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Industry 4.0 Transformation Model

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Industry 4.0 Transformation Model (O3.1)

Danube Region Wood Industry Transformation

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Executive summary

This document presents a comprehensive framework for supporting Industry 4.0 transformation in the forest-based industry, with a particular focus on the Danube Region and the DRWO4.0 participating countries. It combines analytical methodologies with practical insights to assess current transformation levels, identifies key barriers and defines enabling approach at both policy and company levels.

The analysis is built on two complementary methodological pillars, the Value Chain Analysis (VCA) and the CULIS methodology. The VCA approach is used to examine the forest-based value chain holistically, capturing interactions between upstream and downstream activities and identifying where value creation, inefficiencies and transformation gaps occur. A structured VCA model and a harmonised maturity scoring system enable comparable assessments across countries and company sizes, ensuring consistency in evaluating digital, organisational and technological maturity.

The CULIS methodology extends this assessment by analysing transformation readiness through three interconnected pillars: Lean management, Digitalisation and Green performance. The document differentiates findings by company size, demonstrating that while large enterprises are better positioned to adopt advanced I4.0 technologies, small and medium-sized enterprises (SMEs) face structural constraints related to limited financial resources, skills shortages and restricted access to tailored support instruments. Across all company sizes and countries, funding is identified as the main obstacle to Industry 4.0 transformation, not due to a lack of available programmes, but because of limited accessibility, administrative complexity, co-financing requirements and insufficient project development capacity.

To address these challenges, the document outlines enabling conditions for successful I4.0 implementation from both policy and company perspectives. At the policy level, the need for coordinated strategies, sector-specific funding schemes, strengthened innovation ecosystems and support is emphasised. At the company level, the importance of clear transformation strategies, phased implementation approaches and the integration of Lean, Digital and Green objectives is highlighted.

A cross-cutting conclusion of the analysis is the critical role of human capacities. Skills development, vocational training, managerial competencies and continuous learning are identified as decisive factors for successful transformation. Investment in human capital is therefore as essential as investment in technology.

The document demonstrates that Industry 4.0 transformation in the forest-based industry requires a holistic, staged approach. By combining VCA and CULIS methodologies, strengthening human capacities, improving access to funding, and aligning policy and enterprise-level actions, the DR can significantly enhance the competitiveness, resilience and sustainability of its forest-based sector.

Introduction

DRWO4.0 objective is the improvement of Danube Region forest-based industry through the Industry 4.0 transformation supported by the transnational development of the applicable, modifiable and replicable forest-based Industry 4.0 transformation model as a solution for the Danube Region (DR) forest-based industry improvement according to the Industry 4.0 principles.

Europe's forest-based sector is large and strategically important for jobs, rural economies and the bioeconomy. It faces intensifying pressures from climate change, biodiversity targets, supply shocks and changing market demand, all of which make digitalisation and Industry 4.0 tools (IoT, telematics, digital twins, interoperable platforms and analytics) not just efficiency options but strategic necessities to secure resilience, traceability, circularity and added value.

Industry 4.0 is highly relevant to the forest-based industry because it improves resource efficiency and yield across the value chains, reduces downtime and operating cost via predictive maintenance, enables traceability and new circular bioeconomy business models, supports policy goals on resilience and sustainability.

Current pressures and strategic drivers are making transformation necessary:

- Climate change and risk management: increased drought, pests and wildfire risk require near-real-time monitoring, early warning and scenario planning; digital twins and integrated remote sensing are emerging responses;
- Policy and sustainability requirements: EU Forest Strategy (2030), Biodiversity targets and broader Green Deal goals increase demand for accurate monitoring, chain-of-custody proof and lifecycle reporting (digital traceability);
- Market opportunity for higher value wood products: engineered timber and advanced bio-products require precise raw-material matching and process control; Industry 4.0 improves product consistency.
- Supply chain resilience: fragmentation (many small owners/contractors) and the experience of recent supply shocks highlight the need for better visibility across the sector. Digital platforms and telematics provide that visibility.

The implementation of Industry 4.0 technologies is proving to be a powerful driver of progress in the forest-based sector. By embedding sensors and advanced analytics into mills and processing lines, companies are able to recover more material from every cubic metre of wood while reducing waste, creating both economic and environmental gains. At the same time, predictive maintenance supported by continuous condition monitoring keeps expensive machinery and assets running more reliably, extending their lifespan and reducing the costly disruptions caused by unexpected breakdowns.

The benefits extend beyond the factory floor. Connected harvesting equipment and transport fleets equipped with telematics enable smarter logistics planning, cutting unnecessary trips, lowering fuel consumption and reducing emissions, improvements

that often pay for themselves within a short time. Alongside these efficiency gains, digital traceability solutions, using technologies such as QR codes or RFID tags linked to secure data platforms, are strengthening supply chain transparency. This not only builds trust with customers but also allows producers to access premium markets and meet increasingly strict procurement requirements for sustainable sourcing.

Equally important is the role of digital tools in strengthening resilience. With the help of digital twins and remote sensing, forest managers can plan harvesting cycles more effectively, model different scenarios and respond proactively to risks such as pest outbreaks or wildfires. In this way, Industry 4.0 is not simply about automation or cost savings. It is about building a smarter, more sustainable and future-ready forest-based industry.

Glance of Industry 4.0 technologies¹

Industry 4.0 refers to the transformation of manufacturing and industrial systems through the integration of advanced digital technologies. By combining the industrial Internet of Things, artificial intelligence, big data analytics, robotics and automation, it creates connected and intelligent production environments. The goal is to drive higher productivity, efficiency and adaptability, while supporting smarter decision-making and enabling greater customisation across manufacturing and supply chain operations.

At the heart of Industry 4.0 lies the ability to harness *Big Data and AI analytics*. Information is no longer gathered only from machines but also from across the business environment and beyond, from customer feedback and market signals that guide product design to weather forecasts and traffic data that optimise logistics. When analysed in real time using artificial intelligence and machine learning, this data provides actionable insights that improve decision-making, strengthen automation and create a more agile supply chain.

A second feature of Industry 4.0 is *horizontal and vertical integration*. Horizontally, digitalisation links production processes across factories, facilities and even entire supply chains, ensuring smooth coordination at the operational level. Vertically, it connects every layer of the organisation, allowing information to flow seamlessly between the shop floor and the executive level. This integration breaks down silos, aligns R&D, quality management, marketing and other functions with real-time production data, which leads to streamlined operations and greater organisational coherence.

Transformation encompasses *cloud computing*, which provides the infrastructure for connectivity and innovation. The cloud enables the storage, processing and sharing of the massive data streams generated by modern manufacturing, while also hosting advanced technologies such as AI, IoT and cyber-physical systems. It is the foundation that allows machines, platforms and people to interact in real time across dispersed locations.

Emerging technologies such as *augmented reality (AR)* further enhance the human-machine interface. By overlaying digital content onto physical objects, AR tools, delivered through smart glasses or mobile devices, allow technicians to view sensor data, follow repair instructions or receive training while working directly on equipment. Although still

¹ <https://www.sap.com/industry-4-0>

in development, AR has significant potential for maintenance, service quality and worker safety.

The *Industrial Internet of Things (IIoT)* is perhaps the most defining technology of Industry 4.0. By equipping machines, robots, products and equipment with sensors, companies gain real-time visibility into performance, condition and location. This connectivity allows smoother supply chain management, proactive maintenance, faster product development and precise tracking of inventory and consumer preferences.

Additive manufacturing has evolved from a prototyping tool into a versatile production method like 3D printing. By storing product designs digitally and printing components on demand, companies can reduce inventory costs, avoid offshore production dependencies, and offer customised products. Increasingly, 3D printing is expanding into new materials, including metals, advanced polymers, ceramics and even biomaterials, wood-based filaments, opening fresh opportunities for distributed manufacturing.

Another transformative element is the rise of *autonomous robots*. Unlike earlier generations, these machines combine sensors, AI and machine vision to adapt to their environments and perform complex tasks with minimal human oversight. From drones scanning inventory to mobile robots managing material flows, they enhance efficiency, precision and safety across diverse industrial contexts.

Closely related are *simulation and digital twins*, which create virtual replicas of machines, processes or entire systems. Fed by real-time sensor data, digital twins make it possible to model performance, predict failures and optimise operations without disrupting physical assets. They allow operators to test scenarios, refine designs and improve reliability in a risk-free digital environment.

Finally, the increased reliance on data and connectivity makes *cybersecurity* indispensable. Protecting networks, platforms and intellectual property require advanced strategies such as Zero Trust architectures, machine learning-based threat detection and blockchain for secure transactions. By embedding cybersecurity into the transformation journey, companies safeguard both operational continuity and stakeholder trust.

Transformation methodology

The transformation of the forest-based industry requires methodological approaches that are capable of addressing both operational complexity and long-term sustainability challenges. Due to the sector's strong dependence on natural resources, energy and multi-stage production systems, selected methodologies must enable a comprehensive understanding of value creation while simultaneously supporting practical and scalable improvement measures.

DRWO4.0 partners selected the Value Chain Analysis (VCA) as a suitable analytical foundation because it provides a structured perspective on how value is generated and distributed across production systems. By focusing on process linkages and value-creating activities, VCA enables a systematic examination of organisational structures and production flows without prescribing predefined solutions. This makes it particularly appropriate as a diagnostic method for identifying improvement potential within the wood industry.

To complement this analytical perspective, DRWO4.0 project partners chose the CULIS methodology as a transformation framework capable of translating analytical insights into concrete actions. Its integrated structure, based on Lean, Digital and Green principles, allows organisations to address operational efficiency, technological development and sustainability in a coherent manner. Importantly, the methodology supports selective and modular application, enabling organisations to focus on those elements that are most relevant to their specific context and development stage.

Together, VCA and the CULIS methodology form a complementary methodological approach in which analytical understanding and practical transformation are closely linked. This combination provides a consistent foundation for examining improvement potential and implementing targeted measures across different organisational contexts within the wood industry, forming the basis for the subsequent analysis of application across enterprises of varying size and complexity.

Value Chain Analysis (VCA)

The Value Chain Analysis (VCA) framework represents a structured approach to analysing the furniture and forest-based industry, with a focus on sustainability and digital transformation. It builds on established value chain concepts and life-cycle thinking, recognising wood processing as a sector of growing importance in the transition toward a sustainable and circular economy. Due to its capacity for long-term carbon storage and recyclability, wood-based production is increasingly positioned as a key component of climate-neutral development.

The framework is grounded in the understanding that value creation occurs through a sequence of interconnected activities, from raw material inputs to end-of-life management. In this context, value chain analysis goes beyond economic performance and integrates environmental and technological dimensions, including low-energy production processes, digital tools and circular resource flows. Such an approach enables a comprehensive view of how value is generated and enhanced across the sector.



Figure 1 VCA infographic

The VCA framework combines a value chain-based structure with a maturity-oriented perspective that allows the assessment of digitalisation and circular economy readiness. By linking technological and sustainability drivers to concrete stages of the value chain, the framework ensures comparability across different organisational and national contexts while reflecting structural differences within the sector.

The primary objective of the framework is to assess the current state and development potential of furniture manufacturing enterprises, with particular emphasis on micro and small companies that dominate the industry. Through the identification of strengths, weaknesses and development gaps along the value chain, the framework supports the definition of development priorities and provides a foundation for coordinated improvement measures and policy recommendations.

Structure of the VCA model

The model establishes a flexible European framework for assessing digital and circular maturity across manufacturing value chains in the wood-based sector. While the DRWO4.0 project applied this framework specifically to furniture manufacturing (NACE C31) for development, testing and empirical validation, the underlying analytical structure is intentionally generic and transferable.

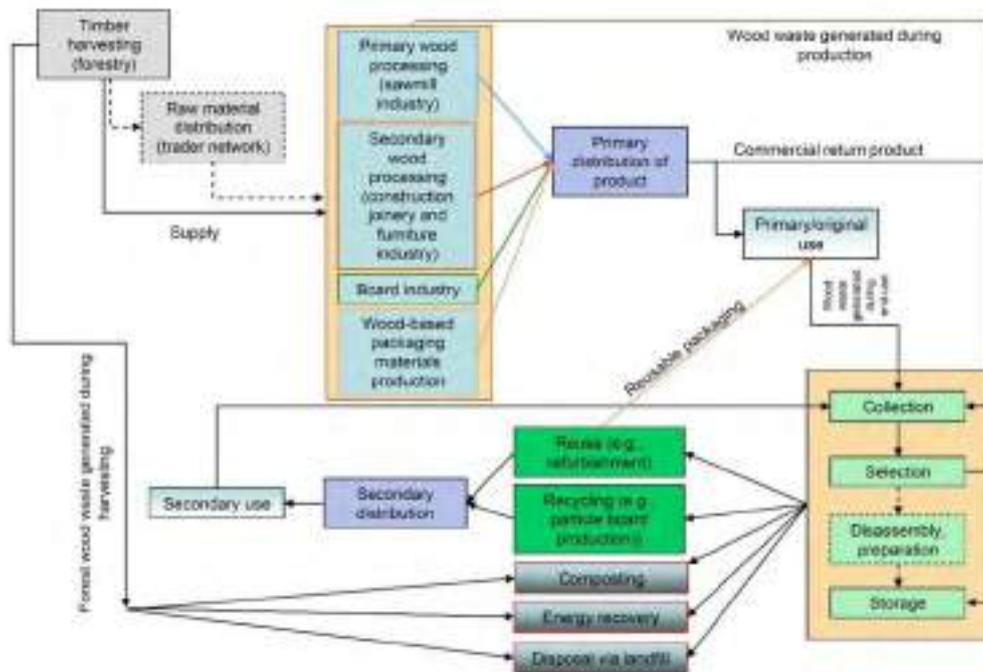


Figure 2 Full life-cycle model of a forest-based product (Németh 2008)

The value chain stages (Inputs → Primary Processing → Secondary Processing → Distribution & Sales → Use Phase → End of Life) and the five assessment drivers (Digital Design, Process Automation, Quality Control & Traceability, Logistics Digitalization, Sustainability & Circularity) represent common elements found across diverse wood-based industries, including:

- Sawmilling and primary wood processing,
- Engineered wood products manufacturing,
- Wood-based panel production,
- Joinery and carpentry sectors,
- Packaging and pallet manufacturing.

Adaptability principle: The framework maintains consistent assessment logic while allowing sector-specific customization of:

- Value chain stage definitions (e.g., incorporating forest management for upstream integration),
- Driver interpretation (e.g., emphasizing moisture control quality systems in sawmilling),
- Maturity indicators relevant to specific production technologies,
- Company size considerations appropriate to sector structure.

This approach ensures that the framework serves both as a furniture industry reference case with concrete, validated application and as a methodological template applicable to other wood-based manufacturing contexts with similar characteristics - particularly SME-dominated sectors facing comparable digitalization and sustainability challenges. Its purpose is to enable cross-country comparison, identify weaknesses along the value chain, define development priorities and support joint EU-level recommendations.

The structure of the model is defined by two interrelated elements:

- Value chain-based approach, which links the analysis to real industrial processes,
- Maturity scoring model, which evaluates current and potential levels of digitalisation and circularity.

Attention is given to the needs and constraints of micro and small enterprises, which often face limited resources, skills shortages and restricted access to tailored support instruments, yet play a central role in European manufacturing landscapes.

Value chain approach (VCA)

The model applies a generic value chain structure that can be adapted to different manufacturing and processing sectors. For illustrative purposes and based on its application within the DRWO4.0 project, the value chain is structured into six overarching stages:

- Inputs
- Primary Processing
- Secondary Processing
- Distribution & Sales
- Use Phase
- End of Life

This structure reflects common stages found across many industrial value chains and can be flexibly adjusted to sector-specific processes where necessary, for example by

integrating activities such as after-sales services, maintenance, refurbishment or take-back schemes. At the same time, it ensures international and cross-sector comparability, as diverse examples, challenges and digitalisation characteristics can be analysed within a consistent set of process blocks.

Maturity Model (Maturity Scoring, 0-3 scale)

Digitalisation and circular economy readiness are assessed across five key drivers:

1. Digital design (CAD/CAM)
2. Process automation (CNC/ERP integration)
3. Quality control & traceability
4. Logistics & distribution digitalisation
5. Sustainability & circularity

Digital and circular maturity is assessed through a maturity model based on a harmonised 0–3 scoring scale. Each driver is assessed using two values: the current state and a realistic potential state achievable within a five-year horizon. The difference between these values indicates the development gap and highlights priority areas for improvement. The scoring levels are defined as follows:

The maturity scoring system evaluates both digital adoption and circular economy practices across a four-level scale:

Level 0: Absence of digital systems and circular practices

- Processes are entirely manual with paper-based documentation
- No digital tools for production planning, tracking, or quality control
- Resource management is reactive with no systematic waste reduction
- End-of-life considerations are not integrated into operations.

Level 1: Basic adoption of isolated digital tools

- Individual software applications exist (e.g., basic CAD, standalone accounting software) but operate independently
- Digital tools are used by specific individuals rather than organisation-wide
- Some awareness of sustainability issues but no systematic approach
- Minimal data collection; information flows remain largely manual.

Level 2: Developing integration with partial automation

- Digital systems begin to connect (e.g., CAD data partially feeds production equipment)
- Some automated workflows exist in specific departments

- Resource efficiency measures are implemented (e.g., waste monitoring, energy tracking)
- Data is collected regularly but analysis remains primarily manual
- Basic circular practices emerge (e.g., scrap recycling, material take-back schemes).

Level 3: Advanced, fully integrated digital and circular systems

- End-to-end digital integration across value chain stages (design → production → distribution)
- Automated data flows enable real-time monitoring and decision support
- Smart manufacturing practices include predictive maintenance, adaptive production control
- Circular economy principles embedded: design for disassembly, full material traceability, closed-loop resource flows
- Digital platforms support collaboration with suppliers and customers.

The assessment is based on structured self-evaluation, ensuring feasibility and scalability, particularly for smaller enterprises and can be supported by DRWO4.0 partners, who may provide guidance, moderation and expert input to enhance consistency, objectivity and interpretation of results.

Beyond assessment, the VCA approach is intended as a strategic support tool. It helps translate analytical insights into development priorities and provides an evidence base for coordinated recommendations at EU and national levels. By demonstrating its applicability through the furniture sector while remaining adaptable to other industries, the model offers a scalable and replicable foundation for supporting digital and circular transformation across diverse manufacturing domains.

VCA in DRWO4.0 countries

The VCA approach was implemented across all DRWO4.0 partner countries through a standardized methodology focusing on NACE C31 (Manufacture of Furniture) as a representative sector of national wood-based industries. Each partner conducted:

- Semi-structured interviews with 3–5 furniture manufacturing SMEs
- Desk research using national statistical sources
- Value chain mapping using the harmonized template structure
- Maturity scoring assessments across five key drivers.

National reports and interview data were compiled and analysed to identify cross-regional patterns in digital maturity, development gaps, and transformation potential. The

synthesis of these findings reveals consistent patterns across the European wood and furniture manufacturing sector.

Logistics and distribution digitalisation drivers display strong cross-country variation. Export-oriented countries tend to have more advanced practices, while domestically focused markets rely heavily on manual coordination. Despite moderate current scores, nearly all countries identify logistics digitalisation as a key competitive factor, with large development gaps indicating strong growth potential.

Quality control and traceability drivers are widely established but remain largely manual or only partially digitalised. High potential values across countries suggest strong awareness of the strategic importance of digital quality systems, with barriers mainly linked to investment capacity and organisational constraints rather than technology.

Digital automation drivers represent the most critical development areas. CNC usage is widespread, but integration with ERP systems is limited and ERP/CRM integration is currently one of the weakest areas overall. Nevertheless, all countries report high and realistic expectations for progress, with the enterprise-level system integration as a top priority for future digitalisation.

Sustainability and circularity drivers show the lowest and most heterogeneous current maturity. Practices are often limited to basic waste or energy use solutions, while interpretations of circularity vary significantly across countries. Potential values are generally optimistic; circularity is not yet embedded in routine operations and appears closely linked to broader technological and digital development.

Overall, the analysis confirms a clear regional consensus: while current digital maturity in the furniture sector remains limited, all drivers exhibit substantial and realistic development potential. The main challenges lie in system integration, standardisation of practices and assessments, investment capacity and skills development rather than in the availability of technology itself.

CULIS methodology

The CULIS methodology represents an original and integrated approach to business transformation that connects Lean principles, digital transformation and elements of green industry. Developed in 2018, it was designed as a universal framework applicable across various organisational environments, from industrial and service companies to public and educational institutions. The greatest value of the methodology is realised in projects focused on sustainability, digitalisation and the development of competitive business models.

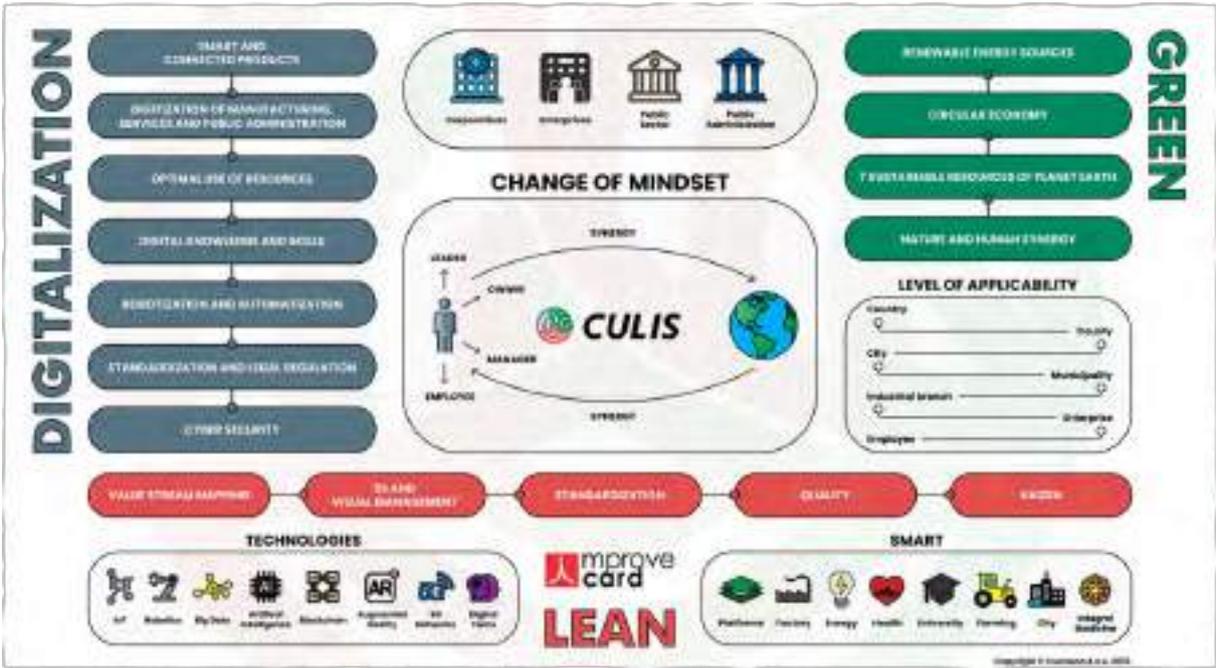


Figure 3 CULIS infographic

Successful implementation of CULIS begins with process optimization, clear process structuring and the introduction of digital technologies that enable measurability, monitoring and improved resource management. Although the methodology also includes technical elements such as ICT infrastructure mapping, interoperability and digital quality tools, its key emphasis lies on the human factor.

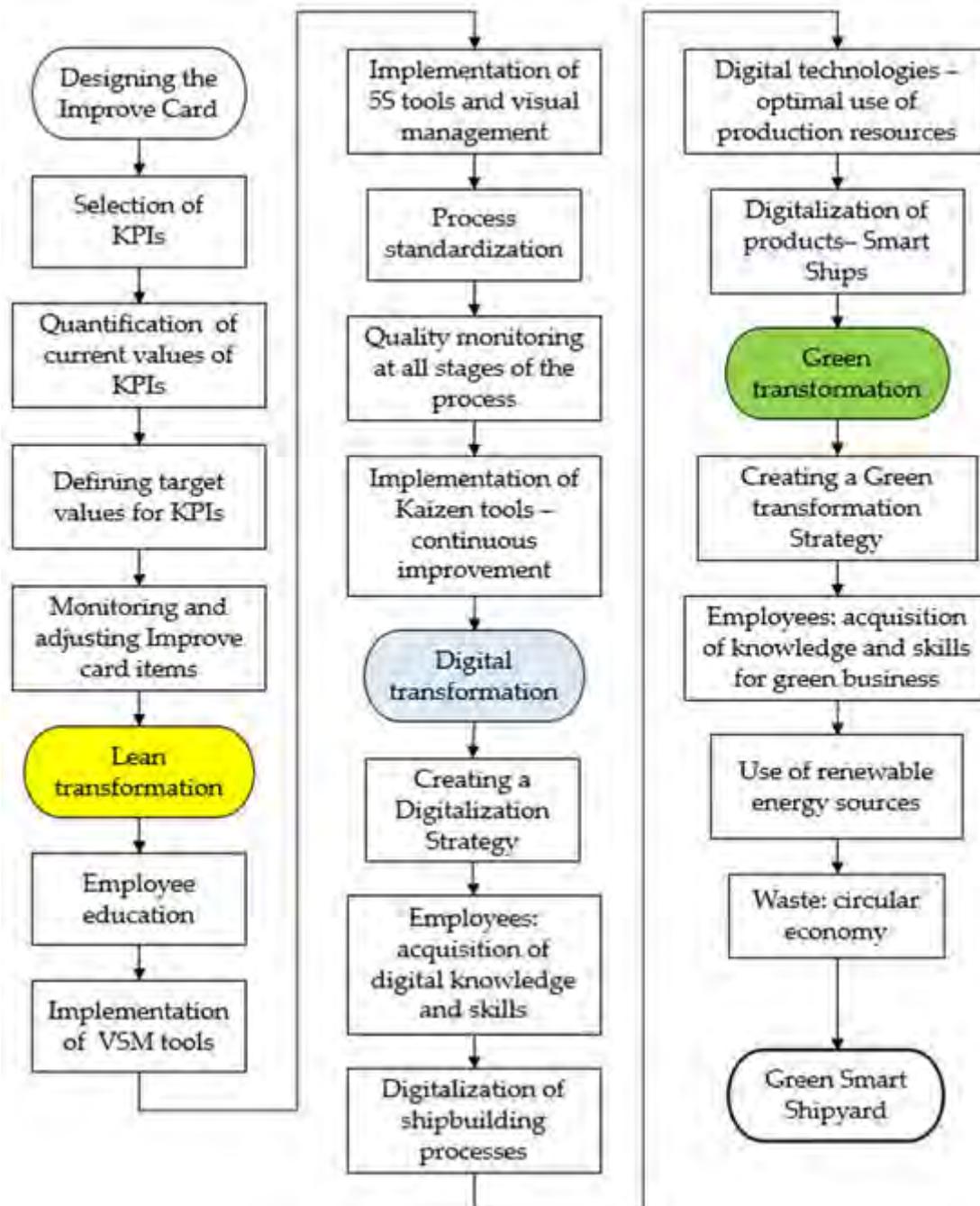


Figure 4 CULIS logic

At the core of CULIS is the individual (the employee, the expert or the manager) whose role becomes crucial for the acceptance and execution of change. The methodology emphasises the development of competencies, a shift in mindset and the building of an organisational culture oriented toward learning, collaboration and openness to innovation. Such an approach enables faster, easier and more sustainable implementation of new solutions in practice.

CULIS is therefore viewed as a transformational framework that connects processes, technology and people, with the aim of creating agile, competitive and sustainable organisations. In the following section, the focus is placed on the three fundamental pillars of the methodology – Lean, Green and Digitalisation – through which its principles are implemented in practice.

Lean implementation pillar

Lean implementation pillar represents the initial phase of transformation in which processes are optimised, waste is eliminated and a stable foundation is established for the further development of the organisation. It is focused on people, value streams and continuous improvement, delivering fast and measurable results such as increased productivity, shorter process times and cost reduction. Since Lean can be applied in any environment that contains processes, its success depends on the size of the organisation, its culture, the level of waste and the objectives to be achieved:



Figure 5 Lean excerpt (CULIS methodology)

As illustrated by the CULIS methodology excerpt in *Figure 5*, the emphasis is placed on key Lean tools that form the basis of every successful transformation:

- Value Stream Mapping,
- 5S systems and visual management,
- Standardisation,
- Quality management,
- Kaizen approach (continuous improvement).

When applied together, Lean tools create an environment in which processes become clear, stable and predictable. The effects are reflected not only in waste reduction, but also in higher employee engagement, improved communication and faster problem-solving. Lean therefore operates not only at a technical level, but gradually transforms the organisational mindset, from a focus on individual tasks to an understanding of the entire value stream. This shift in perspective enables improvements to be viewed not as isolated activities, but as a continuous process that naturally leads the organisation toward greater efficiency and long-term sustainable growth.

Digitalisation pillar

Digitalisation pillar represents a key of modern business and an essential element of the CULIS methodology, as it enables real-time access to information, improved process coordination and faster decision-making. It is focused on employees who use modern technologies, as well as on the transformation of products, services and organisational structures toward greater connectivity, transparency and efficiency. In this way, digitalisation connects horizontal and vertical processes within the organisation, develops employees' digital competencies, and creates the prerequisites for robotisation, automation and smart products.



Figure 6 Digitalisation excerpt (CULIS methodology)

To achieve these effects in practice, various digital tools and systems are applied, as illustrated in *Figure 6*. The most important include:

- IoT – Internet of Things,
- Cloud computing,
- Robotics,
- Big Data analytics,
- Augmented reality,
- Virtual reality,
- Digital twin,
- Smart planning,
- MES + MRP + ERP systems,
- 5G,
- Cybersecurity,
- Artificial intelligence.

Digitalisation therefore changes not only technology, but also the way an organisation thinks, communicates and makes decisions. When data are available in real time, processes are interconnected and employees are ready to use modern tools, the company begins to operate faster, smarter and more securely than ever before. At this point, it becomes clear that digitalisation is not merely a support function, but a force that fundamentally reshapes the business and opens up opportunities that once seemed distant, but are now becoming the standard.

Green pillar

The Green pillar of the CULIS methodology is focused on responsible resource management and the application of technologies that reduce the negative environmental impact of business operations. The emphasis is not only on energy savings, but also on the rational use of materials, emission reduction, a circular approach to resource utilisation, and the creation of sustainable processes that increase organisational efficiency in the long term. In addition to environmental benefits, Green initiatives also contribute to socially responsible business practices, strengthen organisational reputation, and support compliance with modern sustainability standards.

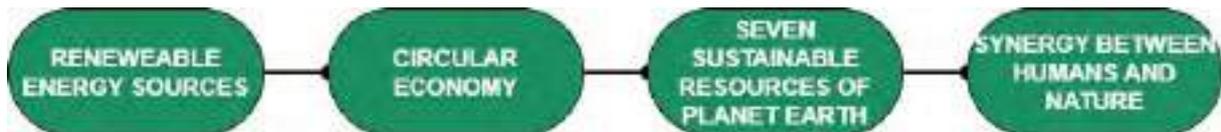


Figure 7 Green excerpt (CULIS methodology)

As illustrated in *Figure 7*, the Green approach encompasses key sustainability areas:

- Renewable energy sources,
- Circular economy,
- Seven sustainable resources of planet Earth (water, soil, biomass, air, solar energy, wind and geothermal renewable thermal sources),
- Synergy between humans and nature.

Ultimately, Green is not merely a set of environmental initiatives, but a mindset that enables organisations to transform costs into savings, challenges into opportunities and sustainability into a genuine competitive advantage.

CULIS in DRWO4.0 countries

The CULIS methodology was applied and tested within the DRWO4.0 project through the Baseline Status Assessment Report, which provides an overview of the current state of the forest-based industry in the participating countries. The report analyses production capacities, resource availability and economic relevance, while assessing the sector's readiness for Industry 4.0 by identifying gaps in infrastructure, investment, skills and technological capabilities. To address these gaps, DRWO4.0 partners developed a Transnational Action Plan² that outlines targeted recommendations for capacity building and modernisation in line with I4.0 standards.

The application of the CULIS methodology to Lean, Digital and Green transformation revealed several key insights. These three dimensions are strongly interconnected, with

² <https://interreg-danube.eu/projects/drwo40/library?page=2>

progress in one area reinforcing development in the others. Lean management shows uneven maturity across the region, particularly among micro and small enterprises, highlighting the need for capacity building, training and stronger institutional and cross-border support. Embedding Lean principles in education is seen as essential for fostering a culture of continuous improvement and operational efficiency, which also enables further digital and green transformation.

Digital transformation remains uneven, with larger enterprises leading adoption. To prevent smaller companies from lagging behind, investment in digital infrastructure, skills development and public-private partnerships is crucial. Digital technologies not only improve competitiveness but also support Lean implementation and provide the foundation for Industry 4.0 and sustainable innovation, with research institutions playing a key role in driving technological integration.

Green transformation similarly varies across the region and company sizes. Advancing sustainability requires tailored support for smaller enterprises, incentives for green innovation in larger firms, and stronger collaboration and knowledge sharing at regional level. Digitalisation and operational efficiency gained through Lean practices are identified as key enablers of improved environmental performance.

Overall, the analysis confirms that Lean management should serve as the starting point for transformation, providing the basis for process optimisation, waste reduction and efficiency gains. Building on Lean, clearly defined digital and green strategies, particularly digital product innovation in the forest-based industry, will enhance competitiveness, productivity and sustainability across the DR. This is the reason why Lean was one of key topics in the capacity building activities implemented within the DRWO4.0 project.

Application of VCA and the CULIS methodology in the forest-based industry

The application of structured transformation approaches is particularly relevant in the wood industry due to its complex production processes and strong dependence on natural resources, materials and energy. Production systems in this sector often involve multiple processing stages, variable input quality and strong interdependencies between upstream and downstream activities. As a result, improving overall performance requires more than isolated optimisation measures; it requires a holistic understanding of how value is created, transferred and lost throughout the entire production system.

Within this context, Value Chain Analysis (VCA) serves as a foundational analytical method for examining the forest-based industry. By analysing material flows, process interdependencies and value-creating activities, VCA enables organisations to systematically identify key areas for improvement across the value chain. The analysis reveals where inefficiencies, bottlenecks and resource losses occur, as well as where sustainability-related challenges emerge, such as excessive energy consumption, material waste or limited circularity. Importantly, VCA helps clarify which parts of the organisation or value chain require intervention and which processes have the greatest impact on overall performance.

The insights generated through Value Chain Analysis form the basis for targeted transformation actions. At this stage, the CULIS methodology is applied as an integrative and flexible framework that translates analytical findings into practical improvements. Rather than requiring full-scale implementation of all methodological components, CULIS enables a focused and modular application of its three pillars (Lean, Digital and Green) depending on the specific needs identified through the value chain analysis.

Lean elements are typically applied where process instability, inefficiencies or waste are detected, supporting process standardisation, flow optimisation and improved operational discipline. Digital elements are introduced where increased transparency, data availability or process connectivity is required, enabling better coordination, monitoring and decision-making. Green elements address areas related to resource efficiency, energy use, emissions and circular practices, ensuring that improvements are aligned with the environmental characteristics of the wood industry.

Through this complementary use of VCA and the CULIS methodology, transformation efforts remain clearly structured and aligned with real operational challenges. The analytical clarity provided by value chain analysis, combined with the selective application of Lean, Digital and Green measures, ensures that improvement initiatives are relevant, proportionate and suited to the organisational context of wood industry enterprises. In this way, structured analysis and integrated transformation support sustainable performance improvement without imposing unnecessary complexity.

This approach does not rely on a rigid division between small, medium and large enterprises, but allows the scope and intensity of analysis and implementation to evolve fluidly in line with organisational complexity, maturity and development needs.

Application of VCA and CULIS methodology in small sized enterprises

Small wood enterprises typically operate with limited resources and strong day-to-day involvement of owners and employees in production activities. Their organisational structures are usually simple, with processes that evolve gradually and intuitively, often without formal standardisation or systematic performance monitoring. At the same time, such enterprises benefit from high flexibility and fast decision-making, which represent an important advantage in the dynamic wood industry environment.

In this context, Value Chain Analysis (VCA) is applied in a simplified form, focusing on gaining a clear overview of core processes, material flows, and key value-creating activities. The primary role of VCA in small enterprises is to identify the most critical inefficiencies and improvement areas without introducing unnecessary complexity.

Critical inefficiencies are identified through a systematic assessment process combining:

- Material flow analysis – examining where material losses, excess inventory, or bottlenecks occur,
- Process time mapping – identifying activities with disproportionate duration relative to value added,
- Resource utilization assessment – evaluating equipment downtime, labour deployment efficiency, and energy consumption patterns,
- Quality incident tracking – analysing where defects, rework, or customer complaints concentrate,
- Comparative maturity scoring – highlighting the largest gaps between current state (0-3) and realistic potential (0-3) across the five drivers.

For small enterprises, this assessment is conducted collaboratively with company management through structured interviews and workshop sessions, supported by DRWO4.0 partner facilitation. The focus remains on identifying 2–3 high-impact improvement areas rather than comprehensive optimization, ensuring alignment with resource constraints and organisational capacity.

Example: A small furniture manufacturer might identify critical inefficiencies such as:

- Excessive material waste in cutting processes (Process automation driver, current score: 0, potential: 2),
- Manual order tracking causing delivery delays (Logistics digitalization driver, current score: 0, potential: 2),
- Lack of quality documentation limiting premium market access (Quality control & traceability driver, current score: 1, potential: 3).

Building on these insights, the application of the CULIS methodology in small wood enterprises does not start with advanced technological solutions, but with process stabilisation and a gradual shift in operational mindset. The focus is placed on introducing basic Lean principles, simple digital tools, and fundamental elements of sustainable

resource management. This approach allows improvements to be implemented in line with the company’s capabilities, while maintaining operational stability.

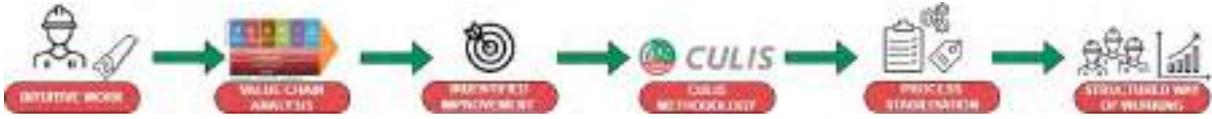


Figure 8 VCA/CULIS implementation - small enterprise

Within this framework, CULIS supports small forest-based enterprises in transitioning from a predominantly reactive way of working toward more structured process management, with an emphasis on people development, process understanding and long-term sustainability as the foundation for further growth.

Application of VCA and CULIS methodology in medium sized enterprises

Medium-sized wood enterprises are typically positioned in a transitional phase between operationally driven organisations and systematically managed production systems. They usually employ a larger workforce, operate more developed product portfolios, and manage more complex technological processes, while often retaining elements of informal organisation and partially standardised workflows. This combination of organisational growth and increasing complexity, coupled with limited process visibility, represents one of the key challenges faced by medium-sized companies within the wood industry.

In this context, Value Chain Analysis (VCA) provides a structured analytical approach for understanding how value is created and transferred across departments and production stages. By examining material flows, process interdependencies, and organisational responsibilities, VCA helps identify coordination gaps, performance deviations, and inefficiencies that may not be visible through day-to-day operational management. The analysis enables management to gain a clearer overview of the entire production system and to identify improvement areas with the greatest impact on overall performance.



Figure 9 VCA/CULIS implementation - medium sized enterprises

Building on these insights, the application of the CULIS methodology in medium-sized wood enterprises focuses on strengthening governance structures and improving process transparency. Unlike small enterprises, where the primary objective is basic process

stabilisation, medium-sized companies require clearly defined roles, measurable objectives and systematic performance monitoring at both process and departmental levels. Lean principles, digital tools and Green practices are therefore no longer applied as isolated initiatives, but are integrated into a coherent operational framework.

A key aspect of this transformation is a shift in managerial mindset. The focus moves from reactive, operational problem-solving toward proactive process management, data-driven decision-making and structured planning. This change supports the development of a culture of accountability, in which objectives, priorities and performance indicators are clearly defined and understood across the organisation. As a result, collaboration between production, logistics, maintenance and management becomes more effective and aligned.

In this role, the CULIS methodology acts as a connecting framework that aligns organisational structures, technological capabilities, and sustainable resource management. Through the gradual introduction of standardisation, digital process support, and increased awareness of energy and material efficiency, medium-sized wood enterprises establish a stable foundation for continued development, improved competitiveness and readiness for more advanced forms of digital and green transformation.

Application of VCA and CULIS methodology in large sized enterprises

Large wood enterprises are characterised by high organisational complexity, a large workforce, technologically demanding processes and strong integration with suppliers and markets. Production is typically distributed across multiple plants or production lines, while operations take place within clearly defined regulatory, environmental and market frameworks. In such an environment, challenges are no longer related to the stability of basic processes, but rather to their coordination, optimisation and long-term sustainability across the entire system.

Within this context, Value Chain Analysis (VCA) is applied as a comprehensive analytical tool that provides visibility across complex and interconnected value chains. By examining material, information and energy flows across multiple organisational units and external partners, VCA enables the identification of systemic inefficiencies, coordination gaps and improvement potentials that cannot be detected at the level of individual departments. The analysis supports a shift from local optimisation toward a holistic understanding of system-wide performance and value creation.



Figure 10 VCA/CULIS implementation - large size enterprises



Building on these insights, the CULIS methodology is applied to translate value chain findings into an integrated transformation approach. In large wood enterprises, Lean, Digital and Green elements are no longer treated as separate initiatives, but are aligned within a unified management framework. Lean principles support organisation-wide standardisation and process stability, digital solutions enable real-time data availability and advanced analytics, while Green practices address energy efficiency, resource management and environmental impact across the full value chain.

A key aspect of this transformation occurs at the level of top management and senior leadership. The focus shifts from optimising individual functions toward managing the performance of the entire production and supply system, including suppliers, logistics networks and downstream markets. Transparency, traceability and accountability become central management principles, supported by data-driven decision-making and integrated digital platforms.

Through the combined application of VCA and the CULIS methodology, large wood enterprises are able to connect high levels of automation, digital infrastructure and green technologies into a coherent and sustainable business model. This integrated approach establishes a strong foundation for long-term competitiveness, regulatory compliance and the ability to adapt to future market and technological developments.

Main obstacle for the Industry 4.0 transformation

Within the DRWO4.0 Transnational Action Plan for the improvement of DR forest-based industry according to the I4.0 standards (O1.1), across all analysed countries, funding for Industry 4.0 transformation is widely recognised as a major obstacle, despite the availability of numerous European and national financial instruments. The review shows that forest-based industry theoretically has access to a broad spectrum of funding programmes, including Horizon Europe, ERDF, EAFRD, LIFE, Digital Europe, Interreg, InvestEU, IPA funds, national recovery and innovation schemes. These programmes support digitalisation, automation, sustainability, skills development and innovation, all of which are essential for I4.0 implementation.

Countries such as Austria, Croatia, Romania, Slovenia and the Czech Republic benefit from relatively well-structured funding ecosystems, including Digital Innovation Hubs, cluster-based support and dedicated SME instruments that facilitate access to funding and reduce investment risks. In contrast, countries like Bosnia and Herzegovina, Moldova, Ukraine and parts of Hungary face more fragmented, irregular or sector-unspecific funding landscapes, often relying on ad-hoc calls, international donor programmes or general innovation schemes not tailored to the forest-based industry.

A common challenge across the region is that available funding is often difficult for SMEs to access due to complex application procedures, co-financing requirements, limited administrative capacity, lack of project development skills, or insufficient awareness of suitable programmes. In several countries, funding exists primarily for research, sustainability, or general digitalisation, while targeted support for Industry 4.0 adoption in the forest-based sector remains limited.

Overall, while funding opportunities for Industry 4.0 transformation are substantial at EU and national levels, the main barrier lies not in the absence of financial instruments, but in their accessibility, sectoral relevance and effective uptake by SMEs. Strengthening advisory support, simplifying access mechanisms, improving project preparation capacities and developing sector-specific funding schemes are critical to overcoming funding-related obstacles to Industry 4.0 transformation.

Enabling the implementation of Industry 4.0 - policy and company perspectives

Policy level approach to the transformation

At the policy level, the transformation towards Industry 4.0 in the forest-based industry must be seen as part of a broader strategy for competitiveness, sustainability and the circular bioeconomy. Policymakers have a unique role in setting the enabling conditions under which companies can modernise and collaborate.

A central priority is the creation of a supportive regulatory and incentive framework. Policies that promote digital traceability, data sharing and certification standards help to align the sector with global sustainability demands while ensuring access to premium markets. Incentives such as tax breaks, grants or innovation vouchers can lower the barriers to investment for SMEs and small forest owners, who are often not able to bear the costs of new technologies.

Another critical policy lever is the development of digital infrastructure and interoperability standards. Investments in broadband connectivity in rural regions, enabling data platforms for resource management and protocols for machine-to-machine communication, create the backbone for Industry 4.0 adoption.

Equally important is the investment in human capital. National training programmes, curricula for schools and reskilling initiatives for workers ensure that the future workforce can engage with digital tools. Policymakers can also foster collaborative ecosystems by bringing together industry, academia and technology providers to test solutions in pilot projects.

Finally, policies should encourage system-level integration, not only supporting technologies within individual companies but also enabling cooperation across the value chain ensuring that stakeholders share data, align incentives and create collective value.

Transformation at the company level

For companies, the approach to Industry 4.0 transformation must balance strategic ambition with practical implementation. Companies focus on tangible returns, risk management and organisational change.

The first step is to establish a clear digital strategy. This requires defining business objectives, whether to improve efficiency, enhance product traceability, diversify into bio-based products, or meet new customer demands, and aligning them with a digitalisation roadmap. Quick wins, such as predictive maintenance or telematics in transport fleets, can demonstrate early returns and build momentum for more advanced initiatives like digital twins or fully integrated value-chain platforms.

Strong leadership commitment is essential. Senior managers must champion the transformation, allocate resources, and communicate the strategic importance of digitalisation to the entire organisation. This commitment must be matched by a culture of change, where employees are encouraged to adopt new practices, contribute ideas, and experiment with digital solutions without fear of failure.

Workforce development is another cornerstone. Companies need to invest in training and upskilling to ensure that operators, technicians, and managers can interpret data, use new tools, and adapt to digitally enabled workflows. This helps to overcome the human barriers of resistance and skill gaps.

At the operational level, companies should pursue incremental but scalable adoption. Pilot projects are an effective way to test new technologies, prove their value, and refine implementation before scaling across sites or value chains. Partnerships with technology providers, universities, or other companies can reduce risks and costs, while participation in sector-wide initiatives ensures alignment with evolving standards.

Lastly, companies must integrate measurement and feedback mechanisms. By tracking KPIs such as efficiency gains, waste reduction, downtime hours, or carbon footprint, businesses can evaluate progress, justify further investments, and continuously refine their transformation journey.

In sum, the policy-level approach focuses on creating the enabling environment (standards, incentives, skills, infrastructure) while the company-level approach emphasises leadership, culture, workforce readiness and pragmatic adoption. Together, these perspectives ensure that Industry 4.0 transformation is not only technologically feasible but also socially accepted, economically viable, and environmentally sustainable.

Importance of human capacities for the Industry 4.0 transformation

The transformation towards Industry 4.0 in the forest-based sector cannot be reduced to a question of technology alone. While sensors, analytics and digital platforms form the visible face of innovation, it is the human dimension that ultimately determines success or failure. Without strong leadership, engaged employees and a culture of learning, even the most advanced technologies will fail to deliver their potential.

Leadership commitment is a decisive factor. Industry 4.0 represents a profound change in mindset, requiring leaders at every level, from policymakers to company executives, to articulate a compelling narrative of why transformation is necessary and to embody that vision in concrete actions. This includes not only financing digitalisation but also investing

in long-term capacity building, ensuring that organisations and the wider sector are prepared for continuous adaptation. Leaders must also model openness to innovation, encourage cross-functional collaboration and create the psychological safety that allows employees to experiment and learn.

Equally critical is the cultural transformation within organisations. Traditional routines, hierarchical structure and working practices often conflict with the agile, data-driven and collaborative approaches demanded by Industry 4.0. Change management becomes a core task: companies and institutions must consciously nurture cultures that value experimentation, embrace continuous learning and promote cross-sectoral collaboration. Such cultural change requires time, but it is essential to embed digitalisation as a natural part of everyday work rather than as an external imposition.

Workforce upskilling stands at the centre of this transformation. Employees at all levels need training to understand and interpret digital data, operate advanced tools and see themselves as active contributors to innovation. For operators or contractors, this may mean learning to use predictive maintenance systems or telematics platforms. For managers, it means developing the ability to make data-driven decisions and integrate digital solutions into strategic planning. Upskilling not only reduces skill gaps but also helps to overcome resistance to change, as workers feel empowered rather than threatened by new technologies.

Organisational readiness further depends on recognising and addressing barriers to transformation. Technical barriers such as outdated infrastructure and fragmented data systems can slow progress, while cultural barriers often manifest as resistance in industries with long-standing traditions. Financial barriers are particularly acute for SMEs, which may lack the resources to invest in advanced equipment or platforms without external support. Human barriers, including digital skill shortages or fears of job displacement, risk undermining adoption unless they are met with inclusive strategies for transition.

Overcoming these challenges requires coordinated action at both policy and company levels. Governments and sectoral bodies can support training programmes and collaborative initiatives that reduce risk and cost for smaller actors. At the company level, pilot projects and demonstration cases can provide tangible proof of benefits, helping to build trust and momentum. By combining policy support, collaboration, and organisational reform, the sector can ensure that human capacities evolve in step with technological capabilities.

Ultimately, the Industry 4.0 transformation in the forest-based industry is as much a social and institutional shift as it is a technological one. The ability to lead, learn and adapt will determine whether digitalisation becomes a driver of resilience and sustainability or not.

Conclusion

DRWO4.0 Transformation Model provides a structured and practical framework for supporting the Industry 4.0 transformation of the forest-based industry, addressing both strategic and operational dimensions of change. By combining value chain thinking, maturity assessment and integrated improvement methodologies, it responds to the sector's need for a transformation approach that is systematic, scalable and adaptable to diverse organisational contexts.

At the core of the model lies the **Value Chain Analysis (VCA)**, which enables companies and policymakers to view transformation not as a set of isolated technological upgrades, but as a coordinated effort across interconnected activities, from forest operations and logistics to processing, manufacturing and market delivery. The structured VCA model helps identify where value is created, where inefficiencies persist and where digitalisation, lean practices and sustainability interventions can generate the greatest impact. This value chain perspective ensures that Industry 4.0 investments are aligned with business strategy, market requirements and environmental objectives.

The maturity model, based on a clear and intuitive 0–3 scoring scale, translates strategic ambition into measurable progress. It allows organisations to assess their current level of readiness, benchmark themselves against peers and define realistic transformation pathways. Importantly, the maturity approach acknowledges that companies are starting from different positions and that Industry 4.0 is a gradual journey rather than a single leap.

The integration of the **CULIS methodology**, structured around lean implementation, digitalisation and green pillars, strengthens the model by linking operational excellence with digital and sustainability goals. Lean principles ensure that processes are stabilised and optimised before digitalisation is applied. Digital technologies then enhance transparency, efficiency and decision-making, while the green pillar embeds resource efficiency, circularity and environmental responsibility into everyday operations. Together, these pillars form a balanced and future-oriented transformation logic.

A key strength of the model is its applicability across **different company sizes**. By explicitly addressing the needs of small, medium-sized and large enterprises, it recognises the heterogeneity of the forest-based industry. For SMEs, the model supports incremental transformation through focused improvements and pilot projects, reducing risk and investment pressure. For larger enterprises, it enables more integrated, data-driven, and scalable Industry 4.0 solutions across complex value chains. This differentiated approach increases the model's practical relevance and transferability.

The model also highlights that successful transformation depends on **enabling conditions beyond the factory or forest gate**. Policy-level measures play a crucial role

in providing strategic direction, financial incentives, skills development and platforms for collaboration. At the same time, companies must translate these frameworks into concrete actions through leadership commitment, clear roadmaps and organisational change. The interaction between policy and company-level efforts is therefore essential for achieving lasting impact.

Finally, the model underscores the **central role of human capacities**. Industry 4.0 transformation is ultimately driven by people, leaders who set direction, managers who guide change and employees who adopt new ways of working. Investment in skills, change management and organisational culture is as important as investment in technology. Without this human dimension, digital tools risk remaining underutilised or resisted.

In conclusion, this transformation model offers a comprehensive yet practical approach to guiding the forest-based industry towards Industry 4.0. By integrating value chain analysis, maturity assessment, lean-digital-green methodologies, differentiated company pathways and supportive policy and human frameworks, it provides a solid foundation for resilient, competitive and sustainable transformation across the sector.

Glossary

5S System

A workplace organisation methodology consisting of five steps (Sort, Set in order, Shine, Standardise, Sustain) aimed at improving efficiency, safety and transparency. The 5S system serves as a basic enabler of standardisation and visual management.

Additive Manufacturing

A production method that builds objects layer by layer from digital designs, commonly known as 3D printing. In the wood industry context, additive manufacturing enables rapid prototyping, customized component production, and on-demand manufacturing, reducing inventory costs and enabling distributed production models.

Artificial Intelligence (AI)

Computer systems capable of performing tasks that typically require human intelligence, such as pattern recognition, decision-making, and predictive analysis. In Industry 4.0 applications, AI analyses production data to optimize processes, predict equipment failures, and support quality control through automated defect detection.

Augmented Reality (AR)

Technology that overlays digital information onto physical objects or environments, typically viewed through smart glasses or mobile devices. In manufacturing contexts, AR supports maintenance procedures, training programs, and quality inspections by providing real-time visual guidance and data display.

Baseline Status Assessment

A systematic evaluation of current conditions, capabilities, and performance levels within an organisation or sector, serving as the reference point for measuring transformation progress. The DRWO4.0 Baseline Status Assessment Report documents the forest-based industry's readiness for Industry 4.0 across participating countries.

Big Data Analytics

The process of examining large and complex datasets to identify patterns, correlations, and insights that inform decision-making. In the wood industry, big data analytics supports demand forecasting, supply chain optimization, quality prediction, and resource efficiency improvements.

Bioeconomy

An economic model based on the sustainable production and conversion of renewable biological resources into products, energy, and services. The forest-based industry plays

a central role in the bioeconomy through sustainable wood production, bio-based materials, and carbon storage.

CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing)

Software systems that enable digital product design (CAD) and direct translation of designs into manufacturing instructions for CNC machines (CAM). CAD/CAM integration represents a fundamental driver of digital design maturity in furniture and wood product manufacturing.

Chain-of-Custody

Documentation that tracks the path of wood products from forest to end-user, verifying sustainable sourcing and legal compliance. Digital chain-of-custody systems enhance traceability, support certification schemes (e.g., FSC, PEFC), and enable access to premium markets requiring sustainability proof.

Circular Economy / Circularity

An economic model aimed at minimising waste and maximising the reuse, recycling and sustainable use of resources throughout the product life cycle.

Cloud Computing

The delivery of computing services (storage, processing, software) over the internet rather than through local servers or personal devices. Cloud infrastructure enables real-time data sharing across distributed production sites, supports collaborative platforms, and provides scalable access to advanced technologies like AI and IoT.

CNC (Computer Numerical Control)

Automated machine tools controlled by computer programs that execute precise cutting, drilling, milling, and shaping operations. CNC technology represents a core element of process automation in wood manufacturing, enabling consistent quality, complex geometries, and efficient material utilization.

CULIS Methodology

An integrated transformation methodology combining Lean management, Digitalisation and Green principles. CULIS functions as an implementation framework that translates analytical insights from Value Chain Analysis into targeted, phased and context-specific transformation measures.

Cybersecurity

Protective measures and technologies designed to safeguard digital systems, networks, and data from unauthorized access, cyberattacks, and breaches. As Industry 4.0 increases

connectivity, cybersecurity becomes essential for protecting intellectual property, operational continuity, and customer trust.

Cyber-Physical Systems

Integrated systems that connect physical production equipment with digital monitoring and control systems, enabling real-time data exchange and autonomous decision-making. Cyber-physical systems form the technological foundation of smart manufacturing and Industry 4.0.

Digital Innovation Hub (DIH)

A support organisation that helps companies, particularly SMEs, access digital technologies, expertise, testing facilities, and funding opportunities. DIHs play a critical role in reducing barriers to Industry 4.0 adoption by providing advisory services, pilot project support, and ecosystem connections.

Digital Traceability

The ability to track and document the complete history, location, and characteristics of products, materials, or components throughout the value chain using digital technologies (QR codes, RFID, blockchain). Digital traceability supports quality assurance, regulatory compliance, circular economy practices, and consumer transparency.

Digital Twin

A virtual representation of a physical asset, process or system that is continuously updated using real-time data. Digital twins enable simulation, optimisation and predictive analysis without disrupting real operations.

Digitalisation Pillar

One of the three core pillars of the CULIS methodology, focused on the use of digital technologies to improve process transparency, connectivity, data availability and decision-making across organisations and value chains.

DRWO4.0 (Danube Region Wood Industry Transformation Model towards Industry 4.0)

A transnational Interreg Danube project aimed at developing an applicable, modifiable, and replicable Industry 4.0 transformation model specifically designed for the forest-based industry in the Danube Region. The project combines value chain analysis, capacity building, pilot environments, and policy recommendations to support digital and sustainable transformation across participating countries.

End-of-Life Management

The final stage of a product's value chain encompassing disposal, recycling, reuse, remanufacturing, or energy recovery. Effective end-of-life management is central to circular economy principles and requires design considerations, material documentation, and take-back systems integrated throughout the value chain.

Enterprise Resource Planning (ERP)

Integrated software systems that manage core business processes including production planning, inventory management, purchasing, sales, finance, and human resources. ERP integration represents a critical milestone in digital maturity, enabling data-driven decision-making and cross-functional coordination.

Forest-Based Industry / Forest-Based Sector

Industries that process wood and non-wood forest products, including forestry operations, sawmilling, wood panel production, furniture manufacturing, pulp and paper production, and bio-based product development. The sector plays a strategic role in the bioeconomy, carbon storage, and rural employment.

Horizontal Integration

The digital connection and coordination of processes across different functional areas, facilities, or organisations at the same level of the value chain (e.g., linking multiple production sites, coordinating with suppliers). Horizontal integration enables synchronized operations, shared data visibility, and collaborative planning.

Green Pillar

One of the three core pillars of the CULIS methodology, addressing resource efficiency, energy use, emissions reduction and circular economy principles. The Green pillar ensures alignment between transformation measures and sustainability objectives.

Industry 4.0

The transformation of industrial systems through the integration of advanced digital technologies such as the Industrial Internet of Things, data analytics, automation and artificial intelligence. Industry 4.0 supports productivity, traceability, resilience and sustainable value creation in industrial value chains.

Industrial Internet of Things (IIoT)

Network-connected sensors, machines, and devices that collect and exchange data in industrial environments. IIoT enables real-time monitoring of equipment performance, predictive maintenance, automated quality control, and optimization of production processes based on continuous data streams.

Interoperability

The ability of different digital systems, platforms, and technologies to exchange data and work together seamlessly. Interoperability is essential for Industry 4.0 transformation, as it enables integration across diverse software applications, machinery, and organisational boundaries.

Kaizen

A continuous improvement approach based on incremental changes and active employee involvement. Kaizen functions as both a cultural principle and an operational practice supporting long-term performance improvement and organisational learning.

Lean

A management philosophy and set of methods focused on process optimisation, waste elimination and continuous improvement. Lean represents the foundational pillar that stabilises processes and establishes the conditions for effective digital and green transformation.

Life Cycle Assessment (LCA)

A systematic methodology for evaluating the environmental impacts of a product, process, or service throughout its entire life cycle, from raw material extraction through production, use, and end-of-life disposal. LCA supports evidence-based sustainability improvements and circular economy design decisions.

Machine Learning

A subset of artificial intelligence that enables systems to learn from data patterns and improve performance without explicit programming. In manufacturing applications, machine learning supports quality prediction, process optimization, demand forecasting, and anomaly detection.

Maturity Model

An assessment framework used to evaluate the current and potential level of digital and circular maturity of enterprises. Maturity is measured using a harmonised scoring system that enables comparison across company sizes and countries and supports the identification of realistic development gaps.

Maturity Scoring (0–3 scale)

A scoring system used within the maturity model to assess transformation readiness, where 0 represents the absence of digital or circular practices and 3 represents fully integrated and advanced systems. The difference between current and potential scores indicates the development gap.

MES (Manufacturing Execution System)

Software that monitors, tracks, and controls production processes in real-time on the shop floor. MES bridges the gap between ERP systems (planning level) and physical production equipment (operational level), providing visibility into work-in-progress, machine status, and performance metrics.

NACE Classification

The statistical classification of economic activities in the European Union (Nomenclature statistique des Activités économiques dans la Communauté Européenne). NACE C31 specifically refers to "Manufacture of Furniture," which was the focal sector for VCA implementation in the DRWO4.0 project.

Pilot Environment (PE)

A controlled, real-world testing environment where new technologies, methodologies, or business models are implemented and evaluated before broader adoption. The DRWO4.0 project established cross-border pilot environments to demonstrate practical application of Industry 4.0 solutions in the forest-based sector.

Predictive Maintenance

Maintenance strategies based on continuous condition monitoring and data analysis that predict equipment failures before they occur. Predictive maintenance reduces unplanned downtime, extends asset lifespan, and optimizes maintenance scheduling compared to reactive or time-based approaches.

Primary Processing

The initial transformation of raw materials into semi-finished products. In the forest-based value chain, primary processing typically includes activities such as sawing logs into lumber, debarking, drying, and initial grading or sorting of wood materials.

Process Standardisation

The establishment of consistent, documented procedures for performing recurring tasks or operations. Standardisation reduces variability, supports quality consistency, enables effective training, and creates the stable foundation necessary for successful automation and digitalisation.

QR Code / RFID (Radio-Frequency Identification)

Digital identification technologies used for product tracking and traceability. QR codes store information accessible via smartphone scanning, while RFID tags use radio waves for automated identification. Both technologies support chain-of-custody documentation, inventory management, and circular economy tracking systems.

Secondary Processing

Value chain activities that transform semi-finished materials into finished products. In furniture manufacturing, secondary processing includes assembly, surface finishing, upholstery, quality inspection, and packaging operations that prepare products for distribution and sale.

Sensor Technology

Devices that detect and measure physical properties (temperature, moisture, pressure, vibration, etc.) and convert them into digital signals. Sensor integration enables real-time monitoring, automated quality control, and data collection essential for Industry 4.0 applications in wood processing.

Simulation

The use of digital models to replicate real-world processes, systems, or scenarios for analysis, testing, and optimization purposes. Simulation enables risk-free experimentation with production parameters, facility layouts, or supply chain configurations before implementing physical changes.

Smart Manufacturing

Production systems that leverage advanced digital technologies (IoT, AI, data analytics) to create adaptive, self-optimizing operations. Smart manufacturing enables real-time responsiveness to changing conditions, autonomous decision-making, and continuous performance improvement.

SME (Small and Medium-sized Enterprise)

Businesses defined by employee numbers and financial thresholds that vary by region but typically include companies with fewer than 250 employees. SMEs dominate the European furniture and wood manufacturing sector and face specific challenges in Industry 4.0 adoption related to resources, skills, and access to support.

Supply Chain Transparency

The visibility and accessibility of information about products, processes, and transactions across the entire supply chain from raw materials to end customers. Digital technologies enable enhanced transparency that supports sustainability verification, risk management, and stakeholder trust.

Telematics

Technology that combines telecommunications and informatics to transmit data from remote equipment or vehicles. In forestry and wood logistics, telematics supports fleet management, route optimization, fuel efficiency monitoring, and coordination of harvesting and transport operations.

Transnational Cooperation

Collaborative activities involving partners from multiple countries working toward shared objectives. The DRWO4.0 project employs transnational cooperation to share knowledge, develop harmonized methodologies, and create replicable solutions applicable across the diverse Danube Region contexts.

Upskilling

The process of teaching the employees new skills or enhancing existing competencies to meet evolving job requirements. In the Industry 4.0 context, upskilling focuses on digital literacy, data interpretation, technology operation and adaptive problem-solving capabilities essential for modern manufacturing environments.

Value Chain

The full sequence of activities required to create and deliver a product or service, from initial inputs through production, distribution, use, and end-of-life management. Value chain thinking emphasizes understanding interdependencies, optimizing system-level performance and identifying where value is created or lost.

Value Chain Analysis (VCA)

A structured analytical approach used to examine the full value chain of the forest-based industry, from raw material inputs to end-of-life stages. VCA identifies value-creating activities, inefficiencies, transformation gaps and development potentials related to digitalisation, sustainability and organisational performance.

Value Stream

The specific sequence of processes and activities required to deliver a particular product or service to a customer. Value stream mapping, a core Lean tool, visualizes these flows to identify waste, bottlenecks and improvement opportunities.

Value Stream Mapping (VSM)

A Lean tool used to visually map material and information flows across value-creating processes. VSM supports the identification of bottlenecks, inefficiencies and improvement opportunities within the value chain.

Vertical Integration

The digital connection of different hierarchical levels within an organisation, linking shop floor operations with management systems and strategic planning layers. Vertical integration enables real-time information flow from production equipment to executive dashboards, supporting data-driven decision-making at all organisational levels.

Visual Management

A set of practices that use visual tools to communicate process status, performance indicators and problems in a clear and accessible way. Visual management supports transparency, faster decision-making and effective problem-solving within Lean environments.

Waste

In Lean methodology, any activity or resource consumption that does not add value from the customer's perspective. The seven classical types of waste include: overproduction, waiting, transportation, over-processing, excess inventory, unnecessary motion and defects. An eighth waste, underutilized human potential, is often added in modern Lean practice.

Zero Trust Architecture

A cybersecurity framework that requires strict identity verification for every person and device attempting to access network resources, regardless of whether they are inside or outside the organisational perimeter. Zero Trust principles become increasingly important as Industry 4.0 expands connectivity and data exchange.