences from work Labour conditions Chemical safety Finished products meet product safety regulations	Distances between suppliers and customers Working efficiency

The main KPIs in each sustainability dimension from the customer perspective support responsible consumption and the development of a company's sustainability practices. From the environmental perspective, the KPIs measure aspects such as recyclability, material efficiency and lost material, and impacts of retailing and distribution, such as transportation emissions and heating. Product-related data and calculations (e.g., carbon footprint and LCA), containing information related to a product's environmental performance, may be accessible for end users and consumers.

Social sustainability KPIs from the customer perspective (Table 3) are related to the significance of work, overall welfare and safety of employees, as well as transparency. The KPIs related to the economic aspect are strongly linked to brand ownership and corporate governance. Examples of the indicators in the economic category include sustainable innovations and willingness to contribute to sustainable development, bio-based strategies, anti-corruption, tax policies, selection of production locations and certified raw materials. The retailer is often responsible for providing product replacements and repair; thus, these can be considered relevant KPIs for the retailer's economic sustainability since they promote sustainable performance and circular economy principles. Consumers are willing to continue following the circular economy principles by utilising a product in a new way or for some other purpose. In this case, the number of potential new applications can serve as an indicator.

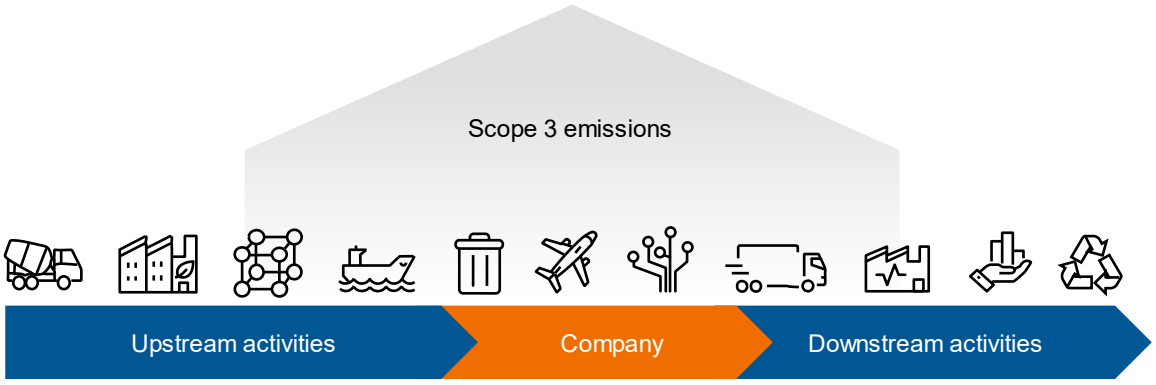
Table 3. Most important indicators and KPIs in the value chain – customer perspective.

	Environment	Social	Economic & Governance
	Customer perspective		
Brand owner	Biodegradability and recyclability Transition to renewables Raw material efficiency Net promoter score Heating and ventilation Transportation distances LCA Carbon footprint Transparency	Meaningfulness and significance of work Welfare Social responsibility Tax policy Employee compensation plan Stakeholder consideration	Innovations for sustainable development Bio-based strategies Increase of sustainable product income Willingness to pay for sustainable products Share of FSC-certified products Certifications for raw materials Selection of production locations Distances between suppliers and customers Costs of transportation damage Anti-corruption Tax policy
Retailer	Lost material Amount of waste Transportation distances Heating and ventilation LCA Transparency	Awareness Stakeholder consideration Social responsibility Employee safety Tax policy Employee compensation plan	Turnover of restored parts Monitoring the conditions for extending the product's lifespan Functionality of the product and possibilities for replacement
Consumers	Longevity and quality Recovery of used products Recycling degree	Product safety Transparency	Potential new applications or uses

In addition to improving internal sustainability performance, KPIs can be used as tools for companies to create competitive advantage. Competitive advantage from the supplier perspective is the value created in the supply chain and for the suppliers themselves. The cooperation that is needed to measure sustainability increases agility throughout the supply chain and enhances the overall perception of the value-chain collaboration. Collaboration and agility increase resilience to unexpected events (e.g., changing legislation or regulatory issues). KPIs improve the overall environmental management, especially from the perspective of data collection and utilisation, which is an important factor for accuracy and transparency. From the customer perspective, the competitive advantage is the value creation for sustainability-conscious customers. More sustainable consumption has increased as the consumers have become more environmentally aware and more critical. Companies with respectable reputations related to sustainability stand out from those that are unsuccessful in their sustainability performance. Utilising and showcasing the KPIs improve communication with both upstream and downstream actors in the value chain.

V. Scope 3 emission calculation

Companies calculate their greenhouse gas emissions – which can be considered one of the sustainability KPIs – as part of sustainability reporting. The Greenhouse Gas Protocol (GHG Protocol) has a classification for the calculations, comprising three scopes of emissions. Scope 1 considers direct emissions from company facilities, vehicles and transportation, among others. Scope 2 includes indirect emissions, typically coming from purchased electricity, steam, heating and cooling for the company's own use. Scope 3 covers all other indirect emissions from upstream and downstream value-chain activities. Upstream-activity emissions can come from purchased goods and services, distribution, waste generation from different operations, employee commuting, and so on. Downstream-activity emissions can come from distribution, processing of sold products, use of sold products, end-of-life treatment, franchises and investments, among others. Based on the emission source, Scope 3 emissions can be divided into 15 categories, as presented in Figure 4. The GHG Protocol includes calculation methods, data requirements and data collection guidance for the different categories (World Resources Institute and World Business Council for Sustainable Development, 2011). Other standards and frameworks, such as ISO 14083 standard and The Global Logistics Emissions Council (GLEC) framework for transportation-related emissions, provide methods and guidelines for emission calculations as well.



1. Purchased goods and services
2. Capital goods
3. Fuel and energy-related activities (not included in scope 1 or scope 2)
4. Upstream transportation and distribution
5. Waste generated in operations
6. Business travel
7. Employee commuting
8. Upstream leased assets
9. Downstream transportation and distribution
10. Processing of sold products
11. Use of sold products
12. End-of-life treatment of sold products
13. Downstream leased assets
14. Franchises
15. Investments

Figure 4. Scope 3 emission categories divided into upstream and downstream activities.

Scope 3 emission calculations are specific to an organisation and concern its whole value chain. In other words, they must not be confused with carbon footprint calculations, which can be made at the level of a company, a specific process, a product or an individual. The use of Scope 3 emission calculations enables uniform measurements in the context of the carbon footprint at the company level (Ibáñez-Forés et al., 2022). Calculating Scope 3 emissions is an important step towards carbon neutrality or the decarbonisation strategies of a company. The Scope 3 emissions (or even one category, e.g., purchased goods and services or transportation) often make up a large proportion of the company's total emissions. Identifying the relevant categories and the sources of the generated emissions is a mandatory step towards minimising the emissions (Hettler & Graf-Vlachy, 2023).

The collected data on Scope 3 emissions can be primary, secondary or a combination of both, depending on the scale of the data collection and data availability. Primary data comprise the

most accurate, product-specific, onsite-collected data. Secondary data are based on industry or product-specific averages. The interviewed company representatives indicated a lot of variations in how they collected data and what the current criteria and targets were for data accuracy and quality. The lack of high-quality data decreases the accuracy of the Scope 3 emission calculations. Using secondary data or more general emission factors, instead of primary data, can also produce inaccurate results. Other issues that prevent accurate reporting are lack of knowledge, double counting or utilisation of different standardisations. Inaccurate reporting can also include 'carbon leakages', which are emissions that are not captured in calculations or unintentional exclusions in reporting, among others (Hettler & Graf-Vlachy, 2023).

The interviewees recognised the need, and both internal and external pressures, to develop Scope 3 calculations. Development targets comprised improvements in reporting, accuracy of calculations, including the transition from secondary to primary data, and the use of more accurate emission factors. As the interviewees also stated, high-quality data collection is challenging. However, the department that is responsible for data gathering can improve this process (Hettler & Graf-Vlachy, 2023). Collaboration (e.g., discussing the data requirements), the value it creates and other benefits could help suppliers in their own data collection and readiness to deliver high-quality data.

The slower adoption of Scope 3 emission calculations is due to the lack of knowledge and expertise. Based on the interview findings, the company representatives stressed that they would view comprehensive guidance as beneficial addition to and help for their work, as similarly highlighted by Hettler and Graf-Vlachy (2023) in their research. Other limitations are the lack of resources and other capabilities. There are also differences in how the information is available in the companies' upstream and downstream activities. The case companies also had many variations in the straightforwardness of their calculations and reporting of their emissions. For example, energy-intensive companies already have a lot of data related to energy usage from their operational units. Comprehensive guidance should align with the GHG Protocol and thus improve the relevance of calculations and industry-specific emission sources.

Most of the interviewees were already calculating and reporting their Scope 3 emissions; hence, they were not slow adopters. However, they had identified their own development needs in order to arrive at more comprehensive and accurate Scope 3 calculations. The same development needs and gaps can turn out to be reasons for slower adoption of the Scope 3 calculations. The interviewees perceived the quality of the data from their supply chain as poor or poorly accessible and recognised plenty of dispersions in the data. Most of the data were not shared automatically thus needed to be requested separately. The value chain can involve companies of different sizes and various resources, which means that the readiness and capability to share data may vary a lot. However, the interviewees also had an understanding of their supply chains, as stated in the following quotation:

> **"The quality of data shared by suppliers is poor and varied. The supplier group includes a wide range of companies of different sizes, which affects the quality and variability of data."**

Many interviewees reported that a large proportion of emissions was generated at the stating point of the value chain, and they believed that it was difficult to influence it. There was a clear need for developing supply-chain transparency and collaboration, which would uniform and automate the data-collection process. Most interviewees had set Scope 3 emission targets for the most relevant categories since they had been identified as having a high impact on total emissions, as recognised by Hettler and Graf-Vlachy (2023). In addition to specific targets, some interviewees focused on overall sustainability, estimating that it served as means to reduce Scope 3 emissions while creating other positive impacts on overall sustainability. The following quotation represents such target setting:

> **"We are not consciously reducing Scope 3 emissions, but strategic programmes and focuses (e.g., raw material selection) automatically reduce emissions, even if we do not consciously do it from the Scope 3 perspective. The aims have been to develop overall sustainability qualitatively and evaluate, for example, the impact of new technologies on overall sustainability."**

VI. Conclusion

This white paper has provided insights and guidance on measuring sustainability in the manufacturing industry, using the wood-fibre-based value chain as an example. It has addressed the drivers and challenges of measuring sustainability, the types and sources of sustainability data, the KPIs for sustainability and the Scope 3 emission calculation as a detailed example of a sustainability KPI. The paper has also highlighted some future research topics and directions for upgrading sustainability measurement.

The current situation of sustainability management in the manufacturing industry is characterised by not only increasing awareness and interest but also significant gaps and challenges. On one hand, there is a growing recognition of the importance and benefits of sustainability for manufacturers, as well as for society and the environment. Many manufacturers have adopted sustainability policies and strategies and implemented various initiatives and measures to improve their sustainability performance and create value.

This white paper concludes that measuring sustainability

- is important and beneficial for the manufacturing industry since it can help improve sustainability performance and value to meet the expectations and demands of various stakeholders, to comply with the regulations and standards and to contribute to the global sustainable development goals.
- requires a holistic and systemic approach that considers the entire value chain, from raw material sourcing to end-of-life management, and the interactions among the actors and stakeholders involved.
- requires the identification, collection and analysis of relevant data and information on sustainability impacts and benefits, as well as the use of appropriate indicators and metrics to communicate and report them in the company and value chain.

On the other hand, the manufacturing industry still faces many obstacles and limitations that prevent it from fully adopting and implementing sustainability. Common and coherent definitions and frameworks of sustainability and how it can be achieved may be missing. There are also the issues of scarcity and unreliability of data on sustainability impacts and benefits. Moreover, the industry has no common agreement on how to measure and evaluate the sustainability performance of the value chain using standardised and comparable indicators and metrics. The industry needs more tools, methods and indicators that can help it assess and improve its sustainability practices. Furthermore, there is a lack of transparency on the sustainability measures and reporting of the value chain. These are some of the gaps and challenges that hamper the effective and comprehensive implementation of sustainability in the manufacturing value chain. In the following quotation, the interviewee described the importance of accurate data, especially in the circular economy, and several challenges related to data sharing.

> **"Monitoring should already be more networked so that data can also be obtained from other parties. Industry averages can be calculated, but if more accurate data are desired, information on other stages is also needed. In the circular economy, this need will increase even further. This is challenging from a contractual point of view, how to make data move."**

Sustainability KPIs are ways to measure and monitor the sustainability performance of the value chain. This white paper has presented the main KPIs for each value-chain stage and sustainability dimension, as well as analysed their benefits and challenges. The KPIs in the upstream part of the value chain aim to minimise biodiversity impacts, reduce emissions and improve production ethics. The customer perspective and downstream value-chain KPIs are created to support responsible consumption and the development of a company's sustainability practices. The utilisation of KPIs creates competitive advantages, such as creating value and agility in the value chain by collaboration and creating value for the customers who prioritise the implementation of sustainability.

This white paper has examined in detail the KPIs related to Scope 3 emissions. Scope 3 emissions cover the indirect emissions from the upstream and downstream activities of a company, such as material sourcing, logistics, distribution and end-of-life management. Scope 3 emissions are divided into 15 categories and require different data sources and calculation methods. Calculating and reporting Scope 3 emissions are important for achieving sustainability targets and creating competitive advantage but also encounter difficulties, such as inferior data quality, data unavailability and interoperability issues.

Future research topics

Some possible directions for future research and development include developing and applying more holistic and systemic approaches to sustainability, incorporating the lifecycle and circular perspectivesinf as well as sustainability indicators throughout the product lifecycle, and using data and information technologies to support sustainability decision-making and improvement. Fostering collaboration and co-creation among the actors and stakeholders of the value chain should also be highlighted. Sustainability must be promoted in communications among company employees and customers.

Four main focus areas for the success of industrial value chains in effectively sharing and leveraging sustainability data are essential (Rantala et al., 2022, 2023), as follows:

Definition of sustainability indicators and data. Clearly define sustainability indicators to gain a comprehensive understanding of the significance of sustainability data. This involves identifying applicable operational data for optimisation purposes.

Strategies for data collection. Evaluate the existing sustainability data, determine additional data needs, and ensure data quality through real-time collection approaches.

Ecosystem-wide data sharing. Establish a network for sharing sustainability data within the ecosystem to encourage sustainable business actions. This requires agreed-upon rules and operational models.

Integration of sustainability into decision-making. Integrate sustainability data into decision-making processes across all organisational levels. The objective is to infuse sustainability data from a strategic level into the operational culture, emphasising that such immersion not only serves reporting but also guides operational decisions.

Effectively utilising high-quality data for decision-making, grounded in factual insights rather than assumptions, demands a comprehensive understanding of the significance and benefits of data throughout the organisation. This involves linking real-time data to decision-making processes from management to employee levels. Ensuring reliability and standardised sharing practices beyond organisational boundaries is crucial. Collaborative efforts across ecosystems are essential for optimising sustainability across the entire value chain.

In conclusion, the authors advocate fostering a sustainability culture in organisations, integrating online data into decision-making processes at all levels and establishing reliable data-sharing practices through common rules and processes. These initiatives are fundamental for achieving sustainability targets in industrial value chains.

VII. References

European Union. (2020). Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088

European Union. (2022a). Directive 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No. 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting.

European Union. (2022b). Proposal for a directive of the European Parliament and of the Council on Corporate Sustainability Due Diligence and amending Directive (EU) 2019/1937.

European Union. (2023a). Commission Delegated Regulation (EU) 2023/2485 of 27 June 2023 amending Delegated Regulation (EU) 2021/2139 establishing additional technical screening criteria for determining the conditions under which certain economic activities qualify as contributing substantially to climate change mitigation or climate change adaptation and for determining whether those activities cause no significant harm to any of the other environmental objectives

European Union. (2023b). Commission Delegated Regulation (EU) 2023/2486 of 27 June 2023 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to the sustainable use and protection of water and marine resources, to the transition to a circular economy, to pollution prevention and control, or to the protection and restoration of biodiversity and ecosystems and for determining whether that economic activity causes no significant harm to any of the other environmental objectives and amending Commission Delegated Regulation (EU) 2021/2178 as regards specific public disclosures for those economic activities

Finnish Forest Association. (2021). Sustainability of Finland's forests. https://forest.fi/wp-content/uploads/2021/06/Sustainability_of_Finlands_forests.pdf

Govindan, K., Aditi, Dhingra Darbari, J., Kaul, A., & Jha, P. C. (2021). Structural model for analysis of key performance indicators for sustainable manufacturer–supplier collaboration: A grey-decision-making trial and evaluation laboratory-based approach. *Business Strategy and the Environment*, *30*(4), 1702–1722. https://doi.org/10.1002/bse.2703

Hanski, J., Uusitalo, T., Rantala, T., & Hemilä, J. (2024). Sustainability assessment in product design—perspectives from Finnish manufacturing companies. In S. G. Scholz, R. J. Howlett, & R. Setchi (Eds.), Sustainable Design and Manufacturing 2023 (SDM 2023). *Smart Innovation, Systems and Technologies*, vol. 377. Springer, Singapore. https://doi.org/10.1007/978-981-99-8159-5_3

Hettler, M., & Graf-Vlachy, L. (2023). Corporate Scope 3 carbon emission reporting as an enabler of supply chain decarbonization: A systematic review and comprehensive research agenda. *Business Strategy and the Environment*, *33*(2), 263–282. https://doi.org/10.1002/bse.3486

Ibáñez-Forés, V., Martínez-Sánchez, V., Valls-Val, K., & Bovea, M. D. (2022). Sustainability reports as a tool for measuring and monitoring the transition towards the circular economy of organisations: Proposal of indicators and metrics. *Journal of Environmental Management*, *320*, 115784. https://doi.org/10.1016/J.JENVMAN.2022.115784

Korin, A. (2024). Exploring how sustainability ratings and certificates are utilized: A case study in the Finnish manufacturing industry. Master's thesis. Tampere University. 120 p. https://urn.fi/URN:NBN:fi:tuni-2023122011056

Näyhä, A., Pelli, P., & Hetemäki, L. (2015). Services in the forest-based sector – unexplored futures. *Foresight*, *17*(4), 378–398.

Neri, A., Cagno, E., Lepri, M., & Trianni, A. (2020). A triple bottom line balanced set of key performance indicators to measure the sustainability performance of industrial supply chains. *Sustainable Production and Consumption*. *26*, 648–691. https://doi.org/10.1016/j.spc.2020.12.018.

Rantala, T., Wessberg, N., Kääriäinen, J., Valkokari, P., Heiskanen, M., Kivikytö-Reponen, P., Nyblom, J., & Mäkeläinen, P. (2023). Data in sustainable production chain management. In I. Bitran, L. Bitetti, S. Conn, J. Fishburn, E. Huizingh, P. Ritala, M. Torkkeli, & J. Yang (Eds.), *Proceedings of XXXIV ISPIM Innovation Conference*. Innovation and Circular Economy International Society for Professional Innovation Management (ISPIM). https://cris.vtt.fi/en/publications/data-in-sustainable-production-chain-management

Rantala, T., Wessberg, N., Kivikytö-Reponen, P., Heiskanen, M., Kääriäinen, J., Valkokari, P., & Nyblom, J. (2022). *Data kestävän kehityksen mukaisessa tuotantoketjun ohjauksessa*. VTT Technical Research Centre of Finland. VTT Technology No. 411. https://doi.org/10.32040/2242-122X.2022.T411

Rantala, T., Wessberg, N., & Korin, A. (2024). Measuring sustainability in wood fibre-based production chain. In S. G. Scholz, R. J. Howlett, & R. Setchi (Eds.), Sustainable Design and Manufacturing 2023 (SDM 2023). *Smart Innovation, Systems and Technologies*, vol. 377. Springer, Singapore. https://doi.org/10.1007/978-981-99-8159-5_4

Saari, L., Heilala, J., Heikkilä, T., Kääriäinen, J., Pulkkinen, A., & Rantala, T. (2022). Digital Product Passport promotes sustainable manufacturing. *VTT White Paper*, vol. 2022. 44 p. https://cris.vtt.fi/en/publications/digital-product-passport-promotes-sustainable-manufacturing-white

Schad, J., Lewis, M. W., Raisch, S., & Smith, W. K. (2016). Paradox research in management science: Looking back to move forward. *Academy of Management Annals*, *10*(1), 5–64.

Smith, W., & Lewis, M. (2011). Toward a theory of paradox: A dynamic equilibrium model of organizing. *Academy of Management Review*, *36*(2), 381–403.

World Resources Institute and World Business Council for Sustainable Development. (2011). *Corporate Value Chain (Scope 3) Standard*. World Resources Institute and World Business Council for Sustainable Development. Available from https://ghgprotocol.org/corporate-value-chain-scope-3-standard

Appendices

Table 4: Terminology and mostly European initiatives related to measuring sustainability, and guide for sustainable manufacturing

Term/initiative	Explanation
Carbon handprint	Carbon handprint calculation is a method of assessing the positive impacts that a company or a product could create. In the corporate context, the company increases its carbon handprint when creating a solution that reduces the carbon footprints of others, typically their customers, compared to a baseline solution.
Carbon footprint	Carbon footprint is the measurement for direct and indirect carbon dioxide (CO_2) emissions and other greenhouse gas emissions as CO_2 equivalents. Carbon footprints can be calculated at the organisational, product or individual level and encompass activities such as energy consumption, transportation and production processes.
CSRD	The Corporate Sustainability Reporting Directive (CSRD) aims to strengthen companies' sustainability reporting with European Sustainability Reporting Standards (ESRS), third-party validation and digital reporting that enhance the usability related to sustainability data. The CSRD incorporates the concept of double materiality, which requires companies to report on how sustainability issues may pose financial risks and to disclose their own impacts on people and the environment.
CSDDD	The Corporate Sustainability Due Diligence Directive (CSDDD) concerns large companies and includes rules on obligations regarding actual and potential adverse impacts on the environment and human rights for their value chain of activities. It covers the upstream business partners of the company and partially, possible downstream activities, such as distribution or recycling.
DPP	The Digital Product Passport (DPP) will provide information about products' environmental sustainability. This information will be easily accessible by scanning a data carrier and will include durability and reparability, recycled content or data related to manufacturing. It should help consumers and businesses make informed choices when purchasing products, facilitate repairs and recycling and improve transparency about products' lifecycle impacts on the environment. The DPP is part of the Ecodesign for Sustainable Products Regulation that will improve EU products' circularity, energy performance and other environmental sustainability aspects.

Term/initiative	Explanation
EU Taxonomy	The EU Taxonomy Regulation is a classification system that sets four-step criteria that an economic activity must comply with to be qualified as environmentally sustainable. In the criteria, one of the environmental objectives must be met, and the activity must not cause harm to the other objectives. The taxonomy is a tool for making contributions to the mentioned objectives. The European Commission has published delegated acts under the EU Taxonomy to list actual environmentally sustainable activities.
GHG Protocol	The Greenhouse Gas Protocol (GHG Protocol) consists of standards and tools for GHG accounting and reporting. The protocol was established by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) in 1998. The protocol, which includes various complementary standards, is estimated to be the most widely used GHG accounting standard in the world.
KPI	Key performance indicators (KPIs) are quantifiable measurements used to measure, for example, a company's overall long-term performance, including strategic, financial and operational achievements. Sustainability KPIs measure the company's sustainability performance from the perspective of three sustainability dimensions: ecological, social and economic.
LCA	Life Cycle Assessment (LCA) is a systematic analysis of the environmental impacts associated with all lifecycle stages of a product, process or service. It considers raw material extraction, production, use and disposal, and its output is the assessment of a set of selected impact categories, such as climate change, eutrophication, acidification and particulate matter.
Scope 3	Scope 3 calculation applies to the entire company and covers its indirect emissions generated by upstream and downstream activities of the value chain. Scope 3 emissions are divided into 15 categories that represent the various emission sources throughout the value chain. Scope 3 emissions can often make up most of a company's overall emissions.
Sustainability data	Sustainability data are collected along the value chain from upstream and downstream activities and can be divided into active and static data, depending on their use. Active data enable improved sustainability performance and sustainable innovations. Static data refer to data that display or monitor sustainability performance.
Wood-fibre-based value chain	The wood-fibre-based value chain refers to the production of goods from wood-fibre raw materials, ranging from forest to consumer products, and includes the main processes involved, such as harvesting, pulping, paper/board manufacturing, and converting wood fibres into various finished products .

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