

THE EVOLUTION OF SCIENTIFIC RESEARCH ON CONTROL IN THE FORESTRY SECTOR

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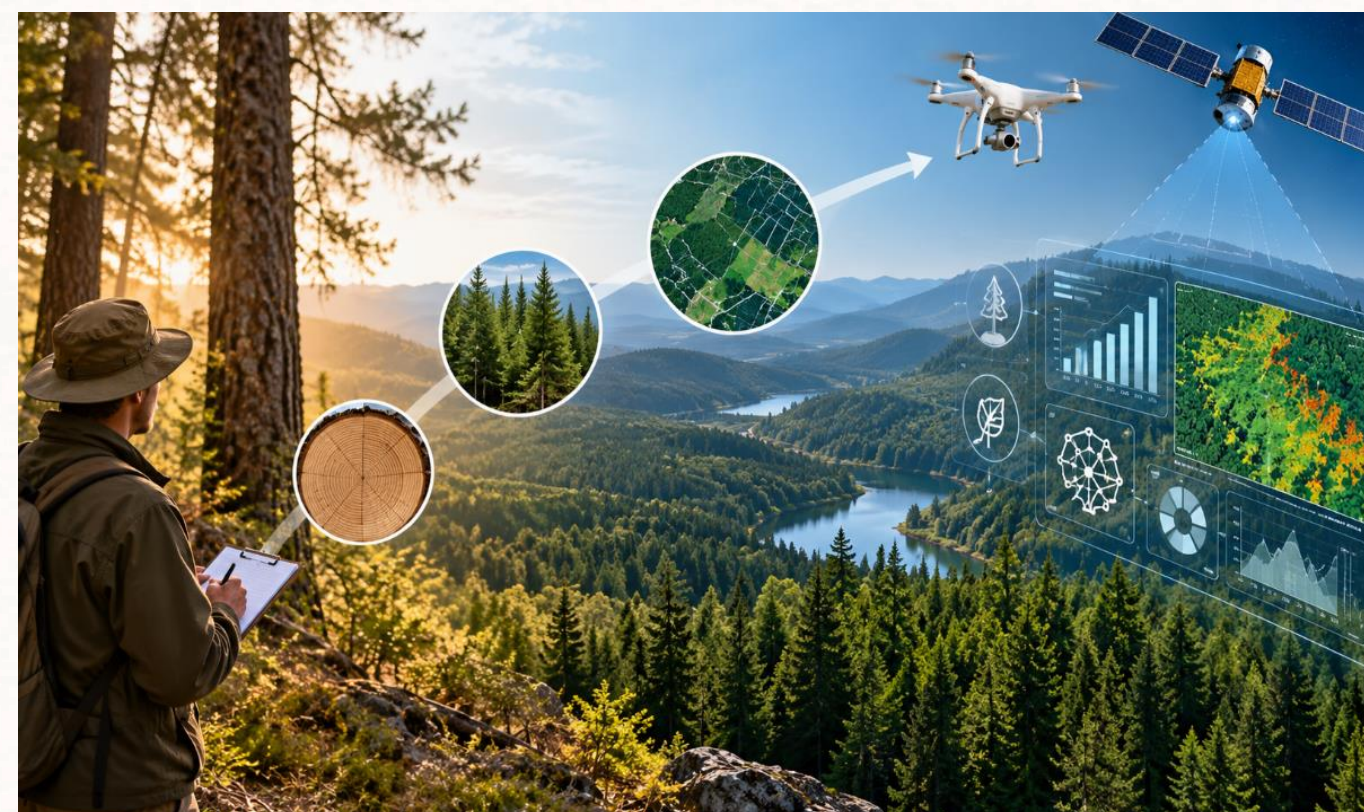
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The study examines the evolution of scientific research on control within the forestry sector through a bibliometric analysis of 5,859 publications from the Web of Science database covering the period 2000-2026.

Why is it needed?



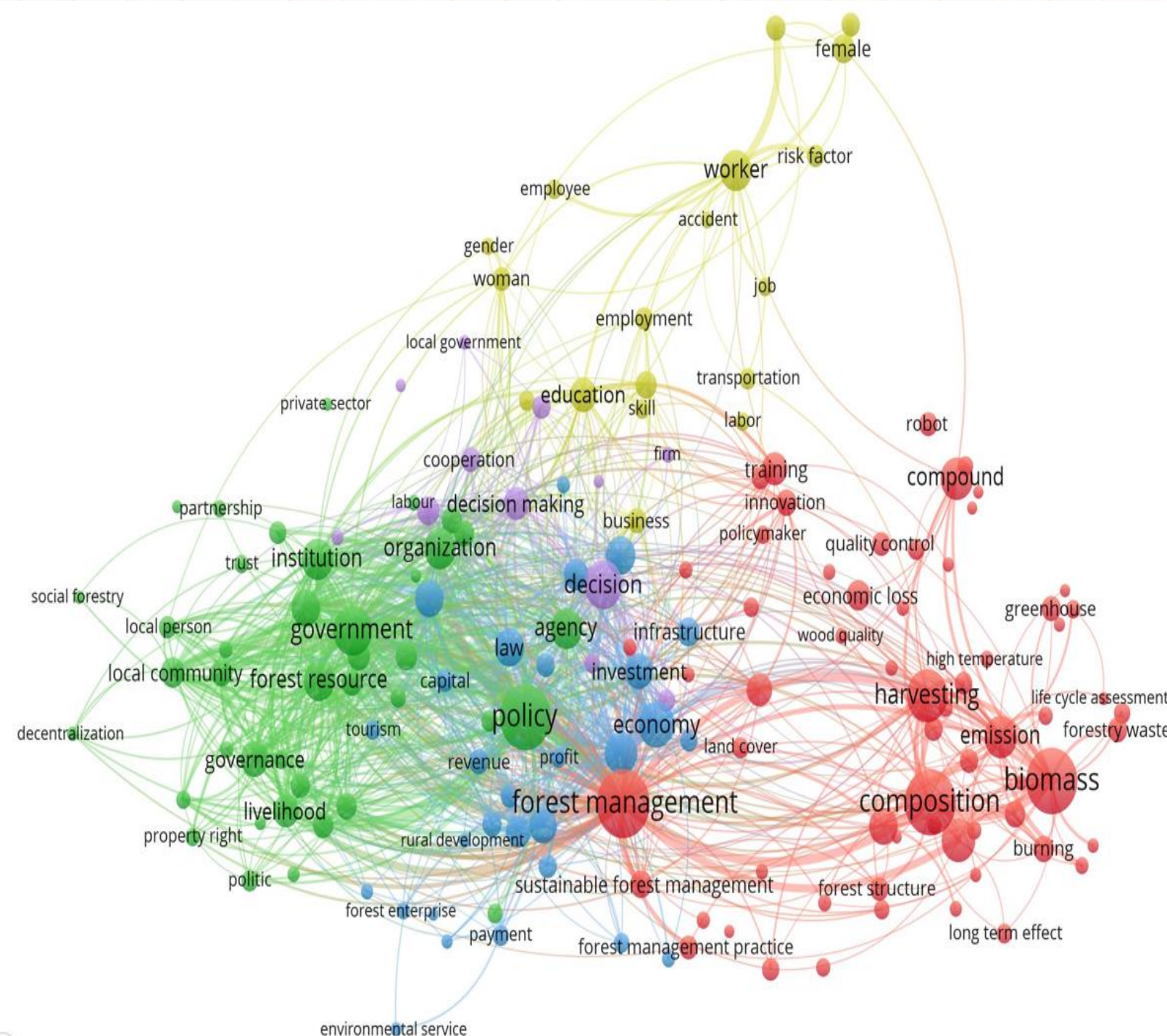


Figure 1. Cluster map of keywords in publications on “control” and “forestry”

Source: Based on data from the Web of Science, processed using VOSviewer, N = 5,859

Cluster 1 (green): “Institutional Control”, with primary publication activity during 2000-2012 and 2016-2025

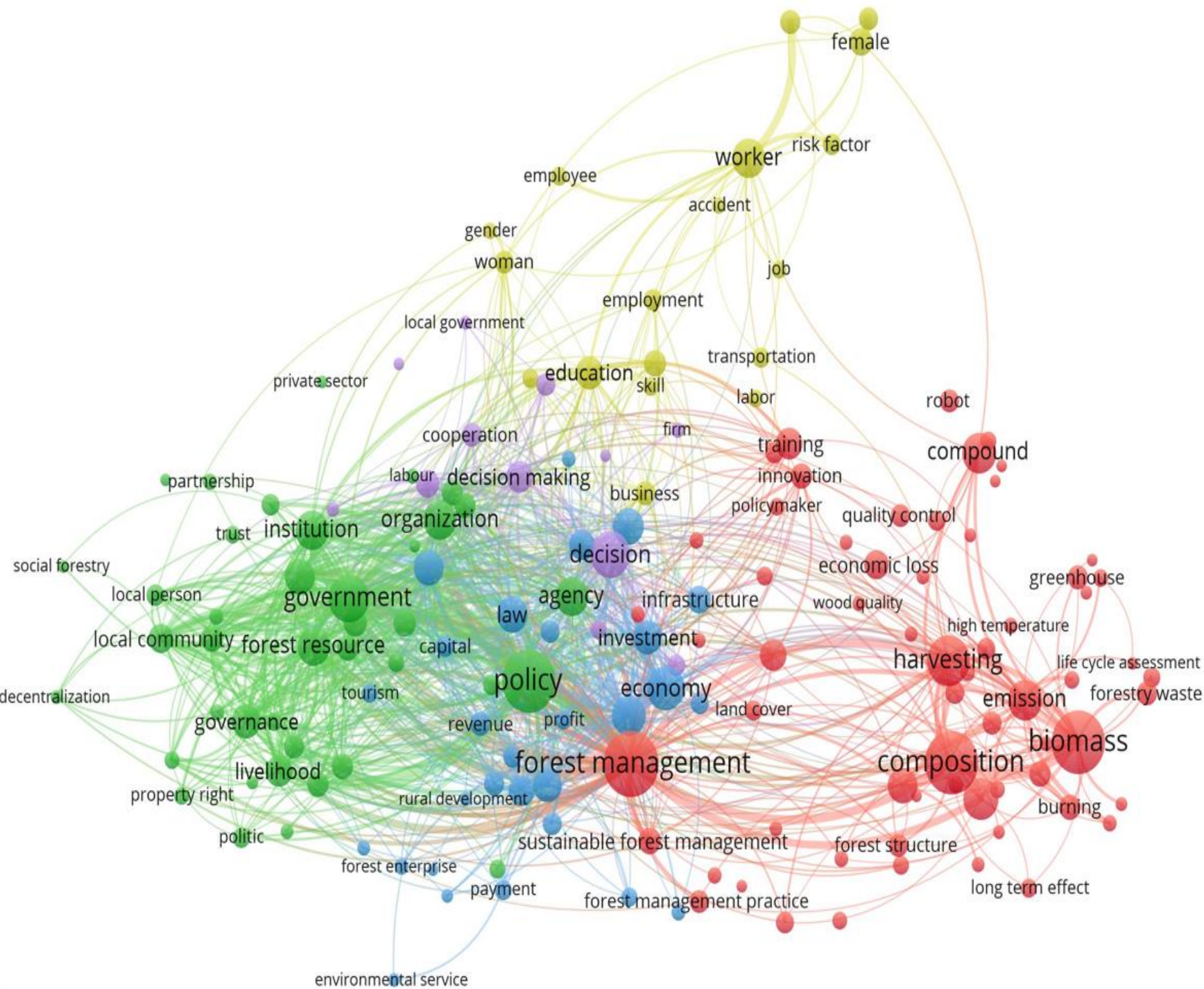
The green cluster covers forestry governance, including government roles, institutions, property rights, and social forestry, reflecting macro-level control over resources and state-community relations. Control functions through state and transnational mechanisms. A key issue is the gap between decentralization and actual power, causing 'bureaucratic recentralization,' where state bodies reassert control, reducing local autonomy and economic benefits. 'Elite capture' hampers social equity, with local elites dominating decision-making. Transnational oversight like FSC and FLEGT is increasingly important in addressing governance issues.

Cluster 2 (blue): “Political-Economic Control”, with primary publication activity during 2002-2015 and 2018-2026

The blue cluster forms the network's core, linking key concepts such as policy, decision, agency, law, economy, investment, infrastructure, and forest management. Control has shifted from normative to managerial and economic, focusing on economic efficiency and accountability rather than sanctions. Tax administration in forestry is crucial for revenue and fighting illegal activities. Integrated indicator systems connect revenues, expenditures, and ecosystem services but face transparency issues, reducing their effectiveness. Many European countries adopt Integrated Forest Management to unify financial, environmental, and social indicators, supporting sustainable management by balancing these goals.

Cluster 3 (red): “Ecological-Technological Control”, with primary publication activity during 2000-2010 and 2016-2026

The red cluster focuses on production and ecological processes, including biomass, harvesting, emissions, forest structure, life cycle assessment, quality control, and forestry waste. Control targets emissions, product quality, and environmental impacts, integrating sustainability and bioeconomy into forestry. Technologies like satellite platforms, LiDAR, and UAVs enable high-res inventory and illegal logging detection in poor weather, transforming control from reactive to real-time. Climate change drives the development of models for risks like fires, droughts, and floods, considering ecosystem and hydrological links, and embedding ecological control within climate security governance.



Cluster 4 (yellow): “Socio-Labour Control”, with primary publication activity during 2005-2016 and 2020-2025

The yellow cluster covers labor and social issues such as workers, employment, risks, accidents, training, education, gender, and skills. Control oversees occupational risks and HR, linking safety, qualifications, and employment. It emphasizes hazard prevention and skill development for high-tech forestry. Risks include noise, vibration, biological agents, and ergonomic strain leading to musculoskeletal problems. New tech like RFID, intelligent systems, and wearables improve safety and coordination. Training uses simulation, gamification, and safety apps to enhance awareness and management skills.

Cluster 5 (purple): “International Organizational Control”, with primary publication activity during 2010-2018 and 2019-February 2026

The purple cluster, situated between institutional and organisational cores, includes concepts like organisation, decision-making, business, firm, cooperation, and labour. It represents an intermediate level between macro control and micro management, emphasizing organisational dynamics and sectoral coordination. Control occurs via internal mechanisms, inter-organisational interactions, and network governance. Firms exert control through coordination, accountability, and CSR. Research indicates that stronger internal controls boost CSR, compliance, and resource management. Digital tools like cloud platforms and real-time monitoring enable detailed tracking of costs and productivity.

Key Findings: Evolution of Forestry Control

Central research core

Forest management, policy, government, economy and decision-making connect the major research streams, while specialised topics—including certification, legality, accountability, fire monitoring, robotics and AI—develop around this core.

From control mechanisms → control as a system

Research increasingly conceptualises control as a multi-layered system, integrating regulatory, financial-managerial, ecological and technological dimensions.

From periodic → continuous control

IoT, sensor networks and intelligent algorithms are shifting control from periodic administrative verification toward continuous, real-time, data-driven monitoring.

From reactive → adaptive & predictive control

Digital technologies do not simply replace traditional command-and-control mechanisms; they extend them toward adaptive and increasingly predictive approaches.

Technology vs. institutions

Technological capabilities are developing rapidly, while institutional weaknesses, corruption and politically supported violations may constrain their practical effectiveness.

Climate change as a new control driver

Wildfires, droughts and other systemic environmental risks are shifting attention toward ecological monitoring, risk prediction and adaptive management.



The results further suggest that the growing intersection between digitalization, innovation, knowledge and value-chain integration offers an important research context for applying artificial intelligence and machine learning. Instead of viewing AI and ML as standalone technological advances, they should be seen as components of a larger shift toward data-driven and intelligent management systems. Their effectiveness relies on enterprises' ability to convert data and technology into practical knowledge and efficient managerial decisions.

Future Research Trends in Forestry Control

Digital and Intelligent Control

Continuous, data-driven monitoring through sensors, satellites, AI and intelligent algorithms, shifting control from reactive to real-time and predictive.

Technology-Institution Gap

Technological capabilities are advancing faster than institutional adaptation, raising challenges related to transparency, governance capacity, corruption risks and inclusiveness.

Hybrid Governance

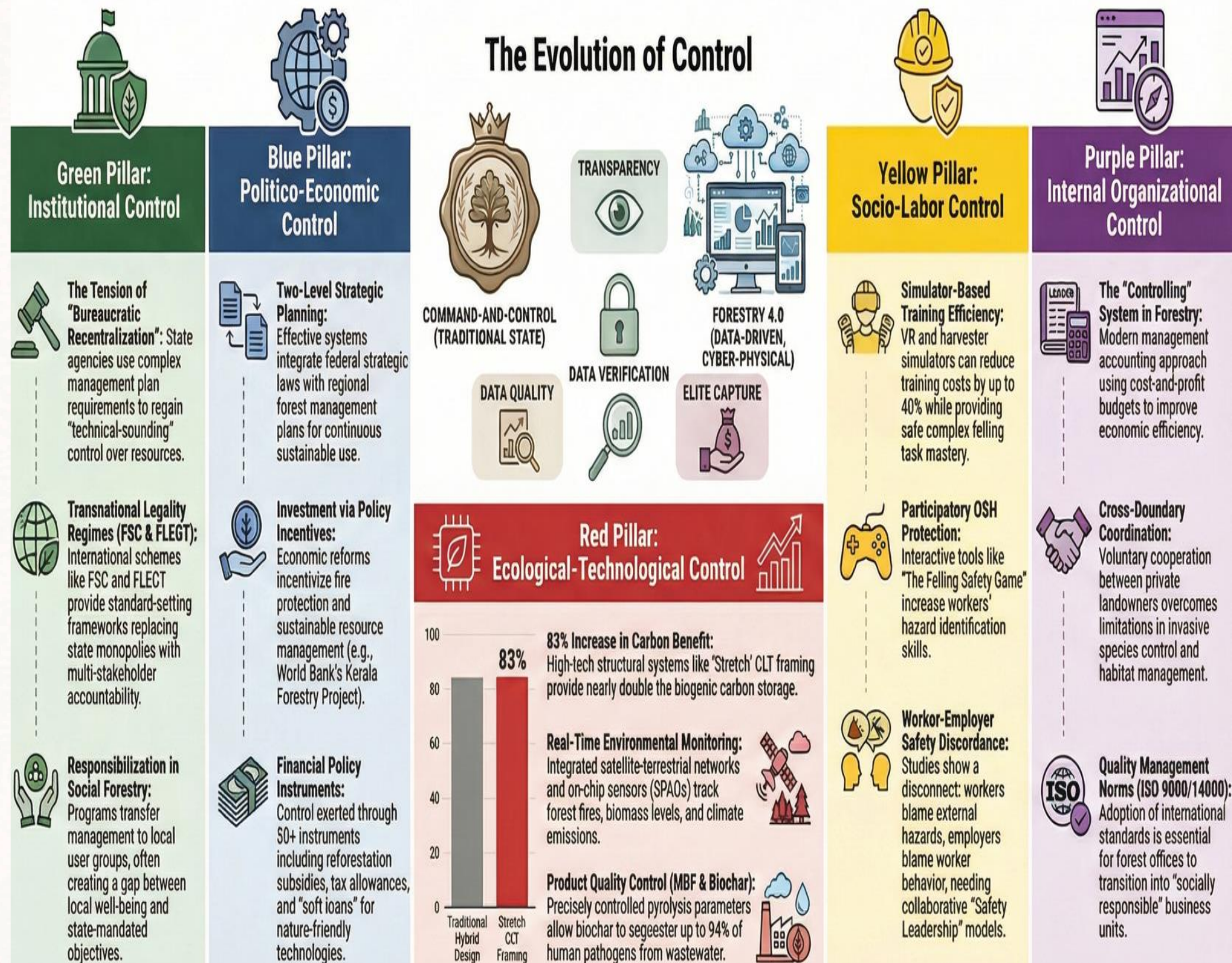
Control increasingly combines public regulation, market mechanisms and transnational initiatives, requiring stronger coordination, trust and information sharing among stakeholders.

Climate-Adaptive Control

Climate change is reshaping control priorities toward wildfire, drought and flood risks, creating demand for predictive models, ecological monitoring and adaptive management.

Human and Organisational Dimension

Digital transformation requires new skills, innovative training and integrated management systems that balance economic, social and environmental objectives.





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