



CALiMERO

IMPROVING BIO-BASED INDUSTRIES LIFE CYCLE SUSTAINABILITY

D5.4

Monitoring procedures of target bio-based industries

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LIST OF ACRONYMS

BMS	Bioeconomy Monitoring System
CE	Circular Economy
EU	European Union
MCA	Multi-criteria Analysis
MCDM	Multi-criteria Decision Making
IDMS	Incentives and Decision Making
DQA	Data Quality and Availability

PROJECT INFORMATION

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List of participants:

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10	Essity ESSITY
11	BIM Kemi AB BIMKEMI
12	Ereks garment EREKS

DELIVERABLE DETAILS

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Abstract:	To support the implementation of the EU Bioeconomy Strategy, this study presents a multi-criteria approach for selecting and evaluating sustainability indicators that align with regional priorities and sector-specific needs. While the EU Bioeconomy Monitoring System (BMS) provides a comprehensive framework, it lacks flexibility for tailoring indicator sets to specific industrial or regional contexts and underrepresents key dimensions such as social equity and circularity complexity. To address these limitations, this work applies Multi-Criteria Analysis (MCA) to assess a broader range of indicators, including indicators proposed in the BMS, the hotspot analysis conducted in WP1, and the results from the multi-objective optimisation of case studies in WP4 and the developed methodologies in WP3, based on relevance, data quality, and stakeholder alignment. The resulting analysis enables a more balanced and actionable selection of indicators for monitoring progress toward a circular and sustainable bioeconomy, empowering policymakers and industry actors to make informed, context-sensitive decisions.

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V1.0	30/06/2025	First draft

1 INTRODUCTION

1.1 Context

To advance the EU Bioeconomy Strategy, the European Union established a framework aimed at promoting a bioeconomy that prioritises the preservation of ecosystems and biological resources, supports the revitalisation of industries and the advancement of primary production systems through bio-based innovation, engages local stakeholders, and safeguards the environment. To support these goals, an action plan was developed, outlining fourteen concrete measures. One of these key actions is to monitor progress towards a sustainable bioeconomy to better understand the ecological boundaries within which the EU bioeconomy operates (European Commission. Directorate General for Research and Innovation., 2018).

A bioeconomy monitoring framework is essential for assessing progress, ensuring all dimensions of sustainability are considered, evaluating the effectiveness of the implemented measures, verifying the overall success of the strategy, and identifying areas where policy intervention is required (Marcone et al., 2022; Robert et al., 2020). To address this need, the EU created the EU Bioeconomy Monitoring System (BMS), specially designed to track progress toward a circular and sustainable bioeconomy, provide guidance to policymakers at the country and macro-regional levels, serve as a model for other regions, and support the management of parallel environmental commitments, such as the 2030 Agenda, the Sustainable Development Goals (SDGs), and the Paris Agreement on Climate Change (Robert et al., 2020). The system is regularly updated, with the most recent revision, dated December 2023, incorporating new socioeconomic indicators. The BMS is a comprehensive monitoring framework that utilises a range of indicators encompassing environmental, social, and economic dimensions. It offers a broad overview of the bioeconomy's performance rather than a customizable selection of progress tailored to specific industrial actors. While the BMS does not provide specific criteria for indicator selection based on individual needs or perspectives, it aligns with the overarching goals of the EU Bioeconomy Strategy (European Commission. Joint Research Centre., 2024; *Guidance Note on Monitoring the Sustainability of the Bioeconomy at a Country or Macro-Regional Level*, 2021)

In collaboration with the Food and Agriculture Organisation at the United Nations (FAO), the European Commission has provided step-by-step guidance on establishing a bioeconomy monitoring system at the country or macro-regional level. This guidance emphasises the importance of developing a robust conceptual framework before progressing to the implementation or assessment phases. According to this guidance, a strong monitoring system requires three key components:

1. A conceptual framework, defining the elements of the monitoring system
2. An implementation framework, focusing on indicator selection and data collection
3. An assessment framework, ensuring results are shared transparently and presented in an accessible manner (*Guidance Note on Monitoring the Sustainability of the Bioeconomy at a Country or Macro-Regional Level*, 2021).

While the EU Bioeconomy Monitoring System provides a broad and structured overview of the bioeconomy's performance, it does not offer a customizable selection process tailored to the specific needs of industrial actors. Moreover, its current scope primarily focuses on a few bioeconomy sectors, considering only a few specific indicators for each. Notably, the social dimensions remain underrepresented compared to economic and environmental aspects. To address these gaps, supplementary indicators developed within the CALIMERO project and other frameworks should be evaluated, thereby enhancing the inclusiveness and robustness of the

monitoring system. This expanded approach allows for a more comprehensive and balanced evaluation, aligning more closely with the multidimensional nature of sustainability.

The process of selecting appropriate indicators for bioeconomy monitoring involves carefully evaluating a range of options based on several criteria, such as applicability to the industry, data quality and availability, and stakeholder influence. Multi-Criteria Analysis (MCA), often used interchangeably with Multi-Criteria Decision-Making (MCDM), constitutes a significant branch of decision theory and operations research. Its fundamental aim is to facilitate the selection of the most suitable alternative from a set of options by systematically evaluating them against multiple criteria (Taherdoost & Madanchian, 2023). MCA is not a single method but rather an umbrella term encompassing a diverse array of tools and methodologies designed to address complex decision problems (Poulsen, 2022). It provides a structured, transparent, and systematic framework for comparing alternatives, proving particularly valuable when decisions involve significant non-monetary aspects, such as social or environmental impacts (Chief Minister, 2022). This structured approach to navigating complexity is central to addressing contemporary sustainability challenges.

In this deliverable, we consider the indicators proposed in the BMS, the hotspot analysis conducted in WP1, and the results from the multi-objective optimisation of case studies in WP4 and the developed methodologies in WP3 for evaluation and assessment. Then we use MCA to select the most relevant monitoring indicators for regional policymakers and industry stakeholders from this selection. By considering interconnections between businesses, sectors, and regional supply chains, MCA provides a tailored list of indicators that better align with the aim of the CALIMERO project and ensures the guidance for monitoring is not only scientifically robust but also contextually relevant, empowering stakeholders to make industry decisions and contribute to the sustainable progress of bio-based industries.

1.2 Aim and objectives

The CALIMERO project, funded by Horizon Europe, aims to improve current methodologies for analysing the sustainability (environmental, social, and economic) of bio-based industrial processes in the following bio-based sectors: construction, textiles, woodworking, bioplastics, and pulp and paper. Consequently, based on the EU Bioeconomy Monitoring System (BMS) and sustainability indicators developed during the project, the main objective of this deliverable is to provide specific recommendations for monitoring indicators targeted at relevant industry actors, as well as policymakers at the regional level. The final results will be useful for policymakers in various sectors and regions to inform their decision-making.

While structuring this report, we have also drawn upon the European Commission's Guidance Note on Monitoring the Sustainability of the Bioeconomy at a Country or Macro-level, ensuring consistency with current EU recommendations. Based on this foundation, region- and sector-specific indicators are identified. A Multi-Criteria Analysis (MCA) is then conducted using clearly defined criteria and sub-criteria, serving as the basis for a practical tool to support policymakers and companies in selecting meaningful, sector-relevant indicators for informed decision-making.

1.3 Report structure

Following this introduction, the report is structured as follows: **Chapter 2** presents the Indicator pool building phase used to achieve the objectives above, including the distinct source of the monitoring indicators, the final list of relevant indicators for the project's context; **Chapter 3** presents the chosen criteria and sub-criteria, and

the developed scoring method; **Chapter 4** presents the results and the analysis of the conducted multi-criteria analysis from a sectorial perspective, but also for policymakers at a regional level, underlying limitations and challenges, and finally **Chapter 5** summarises the results, perspectives and conclusion. The following figure represents a summary of the methodological steps.

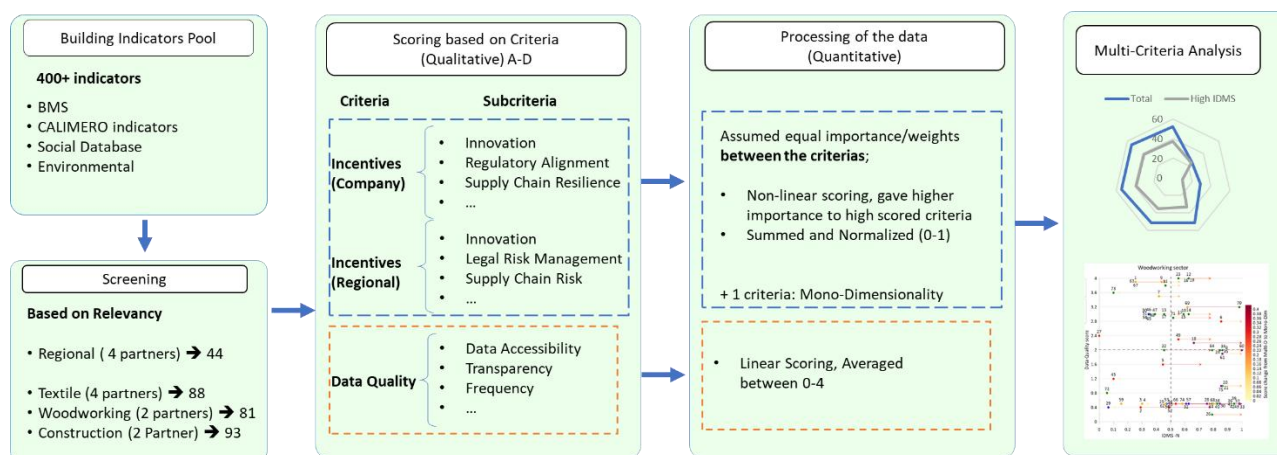


Figure 1 An overview of the methodological steps

2 INDICATOR POOL BUILDING PHASE – SELECTION AND SOURCE OF INDICATORS

2.1 Boundaries and scope for pre-selection of indicators

The objectives of the CALIMERO project defined the scope of this work. The primary focus was on achieving a comprehensive pool of indicators covering various pillars of sustainability (environmental, social, and economic) for two target audiences: regional policymakers and industry actors within the project's three key bio-based sectors (woodworking, textiles, and construction). To achieve that, we consider the indicators proposed in the BMS, the hotspots analysis conducted in WP1 for the sectors, and the methodologies developed within WP3.

From Task 1.2 (Ricardo Méndez & Alfredo Caceres, 2023) within the CALIMERO project, environmental and social hotspots were identified for each sector. For the environmental impact assessment, the Ecoinvent 3.1 database (*Ecoinvent Version 3.1*, n.d.) was utilised, and the impact of all datasets related to the products of the sectors was evaluated. The impact categories which contributed to the top 80% single-score impacts were considered as the hotspots.

For social hotspots, the two major social databases, Social Hotspot DataBase (SHDB) (*Purchase-SHDB Licences*, n.d.) and Product Social Impact Life Cycle Assessment (PSILCA) (*Psilca*, n.d.), were used to identify the important social hotspots of the sectors. A selection of sectoral products was analysed from these databases. Considering the inconsistencies in the hotspots identified with PSILCA and SHDB, the data gaps, and the nuances of this methodology, it was concluded that these hotspots do not accurately reflect reality. To address this, relevant social themes from the UNEP guidelines for social LCA (Benoît & Mazijn, 2009) were also added to the indicator pool for evaluation.

Other indicators from the developed methodologies within the CALIMERO project were also included in the framework. Below is a list of the indicators:

Table 1 Description of included methods developed within CALIMERO

Method/Framework developed	Brief description of the framework/ method
Biodiversity impacts	A novel LCIA method, using circuit theory-based modelling, quantifies forestry land use impacts on ecological connectivity; Characterization Factors (CFs) are provided per m ² /county.
Ecosystem services impacts	Land use CFs assess differences in vegetation's particulate matter removal for biomass production versus a reference system; this indicator is currently under development.
Circularity Indicators	Combined circularity indicators from methods such as the Material Circularity Indicator, Critical Transition indicators, and ISO 59020/2024 are utilized, based on analysis in T3.2
Criticality indicators	An Excel tool evaluates bio-based material criticality using combined indicators from the IRTC tool (metals/minerals) and the BIRD framework (bioeconomy).
Dynamic carbon footprint	Time-dependent global warming indicators (generated via DyPLCA & CCI tools) are integrated over time for a single value, following RE2020 rules for Global Warming Potential (GWP) over 100 years post-product use.
Human Toxicity Novel CFs	A new machine learning method (developed by LIST) generates novel CFs for chemical substances for midpoint ecotoxicity and human toxicity assessments; these are to be added to the Environmental Footprint (EF) method's existing CFs.
Ecotoxicity Novel CFs	Similarly, a machine learning method generates novel CFs for chemicals for midpoint ecotoxicity and human toxicity assessments, supplementing existing EF method CFs.
Occupational Exposure Limits indicator	The qualitative Occupational Exposure Limits (OEL) indicator is suggested for site-specific Social Life Cycle Assessment (S-LCA) studies, usable independently or within a health and safety reference scale.
Process Variables to optimize in the Multi-Objective Optimization framework for all the sectors	Mostly process-based parameters
Job creation Potential	Job Creation Potential (JCP), an S-LCA social indicator, quantifies the total jobs (internal and supplier-based) that can be created by a product system.
Life Cycle Costing indicators	The sum of discounted future cash flows, potentially considering the time value of money.
	Average cost per product unit, indicating the minimum selling price for break-even (Net Present Value = 0).
	Internal Rate of Return (IRR), representing investment return.
	Payback period, the time to recover investment costs.
	Pricing GHG emissions via the EU Emissions Trading System (ETS) at €75 per ton of CO ₂ equivalent.

A process was then defined for selecting the most relevant indicators from the initial pool, by focusing on indicators that demonstrate a strong link to or influence on the selected sectors and the wider regional bioeconomy. This step involved a practical assessment by project partners to filter this pool and identify a preliminary set of relevant indicators based on their expert judgment regarding the relevancy of each indicator. They assigned a score to each indicator reflecting its perceived level of importance or relevance, as shown in Table 2. Based on the project's requirements for clear differentiation, a scoring approach without a middle option was adopted, encouraging partners to make more decisive choices regarding indicator importance.

Table 2 Relevancy scoring description

Score	Relevancy	
1	Very Low Relevancy	The indicator is hardly related to the sector
2	Low Relevancy	The indicator is somewhat related, but not very important.
3	Moderate Relevancy	The indicator is fairly relevant to the sector
4	High Relevancy	The indicator is strongly related to the sector

A key aspect of this participatory assessment was the variation in opinions on the relevance level of an indicator among regional partners. Disagreements were particularly noted when partners' relevance scores for a single indicator showed a significant disparity (e.g., one partner scoring it as low or very low importance (1-2) while another scored it high or very high importance (3-4)). While some participatory methods employ explicit consensus-building workshops or Delphi techniques to resolve disputes, this methodology opted for a quantitative aggregation approach followed by a feedback loop: those scoring higher than a threshold (2.5 for regional and 3 for construction and woodworking sector and 3.1 for textile sectors) were included and then a summary of the results was sent to the partners for their confirmation. This method was chosen due to the large number of disputed indicators, which complicates discussing them separately, given time constraints. This approach yielded a refined shortlist of indicators deemed most relevant for in-depth assessment, based on additional criteria in the subsequent methodological steps. The characteristics of the collected data are presented in Table 3. As it is not possible to include all the indicators in this report, an informational table is included. Please refer to the annex for the complete list of indicators.

Table 3 Summary of the evaluated and short-listed indicators

No. of total indicators evaluated	Shortlisted Indicators			
	Regional	Construction	Textile	Woodworking
409	44	93	88	81

3 MCA STAGE – CRITERIA AND SUBCRITERIA DEVELOPMENT AND SCORING

3.1 Conventional MCA

3.1.1 Definition of criteria and sub-criteria for indicator selection

Following the initial selection of relevant indicators, the subsequent phase involved a detailed assessment based on specific, predefined criteria and sub-criteria. The criteria used for this assessment were developed in collaboration with the project partners. Through multiple interactive meeting sessions and feedback loops, partners contributed to identifying the most critical aspects by which indicators should be judged for their potential utility to policymakers and industry. This ensures the assessment criteria are grounded in the practical realities and information needs of the intended users.

Ultimately, the developed criteria were structured around two main, interrelated categories:

- 1. Incentives and Decision-Making Support (IDMS):** This category focuses on the potential of an indicator to provide meaningful insights that can directly inform strategic decisions, motivate action, track progress towards goals, or reveal opportunities and challenges for policymakers and private sector actors within the bioeconomy.
- 2. Data Quality and Availability (DQA):** This category addresses the practical feasibility of implementing an indicator, considering the reliability, accuracy, timeliness, accessibility, and overall ease of obtaining the necessary underlying data.

For each of these criteria, corresponding sub-criteria were developed, as explained in detail below. Importantly, the current list of sub-criteria is designed to support a bottom-up approach, allowing for the definition of new sets of criteria tailored to the specific aims of future decision-making processes.

3.1.1.1 IDMS – Company point-of-view:

To assess how indicators provide incentives from an industrial private sector viewpoint, the following set of sub-criteria was established. These sub-criteria were designed to capture specific drivers relevant to companies, such as considering regulatory landscapes, reputation and brand, and enhancing market position, which can differ significantly from regional or public sector objectives.

- Innovation and Technological Advancement:** This criterion assesses whether an indicator is related to or stimulates activities that increase the likelihood of innovation and technological advancements within the company or sector. For businesses, innovation is crucial for developing new bio-based products, enhancing processes, gaining a competitive edge, and adapting to shifting market needs and resource availability. (Fernando et al., 2019) Companies can discover how their R&D investments can lead to tangible competitive advantages and track where innovation has a significant impact.
- Legal and Regulatory Risk Management:** This criterion assesses if an indicator can reveal existing or emerging regulatory requirements relevant to the company's bioeconomy activities. Identification of such indicators is essential for proactive risk management, helping companies ensure compliance, avoid penalties, and other reputational losses associated with non-compliance (Whalley & Guzelian, 2017).
In this context, the research by (Ares-Sainz et al., 2025) offers critical insights by systematically identifying key sustainability and governance indicators derived from certification schemes and relevant policy frameworks. Their work highlights the importance of indicators within such systems for industries to demonstrate adherence to regulatory requirements, proactively manage inherent risks in bio-based value chains, and support strategic decision-making in the bioeconomy.
- Supply Chain Risk Identification:** This criterion considers the indicator's usefulness in identifying potential risks within the company's supply chain that could disrupt operations. For businesses reliant on biological resources and complex bio-based value chains, understanding vulnerabilities related to feedstock availability, logistics, or processing is essential (Stampe & Hellingrath, 2021). The escalating frequency and severity of disruptive events, encompassing economic crises, natural disasters, and pandemics, have emphasised the inherent vulnerabilities within supply chains and the importance of risk management.
A study by Al-Sharrah et al. integrated environmental and risk indicators into supply chain optimisation models for process industries, proposing a simplified risk index for sustainability assessment (Ghanima Al-Sharrah et al., 2016). Concurrently, another study, Tseng et al., identified and validated data-driven sustainable supply chain management (SSCM) indicators for the textile industry, categorising them into aspects like "SC risk assessment" and "SC resilience" using a hybrid methodology (Tseng et al., 2022).
- Market Demand:** This criterion evaluates the extent to which an indicator can reveal new or current market demands that may influence a company's competitive positioning. Indicators reflecting consumer preferences for sustainable or bio-based products, market size, growth trends, or shifts in value chains are critical for companies to identify opportunities, tailor product offerings, and maintain market relevance.
Tracking market demand indicators is crucial for navigating today's dynamic and often volatile market landscapes. These indicators, which can range from broad macroeconomic figures like GDP growth and inflation rates that signal the overall health and direction of an economy (Meixell & Wu, 2001) to

more specific product-level "leading indicators" that predict demand trends for particular technology clusters (Gafurdjan Zakhidov, n.d.), provide invaluable insights for forecasting and strategic decision-making.

- **Social Impact:** This criterion evaluates how an indicator affects the local community or society, potentially strengthening or weakening the company's social license to operate. While broad social sustainability is essential, companies specifically focus on aspects of social impact that affect their community relations, workforce stability, and ultimately, the acceptance of their operations by stakeholders.
- **Operational Efficiency and Productivity:** This criterion considers whether an indicator can be leveraged to enhance process efficiency or overall operational productivity within the company. Sustainability indicators, such as those related to resource use efficiency, waste reduction, or energy consumption, can often pinpoint areas for operational improvements, resulting in cost savings and increased productivity.
- **Brand & Reputation Impact:** This criterion evaluates whether an indicator affects the company's brand value, investor confidence, or overall market reputation. A company's performance on sustainability and bioeconomy-related issues is increasingly influencing how customers perceive it, investors (through ESG considerations), and the public, impacting brand loyalty, access to capital, and its overall reputation.

3.1.1.2 IDMS- Policymakers' Point-of-view:

Developing sub-criteria from the regional policymakers' point of view required a holistic view on bioeconomy development. The Food and Agriculture Organization of the United Nations (FAO) report, "Aspirational Principles and Criteria for a Sustainable Bioeconomy" (FAO, 2021), outlines ten aspirational principles developed to guide the transition towards a sustainable and circular bioeconomy globally. These principles were collaboratively developed by the International Sustainable Bioeconomy Working Group (ISBWG), a multi-stakeholder group established in 2016, following a recommendation from 62 ministers of agriculture at the Global Forum for Food and Agriculture in 2015. The development process involved international experts and aimed to create a common ground for discussions on sustainability and circularity, encompassing environmental, social, economic, and governance dimensions. The complete list of the principles is illustrated in Figure 2. This comprehensive set of principles, while non-binding, is designed to be applied by policymakers and other stakeholders in developing and monitoring bioeconomy strategies at various scales, ensuring that sustainability and circularity are embedded from the outset to avoid future risks and trade-offs.

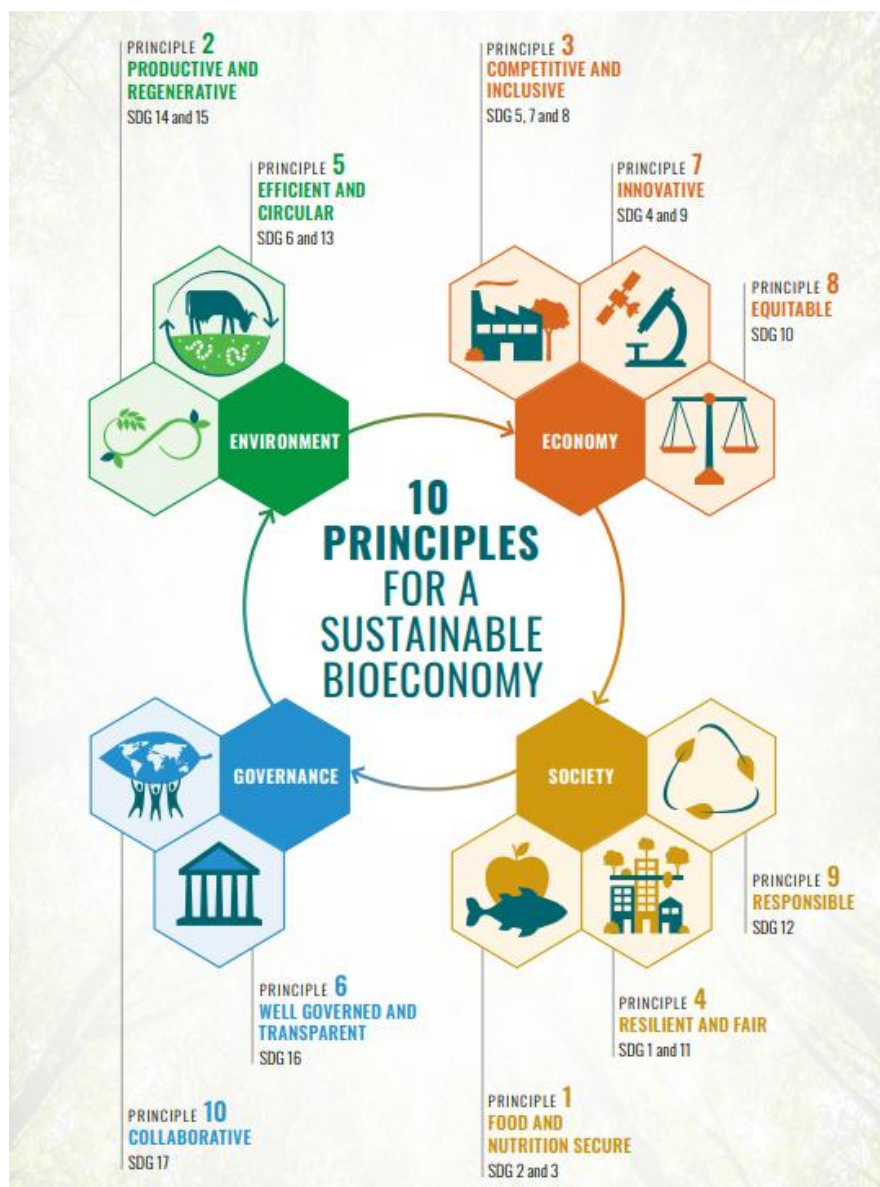


Figure 2 – 10 Aspirational principles for a sustainable bioeconomy (FAO, 2021)

Inspired by these principles, the following criteria were developed.

- Innovation & Technological Advancement (Principles 3 & 7)
- Legal and Regulatory Alignment (Principles 6 & 10)
- Bioeconomy Value Creation (Principle 3)
- Food and Nutrition Security (Principles 1 & 4)
- Sustainable Natural Resource Management (Principles 2, 5 & 9)
- Climate Change Mitigation & Adaptation (Principles 2 & 5)
- Employment & Economic Fairness (Principles 4 & 8)

3.1.1.3 Data Quality & Availability

For the assessment of indicator data quality and availability, a comprehensive approach was adopted, integrating established methodologies from both statistical reporting frameworks and life cycle assessment (LCA) principles. For instance, Eurostat has proposed a scoreboard for selecting indicators within the SDG framework, with parameters focusing primarily on the statistical quality of the indicators, such as timeliness,

data availability, frequency of dissemination, and geographical coverage (European Commission, n.d.). The Bioeconomy Monitoring System (BMS) framework's data quality assessment was also built on Eurostat data quality evaluation criteria (Robert et al., 2020). Complementing these statistical considerations, principles from the pedigree matrix of LCA were utilized for determining the level of uncertainty. Depending on this level of uncertainty, a coefficient of variation is generated which implies the amount of variation as a percentage. The criteria are Technological representativeness, Geographical representativeness, Time-related representativeness, Completeness, Precision/uncertainty, Methodological appropriateness and consistency/accuracy (Weidema & Wesnæs, 1996). Considering that our indicator set comprises a mix of BMS indicators and LCA-based indicators, a combination of these two frameworks was built to be comprehensive.

The following criteria are considered:

- **Data accessibility:** If the data is already available, or if it needs simple/complex calculations to generate
- **Transparency and documentation:** Is the data open-source, request-based, and properly documented?
- **Frequency of dissemination (Updates):** Are data updated yearly, every 2 years, every 3 years, etc.?
- **Comparability over time:** Is the methodology for calculating the indicator stable over time?
- **Timeliness:** How many years does it take for the data of a specific year to be disseminated?
- **Geographical coverage:** If the data is reported for all regions or countries.
- **Technology representativeness (relatable):** If the technology or process used in your study matches the real-life technology it represents or not.
- **Completeness:** Are all necessary data points available without significant gaps?

It is important to note that the inclusion of Accuracy and Precision as a criterion is also important, but the difficulty and impracticality of assessing such criteria for every indicator led to their exclusion from the list.

3.1.2 Scoring method for each criterion

With the assessment criteria categories defined, the next step involved designing the specific methodology for scoring each shortlisted indicator against these criteria. Developing a clear and consistent scoring system is essential for translating qualitative judgments or semi-quantitative information into a format suitable for comparative analysis and aggregation (Singh et al., 2012). Given the distinct nature of the two criterion categories, tailored scoring approaches were developed.

For the DQA criteria, a semi-quantitative to qualitative scoring system was designed. Scoring scales were developed for specific data quality aspects, such as temporal correlation, geographical correlation, technological correlation, reliability, completeness, and accessibility. Partners evaluated each indicator against these aspects, providing ratings or qualitative descriptions based on their knowledge of existing data sources (e.g., the BMS or other relevant datasets) and the practical feasibility of data collection for the target sectors and regions. For indicators related to environmental impact categories, such as EF3.1 and Impact World+ indicators, the robustness of the methodology was considered in relation to data quality. Table 4 demonstrates the scoring criterion.

Table 4 Data Quality and Availability scoring matrix

Criteria	Scoring system			
	D	C	B	A
Data accessibility	Not available or requires complex calculations	Some data is available, but indicators need to be estimated by combining datasets or doing basic calculations	All required data is available and easy to access, but indicator must be calculated (e.g., sum, ratio, %)	Directly available and ready-to-use from a single source
Transparency and documentation	Data is not public, or comes with no explanation	You must request the data, and even then, it has limited explanation	Data is open-source or requestable, and has some documentation	Data is open-source and well-documented
Frequency of dissemination (Updates)	Updated every 4+ years	Updated every 3 years	Updated every 2 years	Updated annually or more frequently
Comparability over time	No data points without methodological break	At least 2 data points without methodological break	At least 3 data points without methodological break	At least 5 data points without methodological break
Timeliness	Released with 4+ years of delay	Released with 3 years of delay	Released with 2 years of delay	Released within 1 year of reference year
Geographical coverage	MS* data represents <50% of EU total or no EU aggregate available	MS data represents 50-75% of EU total and EU aggregate available	MS data represents at least 75-99% of EU total and EU aggregate available	Data for all MS and EU aggregate available
Technology representativeness (relatable)	Data with unknown technology / sector or from distinctly different sector	Data comes from a different sector or technology, but with partial relevance or overlapping features	Data from similar sector or average of sectors with similar technology	Data is from the exact sector, material, or process being studied
Completeness	There are 5+ data points missing	There are 3-4 data points missing	There are 1-2 data points missing	All data points are available
Accuracy & Precision	Data is based on assumptions, expert judgment, or unclear origin and varies significantly across sources or time	Estimated data from grey literature or weak databases; moderate inconsistencies or unexplained variation	Data from reliable sources like recognized databases, but modelled or with some variation across sources or time	Directly measured or peer-reviewed data from trusted sources; stable across years and between sources

For the IDMS criteria, a more holistic scoring approach was adopted to capture the potential utility of each indicator from the perspective of policymakers and industry users. Instead of quantitative metrics, this method relies on expert judgment guided by a set of key principles and guiding questions. These guiding questions prompt scorers to consider various facets, such as the indicator's ability to inform strategic planning, highlight trade-offs, track policy effectiveness, reveal business opportunities, or function as a performance benchmark. They are neither exhaustive nor limiting but serve to stimulate comprehensive reflection on the indicator's potential value for decision support and creating incentives within the bioeconomy sectors. Utilising guiding questions in expert assessments is a recognised method to structure subjective evaluations while allowing for the incorporation of expert knowledge and contextual understanding (Pradhan et al., 2017; Rowe & Frewer, 2000).

The detailed scoring methodologies, including the specific scales or guiding questions for each criterion, were documented and provided to all project partners to ensure a common understanding and approach during the scoring process conducted in the subsequent step. Table 5 and Table 6 showcase the guiding questions. It is essential to note that the questions are provided solely to guide the assessment; however, the list is not intended to be exhaustive. The partners were instructed that when evaluating, the goal is not to assess whether each indicator answers all the questions, but to assess how well each indicator addresses the questions that are applicable to it.

The criteria are scored from A to D, where A indicates the highest relation and connection between the indicator and the criterion concepts, and D indicates the lowest.

Table 5 IDMS criteria for company perspective

IDMS Company Perspective	To score this criterion, ask yourself:
Innovation & Technological Advancement	■ Does the indicator involve or reflect the use of new technologies, materials, or systems? ■ Does it reflect an environment that supports innovation (e.g., policy incentives, infrastructure, market readiness, investments, etc.)? ■ Does it track innovation outcomes, such as adoption, performance improvements, or R&D outputs?
Legal and Regulatory Risk Management	■ Does this indicator reflect a value that is directly limited or regulated by existing law or regulation? ■ Is the indicator monitored by authorities for compliance with existing legislation? ■ Is it linked to eligibility for public subsidies, permits, or environmental licenses? ■ Is the indicator covered by mandatory reporting frameworks or compliance audits?
Supply Chain Risk Identification	■ Does the indicator highlight dependency on specific inputs, or regions? ■ Does it reflect disruption factors that could affect the operation (e.g., political instability, climate risks, price volatility)? ■ Does it help assess the resilience or fragility of the upstream or downstream supply chain?
Market Demand	■ Does it link to a consumption of a specific product/service of interest? ■ Does the indicator reflect customer or societal preferences that is linked to your category of products/services? ■ Does it capture movement toward niche or premium markets that offer strategic positioning potential?
Operational Efficiency and Productivity	■ Is it related to the technical performance of your production process?
Social Impact	■ Would this indicator be linked to publicly sensitive issues with growing societal pressure? (e.g. related to animal welfare, climate justice, biodiversity loss, etc.) ■ Does the indicator reflect an impact on people's health, safety, living conditions, or human rights? ■ Could poor performance on this indicator lead to social tension, protests, or reputational pressure from the public or NGOs? ■ Is it tied to vulnerable or marginalized groups (e.g., farmers, indigenous communities, low-income households)?

Table 6 IDMS for Regional Perspectives

IDMS Regional Perspective	To score this criterion, ask yourself:
Innovation & Technological Advancement	■ Does this indicator track concrete results of innovation within our region? ■ Does it show that existing knowledge is used, or innovation is promoted? ■ Does it involve or reflect the use of new technologies, materials, or systems? ■ Does it track innovation outcomes, such as adoption, performance improvements, or R&D outputs?
Legal and Regulatory Alignment	■ Is this indicator directly linked to existing regulations or policy objectives? ■ Does it highlight areas where new regional legal frameworks might be needed?
Supply Chain Resilience	■ Does it show the security or stability of regional bio-based sourcing? ■ Does it identify vulnerabilities in regional bioeconomy value chains? ■ Does it show external factors affecting supply chain stability (e.g., disasters)? ■ Does it show regional import reliance for key bio-based materials or products? ■ Does it show regional biomass supply (quantity, origin, security)? ■ Does it highlight causes of regional supply chain risk (e.g., external reliance, internal issues)?
Social Impact and Public Concern	■ Does it show impacts of the regional bioeconomy on the health, safety, or quality of life of regional communities or workers? ■ Does it help to measure public or consumer attitudes, acceptance, or concerns regarding bioeconomy? ■ Can this indicator show equity or fairness aspects of the bioeconomy, such as income distribution, access to opportunities, or treatment of specific social groups (e.g., gender, age, smallholders)?
Bioeconomy Value Creation	■ Does this indicator measure economic size or value generated by bioeconomy sectors? ■ Can this indicator show the creation or growth of new bio-based products, markets, or value chains within the region? ■ Does the indicator track financial investment or economic efficiency within the regional bioeconomy (e.g., capital flows, productivity, profitability)? ■ Does this indicator help assess the economic competitiveness or market performance of regional bio-based products or sectors?
Food and Nutrition Security	■ Does this indicator relate to regional food security, addressing aspects like competition for resources, food availability, accessibility, or quality?
Sustainable Natural Resource Management	■ Does this indicator track the state or health of key regional biological resources (e.g., forests, fish stocks, agricultural biomass potential)? ■ Does it show regional bioeconomy resource efficiency or sustainable practices? ■ Does it monitor sustainable regional resource use or extraction rates?
Climate Change Mitigation & Adaptation	■ Does it show regional efforts, policies, or investments aimed at climate change mitigation or adaptation? ■ Does this indicator measure regional GHG emissions, removals (sequestration), or the carbon footprint? ■ Can this indicator show the contribution of the regional bioeconomy to climate change mitigation?
Employment & Economic Fairness	■ Does it measure regional bioeconomy jobs (creation, levels, types)? ■ Does it help assess aspects of economic fairness or equity related to the regional bioeconomy? ■ Does it show the quality of employment or working conditions within the regional bioeconomy?

Following the design of the criteria scoring methodologies, the project partners proceeded to conduct a detailed assessment of the shortlisted indicators. Within the two main categories, IDMS and DQA, the basis for the scoring differed depending on the nature of the criterion being assessed. For the Data Quality and Availability criteria, partners used available documentation related to the indicators and relevant data sources. For the IDMS criteria, scoring was primarily based on the partners' expert judgment and experience within academic research and industry practice.

Considering the long list of shortlisted indicators, the indicators were split among the partners according to their expertise and available resources. The scores assigned by each partner for every criterion of every indicator were systematically recorded on the shared online platform.

A snippet of the framework, as filled in by the partners, is presented in Figure 3. The full table of results is also available in the annex.

Indicator Category	Indicators List	Innovation & Technological Advancement	Legal and Regulatory Alignment	Supply Chain Resilience	Social Impact and Public Concern	Bioeconomy Value Creation
		- Does this indicator track concrete results of innovation within our region? - Does it show that existing knowledge is used or innovation is promoted? - Does it involve or reflect the use of new technologies, materials, or systems? - Does it track innovation outcomes, such as adoption, performance improvements, or R&D outputs?	- Is this indicator directly linked to existing regulations or policy objectives? - Does it highlight areas where new regional legal frameworks might be needed?	- Does it show the security or stability of regional bio-based sourcing? - Does it identify vulnerabilities in regional bioeconomy value chains? - Does it show external factors affecting supply chain stability (e.g., disasters)? - Does it show regional import reliance for key bio-based materials or products? - Does it show regional biomass supply (quantity, origin, security)? - Does it highlight causes of regional supply chain risk (e.g., external reliance, internal issues)?	- Does it show impacts of the regional bioeconomy on the health, safety, or quality of life of regional communities or workers? - Does it help to measure public or consumer attitudes, acceptance, or concerns regarding bioeconomy? - Can this indicator show equity or fairness aspects of the bioeconomy, such as income distribution, access to opportunities, or treatment of specific social groups (e.g., gender, age, smallholders)?	- Does this indicator measure economic size or value generated by bioeconomy sectors? - Can this indicator show the creation or growth of new bio-based products, markets, or value chains within the region? - Does the indicator track financial investment or economic efficiency within the regional bioeconomy (e.g., capital flows, productivity, profitability)? - Does this indicator help assess the economic competitiveness or market performance of regional bio-based products or sectors?
Local economies of countries exporting	Social condition in exporting countries (to	D: Very weak connection	A: Strongly related	B: Moderately related	B: Moderately related	D: Very weak connection
Demand and supply-side market mecha	Market or consumers acceptance	A: Strongly related	D: Very weak connection	A: Strongly related	A: Strongly related	A: Strongly related
Hotspots T1.2	EF3.1 Climate Change	A: Strongly related	A: Strongly related	A: Strongly related	A: Strongly related	B: Moderately related
Hotspots T1.2	EF3.1 Particulate matter	B: Moderately related	A: Strongly related	C: Weak connection	A: Strongly related	C: Weak connection
Hotspots T1.2	EF3.1 Acidification	C: Weak connection	C: Weak connection	C: Weak connection	C: Weak connection	C: Weak connection
Hotspots T1.2	EF3.1 Resource use, fossils	B: Moderately related	C: Weak connection	B: Moderately related	B: Moderately related	C: Weak connection
Hotspots T1.2	EF3.1 Land use	C: Weak connection	C: Weak connection	C: Weak connection	C: Weak connection	C: Weak connection
Hotspots T1.2	EF3.1 Water use	A: Strongly related	B: Moderately related	B: Moderately related	B: Moderately related	B: Moderately related
Hotspots T1.2	EF3.1 Photochemical ozone formation	C: Weak connection	C: Weak connection	C: Weak connection	C: Weak connection	C: Weak connection
Hotspots T1.2	EF3.1 Human toxicity, non-cancer	C: Weak connection	C: Weak connection	C: Weak connection	C: Weak connection	C: Weak connection
Hotspots T1.2	EF3.1 Human toxicity, cancer	C: Weak connection	C: Weak connection	C: Weak connection	C: Weak connection	C: Weak connection
IMPACT WORLD+ V2.1 (Mid-Point Level)	Climate change, short term, fossil	A: Strongly related	A: Strongly related	A: Strongly related	A: Strongly related	B: Moderately related
VALUE CHAIN ACTORS	Corruption	No apparent link. The indicator has B: Moderately related	C: Weak connection	C: Weak connection	B: Moderately related	D: Very weak connection
WORKERS	Child Labour	No apparent link. The indicator has B: Moderately related	C: Weak connection	C: Weak connection	A: Strongly related	D: Very weak connection
WORKERS	Fair Salary	No apparent link. The indicator has B: Moderately related	C: Weak connection	C: Weak connection	B: Moderately related	B: Moderately related
WORKERS	Freedom of Association & Collective Barg	No apparent link. The indicator has No apparent link. The indicator	No apparent link. The indicator has no n	No apparent link. The indicator has no n	C: Weak connection	No apparent link. The indicator has n
Health and Safety	Occupational toxics and hazards	B: Moderately related	A: Strongly related	No apparent link. The indicator has no n	B: Moderately related	No apparent link. The indicator has n
Health and Safety	Occupational injuries and deaths	B: Moderately related	A: Strongly related	No apparent link. The indicator has no n	A: Strongly related	No apparent link. The indicator has n
Governance	Legal system	No apparent link. The indicator has B: Moderately related	C: Weak connection	C: Weak connection	B: Moderately related	D: Very weak connection

Figure 3 A snippet of the IDMS sub-criteria scoring

3.2 Aggregation of the results

The final stage of the methodological process involved aggregating the individual partner scores.

3.2.1.1 Criteria Weighting:

One approach to assessing the indicators is the weighted sum model or the simple additive model, where each criterion is given a weight according to its importance. The weighting of criteria differed between the two main assessment categories.

For the DQA, not all criteria were considered equally important. A double weight (x2) was assigned to the criteria of "Data Accessibility" and "Transparency and Documentation". This decision was based on the principle that data can only be practically utilized if it is available and accompanied by sufficient documentation to validate its credibility. All other DQA criteria received a standard weight (x1), as they could be partially compromised depending on specific project needs.

For the IDMS criteria, equal weighting was applied. This approach ensures that all criteria are given the same level of importance in the baseline assessment. It is acknowledged, however, that for specific applications, weights would need to be assigned based on the unique context of the study, such as the market, country, or policy scenario.

3.2.1.2 Quantitative Scoring Transformation

As the initial scores were qualitative (A to D), a transformation to a quantitative scale was required for the analysis. For the DQA criteria, a linear scoring system was adopted as shown in Table 7.

Table 7 Qualitative to Quantitative scoring for DQA criteria

Qualitative score	A	B	C	D	No information
Quantitative representation (C_n)	4	3	2	1	0

The overall score of each indicator is the sum of the score of each criteria considering their weight:

$$Data\ Q\&A = \sum_{n=1}^m (C_n \times W_n) \quad (\text{Eq. 1})$$

For the IDMS criteria, a non-linear scoring approach was chosen, as detailed in Table 8.

Table 8 Qualitative to Quantitative scoring for IDMS criteria

Qualitative score	A	B	C	D	Not relevant
Quantitative representation (C_n)	20	7	3	1	0

This non-linear scale was selected to assign significantly greater value to indicators that achieved the highest score (A) for any given criterion, thereby promoting the selection of indicators that demonstrate excellence in specific areas. The total IDMS score was then calculated as the sum of these converted scores:

$$IDMS = \sum_{n=1}^m C_n \quad (\text{Eq. 2})$$

3.2.1.3 Mono-Dimensionality

Beyond the composite scores, two additional metrics were developed to visualize the characteristics of each indicator.

- **Mono-Dimensionality (Specificness):** In contrast, this metric measures an indicator's performance on its three strongest criteria, highlighting specialized excellence. It was calculated by averaging the three highest scores an indicator received for the IDMS criteria.

$$\text{Mono - Dimensionality (Specificness)} = \frac{\text{Max} (n_1 + n_2 + n_3)}{3} \quad (\text{Eq. 3})$$

A high score for both "IDMS" and "Specificness" suggests a highly versatile and useful indicator. Conversely, a low score for both implies limited utility. Importantly, a high "Specificness" score can identify a valuable, specialized indicator even if its overall IDMS score is modest, preventing potentially useful indicators from being overlooked.

The next step was to average the scores provided by all project partners for each criterion, resulting in a single aggregated score for each indicator within the two main categories. This produces a multi-dimensional performance profile for each indicator based on the collective expert judgment of the consortium.

Following the aggregation process, the results are intended for an analysis in which the contrasts and similarities among the various indicators are systematically compared.

4 ASSESSMENT AND COMMUNICATION STAGE – FORMULATION OF RECOMMENDATIONS

4.1 Results and analysis of the Multi-Criteria Analysis

Following the scoring of indicators against a set of predefined criteria and sub-criteria, a multi-dimensional performance profile was generated for each indicator. This scoring process is grounded in the collective expert judgment of the CALIMERO project, combining methodological robustness with practical insight across different sustainability dimensions.

For each sector and regional context, two complementary types of visualisations were produced. The first is the indicator distribution graph, which plots each indicator according to its IDMS score (reflecting its strategic importance or incentive for implementation) and DQA score (reflecting data quality and methodological maturity). Each point on the graph represents an indicator, colour-coded by thematic area, with a directional arrow indicating its mono-dimensionality score.

Each plot is divided into four quadrants, offering a strategic lens through which to interpret indicator positioning. Indicators in Quadrant 1 (top-right) represent the most desirable combination of high strategic value and high implementation feasibility and are therefore recommended for inclusion in monitoring frameworks. In contrast, indicators in Quadrant 4 (bottom-right) are also strategically important but are limited by poor data quality or weak methodological development. These indicators represent critical development gaps and should be prioritised for future refinement, investment, and methodological strengthening.

It is important to note that all indicators visualised in this analysis were pre-selected based on their relevance to sectoral and regional sustainability goals. As such, their position in the charts reflects not whether they are relevant, but how developed they are for use in operational frameworks. The following sections provide a detailed analysis of these indicators, organised by sector and region, drawing on both the quadrant positioning and the criteria radar profiling.

4.2 Textile sector

The multi-criteria analysis for the textile sector presents a unique profile, characterised by a dense clustering of indicators around the centre of the graph (Figure 4). This high concentration, particularly along the IDMS axis between 0.4 and 0.7, makes the distinction between quadrants less sharp than in other analyses. It suggests that for this sector, it is possible to redefine the quadrants to include or exclude more indicators. The most strategically relevant indicators for the textile industry are found in Quadrants 1 and 4, which both feature high IDMS scores.

Quadrant 1 (the "Ideal" indicators) contains a balanced mix of themes. It features Circularity metrics, such as #51 (Circular material rate) and #5 (End-of-life recycling rate), as well as other impact-based indicators (#17-19), demonstrating that core circular economy principles are considered actionable. Furthermore, Social indicators focusing on worker rights, such as #82 (Forced Labor) and #83 (Freedom of Association), Migrant labour and corruption were both critical and have high-quality data, which comes from the SHDB database. Some environmental and toxicity aspects, such as Ecotoxicity, freshwater human toxicity, water scarcity and phosphate in rivers, were also in this region. These indicators represent a well-rounded and robust starting point for any textile-specific sustainability framework and should be prioritised for adoption.

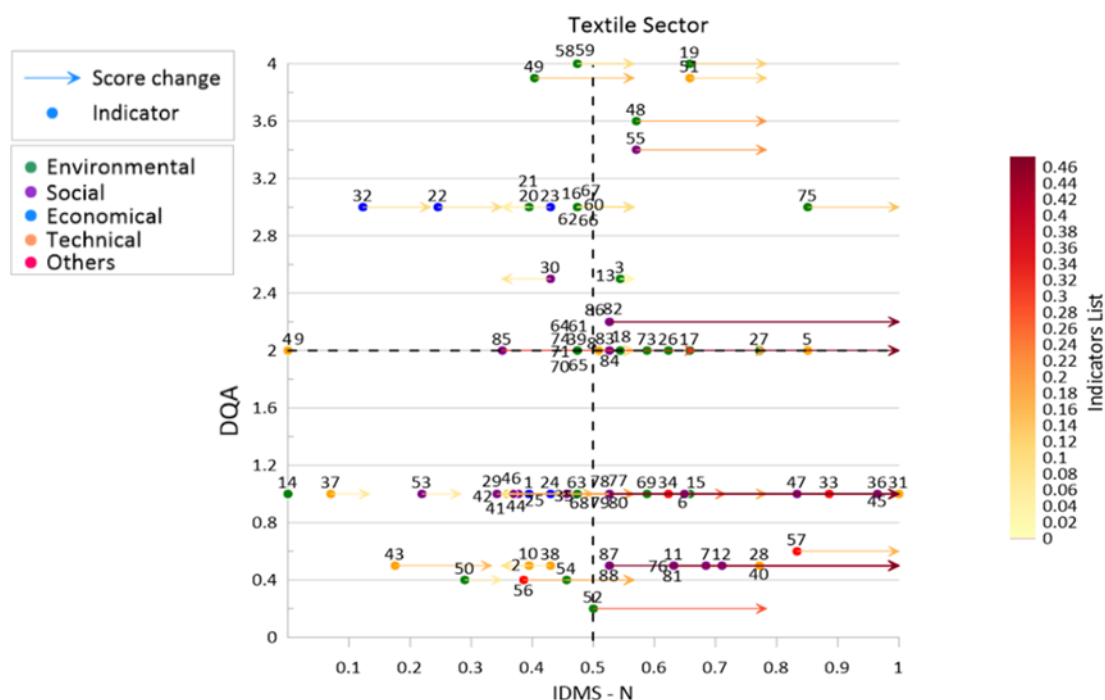


Figure 4 Textile sector indicators distribution

Quadrant 4 (The "Critical but Challenging" Indicators) pinpoints the most significant gaps between the industry's monitoring needs and its current measurement capabilities. This quadrant is overwhelmingly dominated by Social indicators and advanced Circularity/Technical metrics. Foundational social issues like #78 (Child Labour), #79 (Fair Salary), and multiple Health and Safety indicators (#12, #76,) are all located here. Their high IDMS scores confirm their importance, but their low DQA signals a major gap in the ability to monitor them effectively across complex global supply chains. Likewise, advanced circularity concepts like #40 (Reuse rate in closed loop) and #33 (Percent of water demand from circular sources) are desired but not yet readily measurable. This quadrant provides a clear roadmap for the future, highlighting where investment in creating more robust methodologies and data quality enhancement is needed.

Table 9 Textile sector relevant indicators classification

Green= Environmental, Purple= Social, Blue= Economical, Orange= Technical and Red= Others

Q1 (High Quality High incentives)	Q2 (High Quality -Low Incentives)	Q3 (Low Quality- Low Incentives)	Q4 (Low Quality- High Incentives)
51. Circular material rate (BMS)	60. EF3.1 Acidification (HT1.2)	1. Average lifetime of a product or material relative to an industry average (Circularity)	78. Child Labour (PSILCA)
86. Corruption (SHDB)	58. EF3.1 Climate Change (HT1.2)	2. Average number of cycles of a product or material for the defined use phase relative to an industry average (Circularity)	87. Child labour (Social HS)
3. Ecotoxicity, freshwater (CALIMERO)	67. EF3.1 Eutrophication, freshwater (HT1.2)	53. Economic impact of trade in exporting countries (to EU) (BMS)	77. Corruption (PSILCA)
5. End-of-life recycling rate (Circularity)	62. EF3.1 Eutrophication, marine (HT1.2)	63. EF3.1 Ecotoxicity, freshwater (HT1.2)	69. EF3.1 Human toxicity, cancer (HT1.2)

Q1 (High Quality High incentives)	Q2 (High Quality -Low Incentives)	Q3 (Low Quality- Low Incentives)	Q4 (Low Quality- High Incentives)
82. Forced Labor (SHDB)	66. EF3.1 Eutrophication, terrestrial (HT1.2)	68. EF3.1 Human toxicity, non-cancer (HT1.2)	52. Environmental impacts based on product-based LCA and basket of representative products of the bioeconomy (BMS)
8. Fraction of biological materials used which originate from Sustained Production (Circularity)	64. EF3.1 Land use (HT1.2)	54. Environmental footprints in exporting countries (to EU) (BMS)	6. Equal opportunities/ discrimination (PSILCA)
83. Freedom of Association, Collective Bargaining, and Right to Strike (SHDB)	59. EF3.1 Particulate matter (HT1.2)	10. Fraction of the product going to component reuse (Circularity)	79. Fair Salary (PSILCA)
73. Human toxicity cancer (IW+)	61. EF3.1 Resource use, fossils (HT1.2)	14. Impacts of a substituted valorization process (Circularity)	88. Fair salary Social (HS)
13. Human Toxicity, total (CALIMERO)	65. EF3.1 Water use (HT1.2)	56. Market or consumers acceptance (BMS)	7. Forced labour Social (HS)
17. Impacts of the recycling process at the end of life (Circularity)	4. Efficiency of the recycling process at the EoL (Circularity)	24. Market situation of a consumed recycled material (Circularity)	80. Freedom of Association & Collective Bargaining (PSILCA)
18. Impacts of the recycling process for the recycled content (Circularity)	9. Fraction of the product being collected for recycling at EoL (Circularity)	25. Market situation of a produced recycled material (Circularity)	76. Health & Safety (Society) (Social HS)
19. Impacts of the substituted energy source (Circularity)	70. Freshwater acidification IW+	29. Number of times a product is hired (Circularity)	12. Health and Safety (Workers) (Social HS)
26. Mass of unrecoverable waste generated during the recycling process at EoL (Circularity)	71. Freshwater ecotoxicity (IW+)	35. Poverty alleviation (PSILCA)	15. Impacts of a substituted waste treatment process (Circularity)
27. Mass of unrecoverable waste generated during the recycling process for the recycled content (Circularity)	74. Human toxicity non-cancer (IW+)	37. Quality degradation of recycled material (Circularity)	28. Multiple recycling loops in cascades (Circularity)
84. Migrant labour (SHDB)	16. Impacts of the consumed primary raw material (Circularity)	38. Remanufacturing rate (Circularity)	57. Number of labelled or certified bio- based products (BMS)
48. Phosphate in rivers (BMS)	20. Impacts of the substituted production of primary raw materials (Circularity)	41. Safe & healthy living conditions (PSILCA)	31. On-site water circulation (reuse & recycle) (Circularity)
55. Social conditions in exporting countries (to EU) (BMS)	21. Impacts of waste disposal without energy/raw material recovery (Circularity)	42. Sexual harassment (PSILCA)	33. Percent of water demand that is derived from circular sources (Circularity)

Q1 (High Quality High incentives)	Q2 (High Quality -Low Incentives)	Q3 (Low Quality- Low Incentives)	Q4 (Low Quality- High Incentives)
75. Water scarcity (IW+)	22. Internal Rate of Return (IRR) (CALIMERO)	50. Share of renewable energy in gross final energy consumption of bio based industries or bioenergy industries (BMS)	34. Potential uses of a produced recycled material (Circularity)
	23. Life Cycle Costing (LCC) (CALIMERO)	43. Share of water consumed in process and operations that leaves the infrastructure for reuse by another organization or it is returned to the water source with the same/better quality (Circularity)	36. Public commitments to sustainability issues (PSILCA)
	30. Occupational Exposure Limits (OEL) indicator (CALIMERO)	44. Social benefits / social security (PSILCA)	40. Reuse rate in closed loop (Circularity)
	32. Payback Period (PP) (CALIMERO)	46. Wealth distribution (PSILCA)	45. Transparency (PSILCA)
	39. Renewable material content (Circularity)		47. Working hours (PSILCA)
	49. Share of renewable energy in gross final energy consumption (BMS)		
	85. Social Benefits (SHDB)		

While the vector plot (Figure 4) demonstrates the overall performance of individual indicators, it does not show how different indicator sets (e.g., "Total" vs. "High IDMS") perform against each specific sub-criterion. Figure 5 addresses this by presenting the thematic profile, or strength, of the relevant textile sector indicators.

Each axis on the radar chart quantifies this profile by showing the number of indicators within a set that received a high score ('A' or 'B') for that particular criterion. In effect, this representation reveals the collective "personality" or strategic orientation of each indicator group, clarifying which themes are strongly represented and which are lacking. To achieve a balanced selection of indicators, we should aim for a relatively even distribution. For the total indicators in textile, we can see a higher relation for criteria 7, 6 and 5. These major criteria are more influential in the sector as the majority of the indicators are highly associated with them.

Considering the high IDMS (grey line) as a selection of the total relevant indicators, we can see they follow a similar pattern to the total indicators (blue line). Here, if any criteria are deemed underrepresented, the total indicator list can be consulted, and indicators with high mono-dimensionality scores can be included, or if they are overrepresented, some less important indicators can be removed.

The Annexe can be consulted for the complete list of indicators and their scores for each criterion.

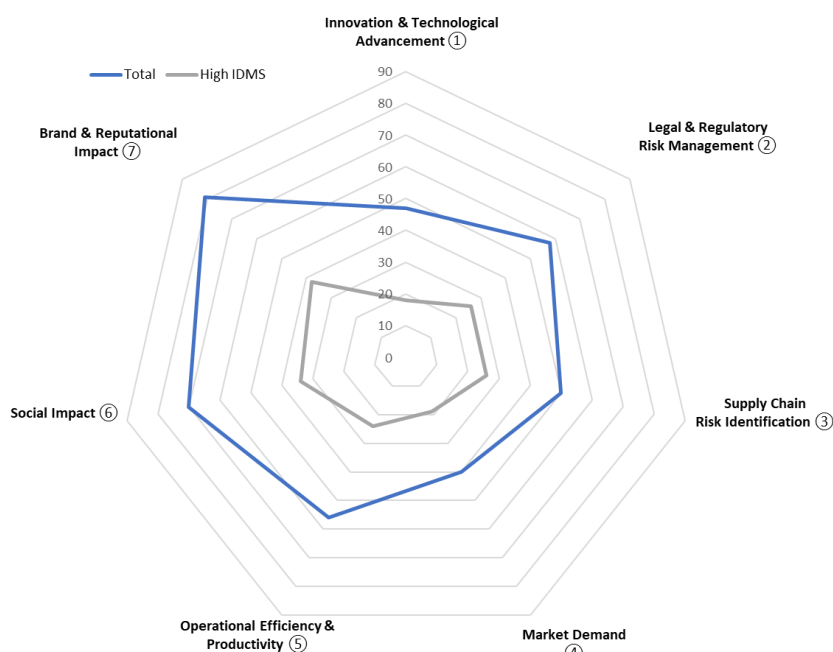


Figure 5 Profile/Strength of the textile sector indicators based on the IDMS criteria

4.3 Woodworking sector

The multi-criteria analysis for the Woodworking sector presents a more structured profile compared to the textile sector, with more precise quadrant boundaries and a broader spread of indicator distribution (Figure 6). A significant cluster of indicators appears along the IDMS axis between 0.5 and 0.9, particularly in Quadrants 1 and 4, suggesting that many relevant indicators are strategically valuable from an incentive standpoint. Unlike the textile sector's central concentration, woodworking allows for more definitive quadrant-based prioritisation. The most strategically relevant indicators for the woodworking industry are again found in Quadrants 1 and 4, which feature high IDMS scores.

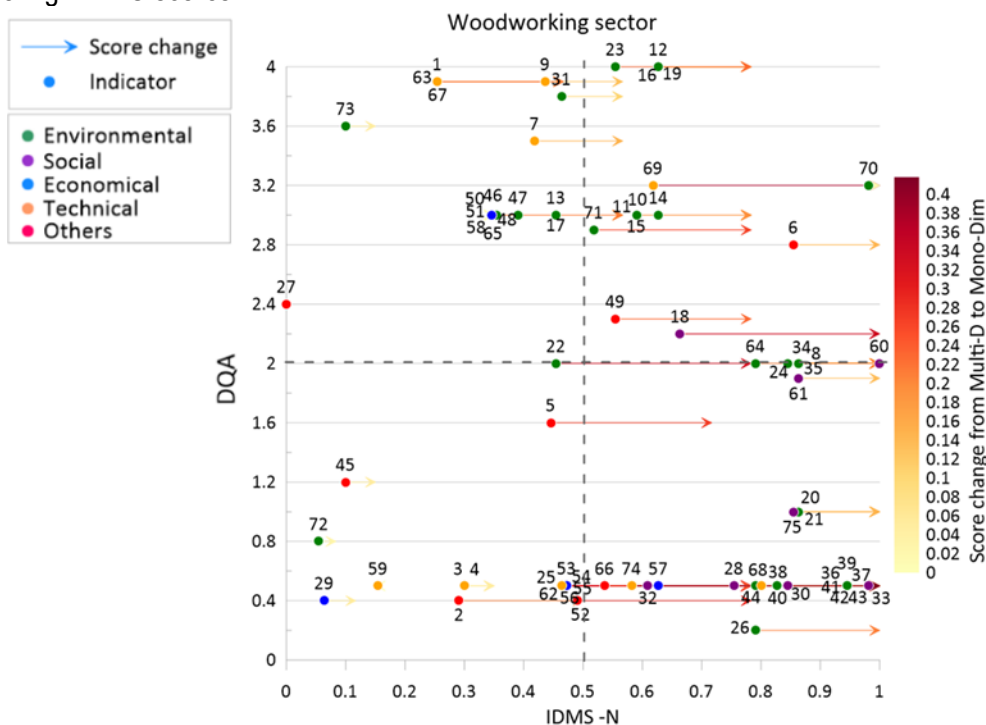


Figure 6 Woodworking sector indicators distribution

Quadrant 1 (The “Ideal” Indicators) contains a dominant share of climate-related metrics, especially those measuring long-term, biogenic and fossil emissions (e.g., indicators #10–16). These reflect the sector’s heavy reliance on biomass and forestry resources, making such indicators highly actionable and relevant. Other environmental indicators, such as resource use, particulate emissions, and certified forests (#8), are also positioned in this quadrant.

Importantly, key Social and Governance themes are represented as well, such as #18 (Corruption, SHDB), reinforcing the robustness of this quadrant across impact areas. These indicators represent the core monitoring backbone for the woodworking sector and should be prioritised in sustainability framework due to both their quality and strategic importance.

Quadrant 4 (The “Critical but Challenging” Indicators) pinpoints major data and methodology gaps in otherwise critical thematic areas. Here, we see a concentration of social indicators such as: #28 (Fair Salary), #30 (Forced Labour), #32 (Freedom of Association), #33 (Health and Safety – Social HS), and #75 (Working Hours).

These reflect essential social conditions that are difficult to monitor across distributed, often informal supply chains. Their presence in this quadrant highlights the need for capacity-building in data quality and collection practices.

Also present are complex Circularity indicators, such as:

- #40–#44 (impacts and substitution processes at the end-of-life stage),
- #33 (Percent of water demand from circular sources), and
- #26 (Environmental impacts based on LCA).

These metrics are conceptually strong and reflect emerging priorities, but they are not yet widely supported by high-quality data or standardised methods. This quadrant outlines a clear development agenda for the sector, both in social sustainability and in end-of-life material flow analytics.

Table 10 Woodworking sector relevant indicators classification

Green= Environmental, Purple= Social, Blue= Economical, Orange= Technical and Red= Others

Q1	Q2	Q3	Q4
6. Candidate List of substances of very high concern for Authorisation (Criticality)	1. Adhesive concentration (%) (CALIMERO)	2. Adoption of new bioeconomy technology... (BMS)	20. EF3.1 Human toxicity, cancer (HT1.2)
8. Certified forests (BMS)	7. Cascade use of wood resources (BMS)	3. Average lifetime of a product... (Circularity)	21. EF3.1 Human toxicity, non-cancer (HT1.2)
10. Climate change, long term, biogenic (IW+)	9. Circular material rate (BMS)	4. Average number of cycles of a product... (Circularity)	26. Environmental impacts based on product-based LCA... (BMS)
11. Climate change, long term, CO2 uptake (IW+)	13. Climate change, long term, land transformation (IW+)	5. By-product dependency (Criticality)	28. Fair Salary (PSILCA)
12. Climate change, long term, fossil (IW+)	17. Climate change, short term, land transformation (IW+)	25. Efficiency of the recycling process... (Circularity) - Others	30. Forced labour (Social HS)
14. Climate change, short term, biogenic (IW+)	22. EF3.1 Land use (HT1.2)	29. Financial support to bio-based sectors... (BMS)	32. Freedom of Association & Collective Bargaining (PSILCA)

15. Climate change, short term, biogenic (IW+)	27. Export restrictions between 2017-2020 (Criticality)	45. Import dependencies for energy... (BMS)	33. Health and Safety (Social HS)
16. Climate change, short term, fossil (IW+)	31. Forest growing stock (BMS)	52. Market or consumers acceptance (BMS)	36. Impacts of a substituted valorization process (Circularity)
18. Corruption (SHDB)	46. Internal Rate of Return (IRR) (CALIMERO)	53. Market situation of a consumed recycled material (Circularity)	37. Impacts of a substituted waste treatment process (Circularity)
19. EF3.1 Climate Change (HT1.2)	47. Land occupation, biodiversity (IW+)	54. Market situation of a produced recycled material (Circularity)	38. Impacts of the consumed primary raw material (Circularity)
23. EF3.1 Particulate matter (HT1.2)	48. Land transformation, biodiversity (IW+)	55. Market situation of consumed recovered energy (Circularity)	39. Impacts of the energy recovery process (Circularity)
24. EF3.1 Resource use, fossils (HT1.2)	50. Levelized Cost of Production (LCOP) (CALIMERO)	56. Market situation of produced recovered energy (Circularity)	40. Impacts of the recycling process at the end of life (Circularity)
34. Human toxicity cancer (IW+)	51. Life Cycle Costing (LCC) (CALIMERO)	59. Number of times a product is hired (Circularity)	41. Impacts of the recycling process for the recycled content (Circularity)
35. Human toxicity non-cancer (IW+)	58. Net Present Value (NPV) (CALIMERO)	62. On-site water circulation... (Circularity)	42. Impacts of the substituted energy source (Circularity)
49. Land-use regulation (Criticality)	63. Operating temperature (°C) (CALIMERO)	72. Share of wood-based constructions (BMS)	43. Impacts of the substituted production of primary raw materials (Circularity)
60. Occupational injuries and deaths (SHDB)	65. Payback Period (PP) (CALIMERO)		44. Impacts of waste disposal without energy/raw material recovery (Circularity)
64. Particulate matter formation (IW+)	67. Pressing time (s) (CALIMERO)		57. Material productivity (Circularity)
69. Resource stocks (Criticality)	73. Share of woody biomass used for energy (BMS)		61. Occupational toxics and hazards (SHDB)
70. Roundwood removals (BMS)			66. Potential uses of a produced recycled material (Circularity)
71. Share of forest area (BMS)			68. Renewable material content (Circularity)
			74. The efficiency of the energy recovery process (Circularity)
			75. Working hours (Social HS)

While the vector plot (Figure 6) demonstrates the overall performance of individual indicators, it does not show how different indicator sets (e.g., "Total" vs. "High IDMS") perform against each specific sub-criterion. Figure 7 addresses this by presenting the thematic profile, or strength, of the relevant Woodworking sector indicators. Each axis on the radar chart quantifies this profile by showing the number of indicators within a set that received

a high score ('A' or 'B') for that particular criterion. In effect, this representation reveals the collective "personality" or strategic orientation of each indicator group, clarifying which themes are strongly represented and which are lacking. To ensure a balanced selection of indicators, we should look for a relatively even distribution across all axes.

In the case of woodworking, we see stronger performance in all the Criteria except 2, and 3. These are highly influential themes in the sector, reflecting its dependency on forestry-based inputs and material flows.

Interestingly, the High IDMS set (grey line) follows a similar pattern to the Total set (blue line), indicating that the strategically relevant indicators are well aligned with the broader indicator pool. This supports the conclusion that the sector is focused on thematically appropriate areas.

However, criteria 2 and 3 appear underrepresented, particularly in the "High IDMS" set, revealing a potential gap in the monitoring framework's coverage. The nature of this underrepresentation differs between the two criteria. For criteria 2, it is noteworthy that almost all indicators from the "Total" set that are strong in this area are also retained in the "High IDMS" set. This indicates that while few indicators cover this criterion, those that do are among the highly valuable and strategically important overall. In contrast, criteria 3 displays the opposite behaviour. The number of representative indicators is significantly reduced when moving from the "Total" set to the "High IDMS" set. This suggests that the existing indicators for this criterion, while present in the initial pool, were not deemed as strategically important.

This analysis points to a clear strategy for balancing the final indicator framework. If more indicators are needed to cover criteria 3, the "Total" indicator list can be revisited to identify high-quality candidates. Specifically, one could search for indicators that possess a high Mono-dimensionality score for this particular criterion even if their overall IDMS score is lower. Conversely, for potentially overrepresented areas like criteria 1, less strategic indicators could be deprioritized to maintain a more focused and balanced thematic profile. The annex can be consulted for the complete list of indicators and their scores for each criterion.

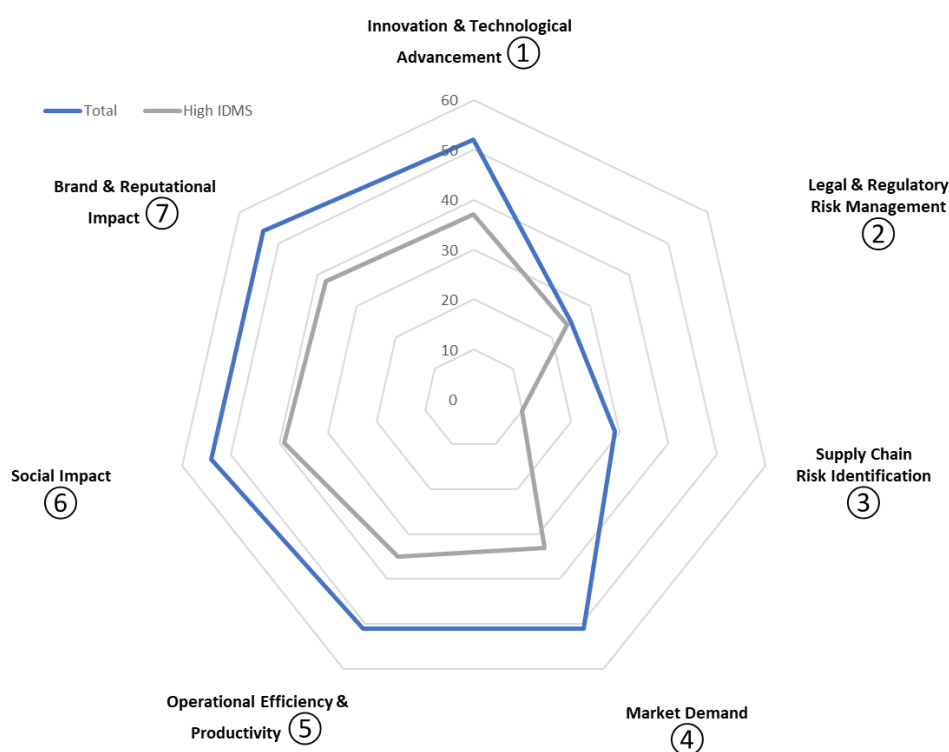


Figure 7 Profile/Strength of the woodworking sector indicators based on the IDMS criteria

4.4 Construction Sector

The multi-criteria analysis (Figure 8) for the Construction sector reveals a moderate spread of indicator performance with a slight clustering around the low-to-mid IDMS range (0.1–0.5). What distinguishes this sector is the vertical dispersion across the DQA scale, which spans from high-quality, well-established indicators at the top to experimental or data-deficient ones at the bottom. This indicates that while construction has many relevant metrics, data reliability remains highly uneven.

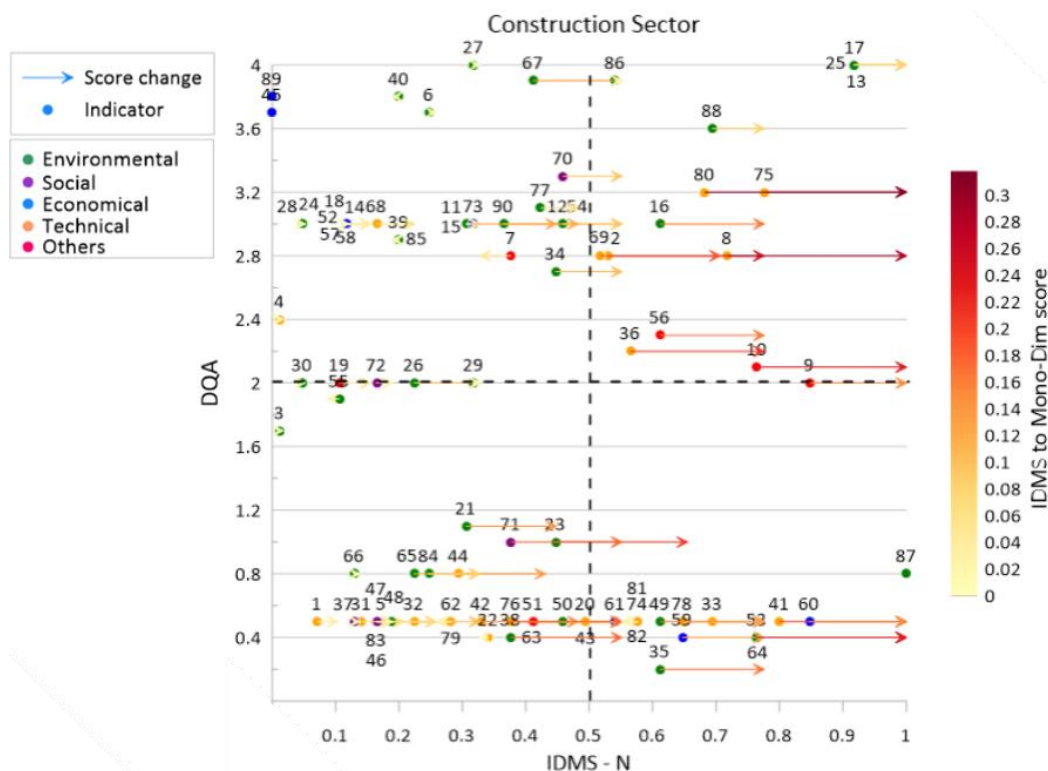


Figure 8 Construction sector indicators distribution

Quadrant 1 (The “Ideal” Indicators) includes a diverse and stable set of metrics that blend environmental, technical and criticality aspects. Key inclusions are: #9 (Certified forests), #13, #16 and #17 (Climate change, long-term fossil and short-term biogenic), and #25 (EF3.1 Climate Change HT1.2). Indicators related to operability aspect of this sector (e.g., #2 – Additives, #8 – Substitute for main biobased material, #60 – main biobased material).

Quadrant 4 (The “Critical but Challenging” Indicators) reveals critical areas where strategic demand is high, but data quality and availability is currently low. These indicators span: Circularity challenges like #33 (End-of-life recycling rate), #49 (Impacts of the recycling process), and #81 (Reuse rate in closed loop), market indicators, such as #60 and #61 (market situation of a consumer. Produced recycled material), and #59 (market or consumer acceptance), Indicators that depend on complex LCA-based models, such as #35 (LCA-based Environmental Impacts -Representative Bioeconomy Products) and #64 (Net GHG emissions from bio-based industries).

This quadrant suggests that while construction stakeholders recognize the need to monitor lifecycle impacts, circular flows, and market, data quality and method harmonization are still evolving. It also emphasises the need for investment in improved modelling frameworks, field data pipelines, and standardisation protocols to accurately capture the actual impacts of circular construction strategies and labour safety practices.

Table 11 Construction sector relevant indicators classification

Green= Environmental, Purple= Social, Blue= Economical, Orange= Technical and Red= Others

Q1	Q2	Q3	Q4
2. Additives (CALIMERO)	4. Annual heating and cooling degree days (BMS)	1. Actual recovery rate relative to the theoretical recovery potential (Circularity)	33. End-of-life recycling rate (Circularity)
8. Substitution for main biobased materials (CALIMERO)	6. Biomass production in EU from primary production systems (agriculture, forests, fisheries) (BMS)	3. Air quality (BMS)	35. Environmental impacts based on product-based LCA and basket of representative products of the bioeconomy (BMS)
9. Certified forests (BMS)	7. Candidate List of substances of very high concern for Authorisation (Criticality)	5. Average lifetime of a product or material relative to an industry average (Circularity)	41. Fraction of biological materials used which originate from Sustained Production (Circularity)
10. City preparedness - # cities signatories of COM - Adaptation (BMS)	11. Climate change, long term, biogenic (IW+)	20. Contribution to economic development (Social HS)	49. Impacts of the recycling process at the end of life (Circularity)
13. Climate change, long term, fossil (IW+)	12. Climate change, long term, CO2 uptake (IW+)	21. Cumulative energy demand (Criticality)	53. Investments in urban adaptation through nature-based infrastructures or EBA (BMS)
16. Climate change, short term, biogenic (IW+)	14. Climate change, long term, land transformation (IW+)	22. Distance to logistics hubs (territorial dimension) (BMS)	59. Market or consumers acceptance (BMS)
17. Climate change, short term, fossil (IW+)	15. Climate change, short term, biogenic (IW+)	23. Dynamic Global Warming Potential over 100 years (dGWP100) (CALIMERO)	60. Market situation of a consumed recycled material (Circularity)
25. EF3.1 Climate Change (HT1.2)	18. Climate change, short term, land transformation (IW+)	31. Efficiency of the recycling process at the EoL (Circularity)	61. Market situation of a produced recycled material (Circularity)
36. Extraction rate (Criticality)	19. Concentration of harvesting (Criticality)	32. Efficiency of the recycling process for the recycled content (Circularity)	64. net GHG emissions (emissions and removals) from BBI (absolute and relative vs. total industrial emissions) (BMS)
56. Land-use regulation (Criticality)	24. EF3.1 Acidification (HT1.2)	37. Fair Salary PSILCA	74. Potential uses of a produced recycled material (Circularity)
69. Main biobased raw materials (CALIMERO)	26. EF3.1 Land use (HT1.2)	38. Financial support to bio-based sectors (climate action) (BMS)	78. Renewable material content (Circularity)
75. Production/consumption increase/decrease over the last five years (Criticality)	27. EF3.1 Particulate matter (HT1.2)	42. Fraction of the product being collected for recycling at EoL (Circularity)	81. Reuse rate in closed loop (Circularity)
80. Resource stocks (Criticality)	28. EF3.1 Photochemical ozone formation (HT1.2)	43. Fraction of the product going to component reuse (Circularity)	82. Reused content Circularity (Circularity)
86. Share of renewables for transport, electricity and heating & cooling (BMS)	29. EF3.1 Resource use, fossils (HT1.2)	44. Growth rate (Criticality)	87. Share of wood-based constructions (BMS)
88. Total consumption of energy, including fossil-based (BMS)	30. EF3.1 Resource use, minerals and metals (HT1.2)	46. Health & safety (Social HS)	
	34. Environmental externalities (GHG emissions costs related to	47. Health and Safety (Social HS)	

	the EU Emission Trading System) (CALIMERO)		
	39. Forest fragmentation and connectivity index (BMS)	48. Impacts of the consumed primary raw material (Circularity)	
	40. Forest growing stock (BMS)	50. Impacts of the recycling process for the recycled content (Circularity)	
	45. GVA to turnover ratio BMS (BMS)	51. Impacts of the substituted production of primary raw materials (Circularity)	
	52. Internal Rate of Return (IRR) (CALIMERO)	55. Landscape fragmentation Index (BMS)	
	54. Land occupation, biodiversity (IW+)	62. Material productivity (Circularity)	
	57. Levelized Cost of Production (LCOP) (CALIMERO)	63. Multiple recycling loops in cascades (Circularity)	
	58. Life Cycle Costing (LCC) (CALIMERO)	65. net GHG emissions (emissions and removals) from bioenergy (absolute and relative vs. total sector emissions) (BMS)	
	67. net GHG emissions (emissions and removals) from LULUCF (BMS)	66. net GHG emissions (emissions and removals) from bio-waste (absolute and relative vs. total waste emissions) (BMS)	
	68. Net Present Value (NPV) (CALIMERO)	71. Occupational Exposure Limits (OEL) indicator (CALIMERO)	
	70. Occupation health and safety in bioeconomy sectors (BMS)	76. Quality degradation of recycled material (Circularity)	
	72. Occupational injuries and deaths (SHDB)	79. Resource intensity index (Circularity)	
	73. Payback Period (PP) (CALIMERO)	83. Safe & healthy living conditions (Social HS)	
	77. Ratio of annual fellings (m3/ha/year) to net annual increment (m3/ha/year) (BMS)	84. Share of consumption of bio-based plastics, textiles and chemicals (BMS)	
	85. Share of forest area (BMS)		
	89. Value Added per sector / Bioeconomy value added (BMS)		
	90. Water scarcity (IW+)		

While the vector plot (Figure 8) shows how indicators perform individually in terms of data quality and incentive value, it doesn't capture the collective thematic balance of the Construction sector's indicator portfolio. Figure 9 (the radar chart) fills this gap by highlighting how well the Total and High IDMS indicator sets score across specific evaluation criteria.

Each axis represents the number of indicators in a given set that received a high rating ('A' or 'B') for a particular criterion. This gives us a view into the sector's strategic identity and the strengths or gaps in its indicator design.

Criteria 1, 2, and 7 dominate the profile and lower representation of criteria 3 and 5, especially in the Total set (blue line). These likely represent that the dominating criteria are more influential among these indicators.

The High IDMS set (grey line) mostly mirrors the overall profile, but with a stronger drop across Criteria 5, suggesting that this dimension (operational efficiency and productivity) is probably highly underrepresented.

This suggests that indicators related to this criterion are weaker in terms of multidimensionality.

The similarity in the radar shapes indicates that priority indicators have been well selected relative to the sector's most material themes. However, the narrower spread of the High IDMS group signals that some areas are over-emphasized while others are still emerging. To improve balance: construction stakeholders can scan the Total pool for strong individual indicators that cover underrepresented criteria, especially if a more rounded sustainability distribution is desired. Conversely, to streamline monitoring: overly clustered themes (like Criteria 1 or 6) can be narrowed by removing lower-value duplicates.

As always, the annex can be consulted to view indicator scores and make adjustments based on mono-dimensionality and theme fit.

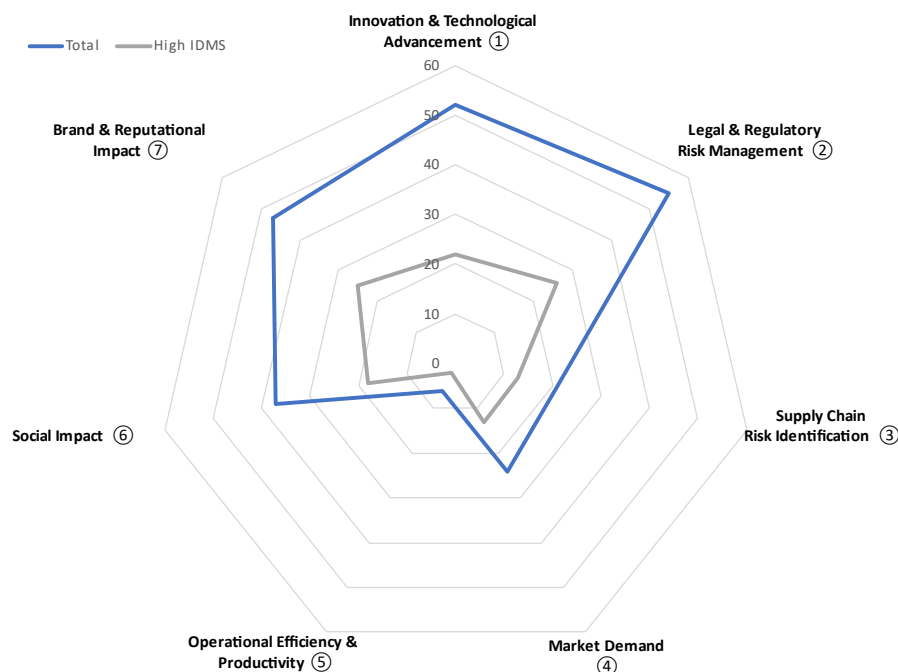


Figure 9 Profile/Strength of the construction sector indicators based on the IDMS criteria

4.5 Region

The multi-criteria analysis for regional implications (Figure 10) displays a well-dispersed set of indicators, with significant diversity along both the DQA (Data Quality Assessment) and IDMS-N axes. Compared to sector-specific profiles like construction or woodworking, this dataset is more polarised, with a mix of very high and very low performers, both in terms of incentive strength and data maturity.

A prominent feature of this plot is the vertical contrast: numerous indicators demonstrate high DQA (>3.0), but others still fall below 1.0, indicating the presence of both established monitoring tools and experimental or underdeveloped indicators in regional governance and environmental policy.

The most strategically important regional indicators fall into Quadrants 1 and 4, which are again distinguished by high IDMS scores.

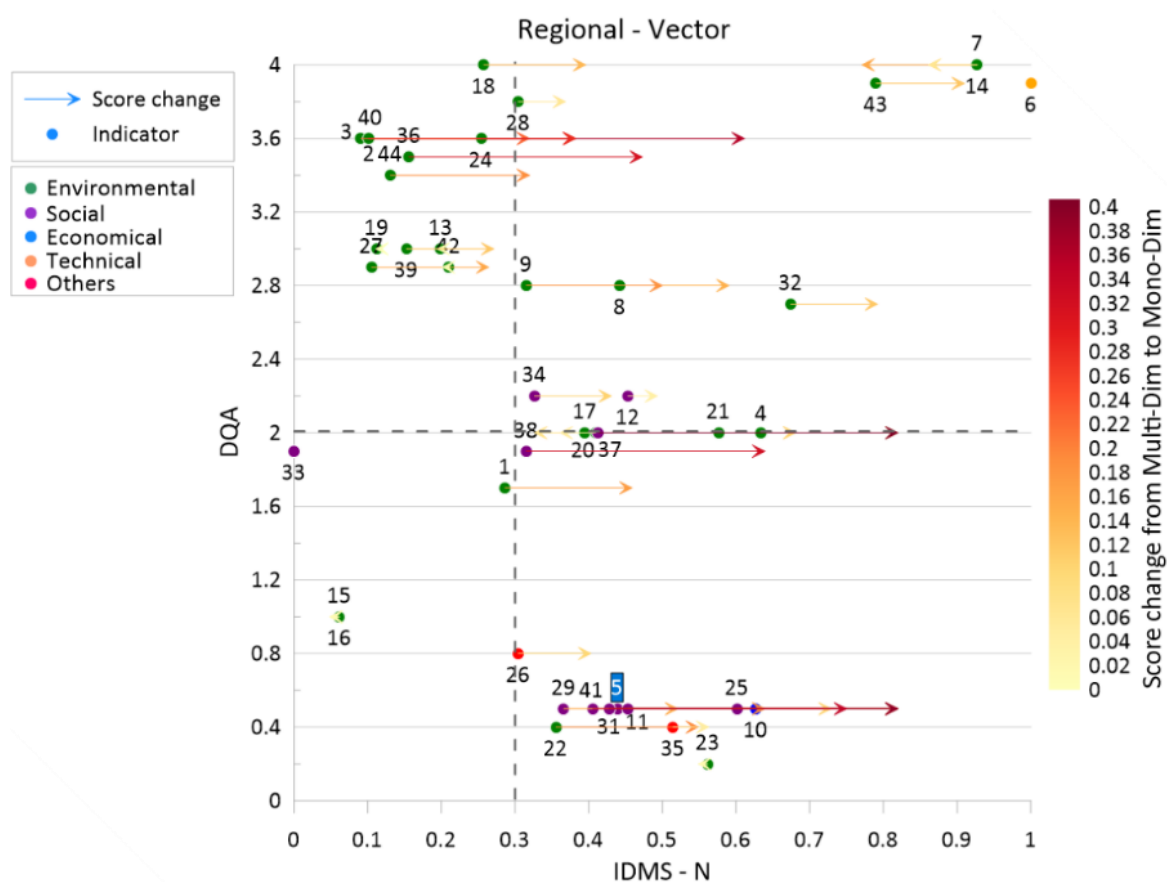


Figure 10 Regional Indicators distribution

Quadrant 1 (The “Ideal” Indicators) clusters around strong environmental and land-based metrics, including: #4 (Certified Forests), #6 (Circular Material Rate), #7 and #14 (Climate change indicators), and #32 (Land cover/use change). Indicators from EF3.1 on climate, land use, and water (e.g., #14, #17, #20 and #21) add a scientific foundation to this quadrant. Social and legal perspectives are also covered, such as: #12 (Corruption – Social), #34 (Legal Systems), and #37 (Occupational Injuries).

These indicators are well-distributed thematically and exhibit high data quality, making them strong candidates for consistent regional monitoring. They represent the core environmental and governance pillars relevant at regional or municipal levels. Quadrant 1 indicators are ready-to-implement indicators for policy development, performance benchmarking, and impact evaluation in regional sustainability strategies.

Quadrant 4 (The “Critical but Challenging” Indicators) reveals the strategic gaps — indicators that are regionally significant but suffer from low-quality data or methodological inconsistencies.

This quadrant is dominated by: Social equity and labour rights issues like #5 (Child Labour), #25 (Fair Salary), #29 (Freedom of Association), and #41 (Safe & Healthy Living). Some of these indicators such as child labour refers to social conditions of countries exporting to / importing from Europe.

Quadrant 4 indicators outline where further investment in regional data disaggregation, qualitative methodologies, and longitudinal tracking is needed. These indicators touch on sensitive or systemic issues — such as health, infrastructure resilience, and governance accountability — that are essential for equitable and just regional transitions, but difficult to quantify or localise effectively.

Table 12 Regional level relevant indicators classification

Green= Environmental, Purple= Social, Blue= Economical, Orange= Technical and Red= Others

Q1	Q2	Q3	Q4
4. Certified forests (BMS)	2. Biochemical oxygen demand in rivers (BMS)	1. Air quality (BMS)	5. Child LabourP
6. Circular material rate (BMS)	3. Bird and butterfly indices EU aggregate (common farmland bird Index, common forest bird index, grassland butterfly index) (BMS)	15. EF3.1 Human toxicity, cancerE	10. Contribution to economic developmentU
7. Climate change, short term, fossilW+	13. EF3.1 AcidificationE	16. EF3.1 Human toxicity, non-cancerE	11. CorruptionP
8. Conservation Status of European Habitats (BMS)	18. EF3.1 Particulate matterE	33. Landscape fragmentation IndexB	22. Environmental footprints in exporting countries (to EU)B
9. Conservation status of grasslandB	19. EF3.1 Photochemical ozone formationE		23. Environmental impacts based on product-based LCA and basket of representative products of the bioeconomyB
12. CorruptionS	24. Exceedance of air quality standards in urban areas B		25. Fair SalaryP
14. EF3.1 Climate ChangeE	27. Forest fragmentation and connectivity index (BMS)		26. Flood regulation (flood control, flow, demand, potential, unmet demand, monetary values)B
17. EF3.1 Land useE	36. Nitrate in groundwater (BMS)		29. Freedom of Association & Collective BargainingP
20. EF3.1 Resource use, fossilsE	39. Percentage area of urban green space (or percentage of natural area within the city boundaries) (BMS)		31. Health and SafetyU
21. EF3.1 Water useE	40. Phosphate in rivers (BMS)		35. Market or consumers acceptanceB
28. Forest growing stock (BMS)	42. Share of forest area (BMS)		38. Occupational toxics and hazardsS
32. Land use / land cover type taken over by agricultural land (BMS)	44. Social condition in exporting countries (to EU) B		41. Safe & healthy living conditionsU
34. Legal systemS			
37. Occupational injuries and deathsS			
43. Share of renewable energy in gross final energy consumption (BMS)			

While the scatter plot helps locate strong individual performers, it does not reveal the thematic orientation of the indicator portfolio. The radar chart (Figure 11) addresses this gap by showing how the Total and High IDMS indicator sets score across core evaluation criteria.

Each axis in the chart reflects the number of indicators with a high monodimensionality score ('A' or 'B') for a specific criterion. The chart captures the strengths, blind spots, and thematic alignment of regional indicator strategies.

Criteria 2 and 4 and 7 dominate both the Total and High IDMS set while criteria 1 6, 9 and 3 are low represented in the Total set but covered completely in the High IDMS selection, hinting at underrepresentation of indicators in the total indicator pool or a misalignment in prioritisation.

The High IDMS follows similar distribution pattern yet more balanced. set shows a strong peak in Criterion 2 and 4, suggesting a bias toward legal and social structure over supply chain, innovation, employment and other criteria.

The radar chart confirms that the High IDMS set is more thematically balanced than the Total pool. For a more holistic monitoring strategy:

- Additional indicators from the initial selection pool should be reviewed for inclusion— especially those well related to the underrepresented criteria.
- Indicators from Criteria 2 and 4 can be trimmed or aggregated to reduce redundancy.

Consult the annex to explore mono-dimensionality and thematic scores for each indicator when tuning the selection for specific regions.

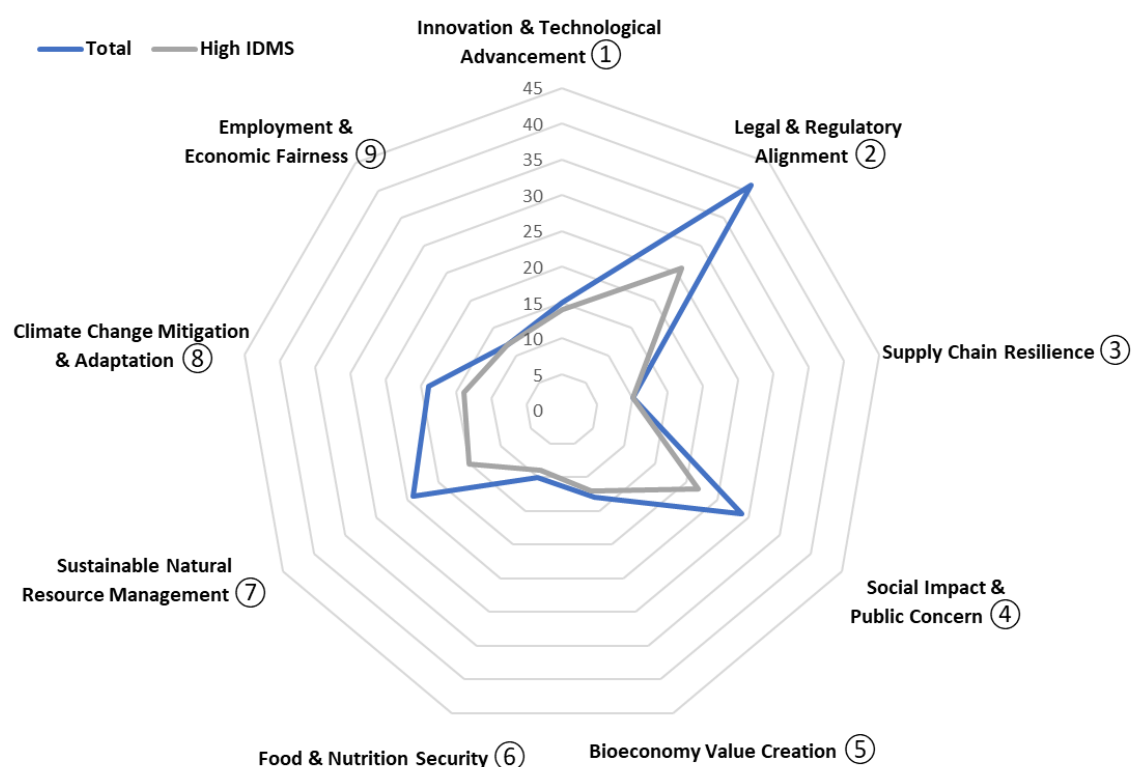


Figure 11 Profile/Strength of the regional indicators based on the IDMS criteria

5 CONCLUSIONS

The multi-criteria assessment conducted across the Textile, Woodworking, Construction, and Regional domains reveals a comprehensive landscape of indicator performance, strategic relevance, and methodological maturity. By combining scatter plot diagnostics, quadrant mapping, and thematic radar profiling, this analysis offers an integrated perspective on where sustainability monitoring is most robust, where critical gaps exist, and how indicator portfolios can be optimised for balanced coverage.

High-Confidence Indicators (Q1)

Across all domains, Quadrant 1 consistently features environmental indicators with well-established methodologies and sectoral alignment, such as climate change metrics (biogenic and fossil), certified sourcing, and circular material rates. These indicators are supported by strong data quality and high relevance, making them suitable anchors for operational frameworks and performance tracking.

These indicators form the core monitoring infrastructure and should be prioritised for baseline tracking, compliance, and strategic decision-making.

High-Priority Gaps (Q4)

Quadrant 4 indicators, those with high strategic value but low data maturity, highlight some of the most pressing challenges across all levels:

- In sectors, this includes social sustainability issues (e.g., fair salary, child labour, health & safety), and advanced circularity metrics that require end-of-life modelling or LCA-based data. These social indicators sometimes reflect situations outside of Europe, for example, in the textile sector. Therefore, it is important to have indicators that allow for comparison of social performance between these countries and Europe.
- In the regional context, indicators around governance, equity, and localised impacts show relevance but lack robust regional methodologies or standardised reporting.

These indicators represent a roadmap for investment in data systems, method standardisation, and capacity-building, especially in global supply chains and localised policymaking.

Thematic Imbalance

Among regional and sectoral levels, there is strong representation of legal and social aspects which shows a good aligning of priorities. In contrast, some sectors show more emphasis on some aspects which is lacking in the regional level, such as innovation and technological advancement. All the sectors also had strong emphasis on the Brand and reputational impact criteria, showcasing the importance of this aspect on the strategic decision-making of industrial sectors. A comparative analysis of the regional and sectoral profiles reveals a strong alignment on the importance of legal and social aspects, suggesting a shared set of core priorities.

However, there are also distinct differences. The sectoral profiles place a much stronger emphasis on Innovation & Technological Advancement and Brand & Reputation Impact than the regional perspective does. This highlights the critical role of market-facing criteria in the strategic decision-making of industrial actors.

Moreover, it is noteworthy that out of the initial 400+ indicators evaluated by the partners, only three were found to be relevant across all analyzed sectors: 'Environmental impacts based on product-based LCA and basket of representative products of the bioeconomy', 'Impacts of the recycling process at the end of life', and 'Potential uses of a produced recycled material'. Significantly, only the first of these, the LCA-based environmental impact indicator, was also deemed relevant at the regional level. This finding is logical, as the cumulative environmental impacts on a region are driven by the activities of the sectors operating within it. This indicator, therefore, serves as a crucial bridge, connecting the overall performance of sectors to the aggregated environmental condition of the region. Conversely, the other two indicators, while important for all

sectors, are more focused on operational and end-of-life management, making them more suitable for sector-specific monitoring rather than high-level regional monitoring.

5.1 Recommendations Moving Forward

To enhance the practical value of this indicator analysis, several strategic recommendations can be made. First, indicators located in Quadrant 1, those with both high data quality and strong strategic relevance, should be prioritised for immediate integration into sustainability monitoring systems and policy frameworks. These indicators represent more reliable and actionable starting points. Second, focused investment is needed to develop Quadrant 4 indicators, particularly those related to social equity, complex circularity processes, and region-specific impacts, which are often recognised as critical but remain underdeveloped in terms of data and methodology. The radar charts should be used as a guiding tool to ensure thematic balance, helping to avoid overrepresentation of well-established environmental metrics while elevating governance and resilience indicators that may be underutilised. Finally, users are encouraged to consult the annexed indicator scores to selectively include or exclude indicators based on their mono-dimensionality strength, ensuring that portfolios remain both focused and inclusive across key sustainability dimensions.

It is essential to recognise that the set of criteria and sub-criteria used in this analysis is not fixed. Depending on the context, emerging policy goals, or stakeholder needs, these dimensions can be revised, expanded, or redefined to meet specific requirements. By adjusting the evaluation framework and reapplying the scoring methodology, users can generate alternative perspectives on the same pool of indicators, revealing different priorities, blind spots, or sectoral alignments. This flexibility makes the framework a living tool, adaptable to evolving sustainability agendas and capable of supporting a wide range of strategic inquiries.

In addition to comprehensive portfolio design, this approach also enables targeted selection of indicators for specific sustainability themes. For example, users interested in climate resilience or social justice can isolate one or two issues and filter the complete indicator list to extract only those metrics most relevant to that domain. This allows for the creation of thematic indicator subsets tailored to focused use cases, such as policy impact assessment, regional benchmarking, or sectoral certification schemes, without losing the methodological rigour of the broader framework.

5.2 Summary of the Role and Relevance of CALIMERO Indicators in the Analysis

The CALIMERO indicators, including metrics on biodiversity impacts, ecosystem services, circularity, criticality, dynamic carbon footprint, novel toxicity factors, occupational exposure, process optimisation, job creation potential, and life cycle costing, were consistently included across the sectoral and regional analyses. These indicators reflect a forward-looking, system-oriented approach to sustainability assessment. Their presence across all domains confirms their strategic relevance, particularly where innovation, lifecycle thinking, and multi-objective decision-making are becoming increasingly important.

Despite their relevance, many CALIMERO indicators fall into Quadrant 4 of the analysis, those that are strategically important but currently suffer from lower data quality or methodological maturity. This suggests that while they address key sustainability concerns, they are not yet fully ready for implementation without further refinement. Indicators such as circularity, criticality, dynamic carbon footprint, job creation, and novel toxicity factors are emerging tools that require investment in data collection, methodological alignment, and sector-specific adaptation to unlock their full potential.

Sectoral differences in CALIMERO uptake are also notable. Construction shows the highest alignment, especially with indicators related to economic performance, optimisation, and material lifecycle impacts. Woodworking is closely tied to biodiversity, circularity, and resource-criticality. In contrast, Textile and Regional applications tend to apply CALIMERO indicators more selectively, typically focusing on aspects like toxicity, job

creation, and ecosystem services. Overall, the CALIMERO set enriches the indicator framework, offering depth and innovation, while also clearly pointing to areas where further methodological development is still needed.

5.3 Limitations and challenges

While this multi-criteria indicator analysis offers a structured and insightful overview of sustainability monitoring across sectors and regions, it is not without limitations. A key concern is the subjectivity embedded in the scoring system. Judgments on data quality (DQA), strategic relevance (IDMS), and mono-dimensionality involve expert input, which, while informed, can vary depending on the evaluators' perspectives, sectoral knowledge, or institutional context. As such, the results should be viewed as a strategic guide rather than a definitive ranking.

Another constraint lies in the static nature of the analysis. The assessment represents a snapshot in time, without capturing how indicators may evolve due to changes in policy, data infrastructure, or technology. This limits its responsiveness to fast-moving developments in sustainability and bioeconomy governance. The analysis would benefit from being integrated into a dynamic or periodically updated tool.

Additionally, the approach treats indicators independently, without modelling the interactions, synergies, or trade-offs that exist between them. For instance, circularity metrics often influence climate and social outcomes, yet these cross-dimensional linkages are not captured in the current framework. This simplification can be helpful for clarity but may obscure important systemic relationships.

There is also a degree of thematic imbalance. Environmental indicators, especially those related to climate and land use, tend to dominate Quadrant 1 due to their well-developed methodologies and standardization. In contrast, social, governance, and lifecycle complexity indicators are more likely to appear in Quadrant 4 or be underrepresented altogether. This bias reflects broader disparities in methodological maturity rather than actual relevance.

Finally, the analysis lacks consideration for contextual and operational feasibility. It does not incorporate sector-specific readiness, policy environments, or resource capacity—all of which affect whether an indicator, even if highly ranked, can realistically be implemented. Moreover, the framework assigns equal importance to all indicators, without accounting for materiality or stakeholder priorities, which could be addressed through tailored weighting or participatory validation.

In summary, while this framework is valuable for identifying strategic priorities and gaps, it should be understood as a decision-support tool, a starting point for deeper dialogue, contextual adaptation, and continuous improvement.

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ANNEXES

Refer to this file for the full list of evaluated indicators for relevancy screening.

<https://www.weloop.org/wp-content/uploads/2025/06/T5.4-EU-Bioeconomy-Monitoring-Indicators.xlsx>

Refer to this file for details on scoring of the indicators based on their criteria and sub-criteria

<https://www.weloop.org/wp-content/uploads/2025/06/All-sectors-and-region-Scored-by-Criteria.xls>