EU Policy and Clean Technologies for Energy-Intensive Industries: Competitiveness, Decarbonisation and Climate Neutrality

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Abstract

Purpose

This policy review analyses how the European Union is combining industrial competitiveness, climate neutrality and strategic autonomy in its current policy framework for energy-intensive industries. It focuses on the main policy instruments and technology pathways affecting basic metals, non-metallic minerals, chemicals, and pulp and paper, which form a strategic industrial base for the European economy.

Design/methodology/approach

The review follows an analytical policy-review approach based on European Union regulations, directives, communications, official analytical studies and policy reports. The analysis prioritises interpretability and policy relevance rather than econometric estimation. It synthesises the role of the Competitiveness Compass, the Clean Industrial Deal, the Action Plan for Affordable Energy, the revised EU Emissions Trading System, the Carbon Border Adjustment Mechanism and selected enabling regulations.

Findings

The review indicates that the EU policy architecture for energy-intensive industries is moving from isolated climate regulation towards a broader industrial transformation agenda. The core challenge is not only emission reduction, but the simultaneous delivery of affordable clean energy, infrastructure deployment, first-of-a-kind investment de-risking, lead markets for low-carbon materials, circularity, critical input security and digital integration.

Practical implications

For firms, decarbonisation should be treated as a strategic investment and business-model challenge rather than as a compliance exercise. For policymakers, competitiveness and climate neutrality require sequencing, delivery capacity, infrastructure readiness and market-formation instruments that reduce uncertainty for energy-intensive sectors.

Keywords: Energy-intensive industries; EU industrial policy; Clean Industrial Deal; Competitiveness Compass; Action Plan for Affordable Energy; EU ETS; CBAM; clean technologies; circularity; industrial decarbonisation; strategic autonomy.

Paper type: Policy review / institutional research paper.

1. Introduction and policy-review objective

Energy-intensive industries occupy a critical position in the European Union economy. They supply essential inputs to construction, mobility, machinery, clean technologies, chemicals, energy infrastructure and other downstream value chains. Their strategic relevance is therefore not limited to direct output or employment. It also concerns Europe's capacity to retain industrial capabilities, reduce strategic dependencies and deliver the green transition without losing productive capacity.

This policy review focuses on four energy-intensive industrial groups at the centre of the European policy debate: basic metals; non-metallic minerals, including ceramics, glass and cement; chemicals; and pulp and paper. These sectors are economically relevant and difficult to decarbonise because they depend on high-temperature heat, process emissions, fossil-based feedstocks, capital-intensive assets and long investment cycles. They are also exposed to high and volatile energy prices, global excess capacity, trade distortions and uneven carbon-cost conditions.

The objective of the review is to clarify how the European Union's current policy mix seeks to reconcile industrial competitiveness with climate neutrality. The review examines the policy instruments, technology pathways and implementation conditions through which the EU is attempting to transform energy-intensive industries while maintaining their role as strategic suppliers within European value chains.

2. Methodological approach and source base

The document follows an analytical policy-review methodology. It does not aim to provide a quantitative impact assessment or a full systematic review of academic literature. Instead, it synthesises official EU policy instruments and institutional evidence to identify the main mechanisms through which the European Union is seeking to support competitiveness and decarbonisation in energy-intensive industries.

The source base includes binding and programmatic EU instruments, including regulations, directives and communications, together with official analytical studies from EU bodies and international organisations. Particular attention is given to the Competitiveness Compass, the Clean Industrial Deal, the Action Plan for Affordable Energy, the revised EU Emissions Trading System, the Carbon Border Adjustment Mechanism, the Critical Raw Materials Act, the Net-Zero Industry Act, electricity-market reform and the Ecodesign for Sustainable Products Regulation.

The review also considers technology-roadmap evidence on electrification, renewable hydrogen, carbon capture, utilisation and storage, circularity, energy efficiency and digitalisation. These pathways are interpreted not as isolated technologies, but as components of a wider industrial transformation architecture requiring infrastructure, finance, standards, permitting, demand creation and multi-level governance.

3. Strategic relevance and vulnerability of energy-intensive industries

3.1 Economic and industrial relevance

Energy-intensive industries are embedded in the upstream and midstream layers of the European industrial system. Their outputs are used by downstream sectors such as automotive, construction, machinery, clean energy technologies, packaging, chemicals, transport equipment and infrastructure. A weakening of these sectors would therefore affect not only their own employment and investment, but also the resilience and competitiveness of multiple European value chains.

The policy relevance of these industries has increased because climate neutrality, digitalisation and security of supply are now closely connected. Low-carbon steel, aluminium, cement, chemicals, glass, ceramics and paper products are necessary for downstream decarbonisation. At the same time, these sectors depend on affordable energy, critical and strategic raw materials, industrial infrastructures and regulatory certainty.

3.2 Competitiveness and decarbonisation constraints

The main competitiveness constraints include structurally high energy costs, exposure to fossil-fuel price volatility, higher capital costs than in some competing regions, complex permitting, fragmented regulation, uneven international competition and insufficient demand signals for low-carbon industrial products. The 2022 energy-price shock reinforced the vulnerability of these sectors and exposed the risk that decarbonisation investment could be delayed by short-term cost pressure.

The decarbonisation challenge is particularly demanding because many energy-intensive industries require high-temperature heat, continuous operations and material transformation processes where emissions are embedded in the production chemistry. The transition therefore cannot rely on incremental efficiency alone. It requires new energy vectors, new production routes, infrastructure networks, carbon-management solutions and market conditions capable of absorbing higher initial costs.

3.3 Sectoral heterogeneity and transformation profiles

The energy-intensive industry category should not be treated as a homogeneous block. Basic metals, non-metallic minerals, chemicals, and pulp and paper share exposure to energy costs and capital intensity, but they differ in emissions profiles, technology options, product markets, trade exposure and the speed at which low-carbon routes can be deployed. This heterogeneity matters because a single policy instrument cannot solve all transformation barriers simultaneously.

Basic metals are highly exposed to electricity prices, scrap availability, alloying inputs, hydrogen infrastructure and international competition. Non-metallic minerals combine thermal energy requirements with process emissions, making fuel switching, material efficiency, clinker substitution, kiln optimisation and carbon management relevant in different combinations. The chemical industry faces a particularly complex transition because energy, carbon and feedstock functions are closely interconnected. Pulp and paper has a different profile, with strong links to biomass, heat recovery, recycling, water management and circular packaging markets.

This sectoral heterogeneity reinforces the need for differentiated transition pathways. EU-level policy can define common objectives and instruments, but deployment will depend on sector-specific roadmaps, site-level feasibility, regional infrastructure, customer demand and the availability of finance for industrial assets with long payback periods. A credible policy review must therefore assess not only the existence of EU instruments, but also their capacity to reach the sectors and value-chain stages where transformation constraints are binding.

4. EU policy architecture for competitiveness and climate neutrality

The EU policy response has evolved towards a more integrated industrial strategy. The central direction is to connect climate ambition with industrial renewal, rather than treating decarbonisation and competitiveness as separate policy domains. Table 1 summarises the main instruments and their policy functions.

Table 1. EU policy instruments and functions for energy-intensive industries.

Policy instrument	Main policy function	Relevance for energy-intensive industries
Competitiveness Compass	Sets an overarching agenda linking innovation, decarbonisation, security, simplification and productivity.	Frames decarbonisation as a competitiveness strategy and identifies structural barriers to industrial investment.
Clean Industrial Deal	Provides a roadmap for competitiveness and decarbonisation, including lead markets, finance, energy and industrial capacity.	Positions energy-intensive industries as central to Europe's industrial renewal and climate-neutrality pathway.
Action Plan for Affordable Energy	Targets energy-cost reduction, grid acceleration, long-term contracting and market-design improvements.	Addresses one of the main cost disadvantages affecting electrification and low-carbon industrial production.
EU ETS and CBAM	Combines carbon pricing with border adjustment to reduce carbon leakage and strengthen investment signals.	Increases decarbonisation pressure while seeking to maintain a level playing field for covered imports.
Critical Raw Materials Act and Net-Zero Industry Act	Supports secure access to strategic inputs and clean-technology manufacturing capacity.	Links industrial decarbonisation with supply-chain resilience, domestic capabilities and investment mobilisation.
Ecodesign and circular economy instruments	Promote lifecycle requirements, recycled content, durability, reparability and circular product governance.	Support demand for low-carbon and circular materials where standards and procurement are aligned.

4.1 The Competitiveness Compass and industrial renewal

The Competitiveness Compass gives political coherence to the EU response by placing innovation, decarbonisation and security within the same strategic framework. For energy-intensive industries, its importance lies in recognising that climate objectives cannot be achieved without maintaining industrial investment capacity, reducing regulatory fragmentation and accelerating the scale-up of clean technologies.

The Compass also changes the policy narrative. Instead of viewing energy-intensive industries as residual high-emission sectors, it treats them as strategic industrial ecosystems whose transformation is necessary for the competitiveness of downstream sectors and for the credibility of European climate policy.

4.2 The Clean Industrial Deal and lead markets

The Clean Industrial Deal is central because it links decarbonisation with demand creation, financing and industrial capacity. Its logic is that clean industrial investment will not scale if low-carbon products remain commercially disadvantaged compared with carbon-intensive alternatives produced under different regulatory conditions.

For energy-intensive industries, this implies the need for lead markets for low-carbon steel, cement, chemicals, aluminium, glass, ceramics and other basic materials. Public procurement, carbon contracts for difference, product standards, recycled-content requirements and labelling can help create predictable demand and reduce uncertainty around green premiums.

4.3 Affordable energy and infrastructure readiness

Affordable clean energy is a binding condition for industrial decarbonisation. Electrification, renewable hydrogen, heat pumps, electric furnaces and industrial digitalisation all depend on electricity availability, grid capacity, interconnection and stable price conditions. The Action Plan for Affordable Energy therefore addresses a structural constraint rather than a peripheral cost factor.

Long-term power purchase agreements, contracts for difference, accelerated permitting, grid reinforcement and cross-border infrastructure are relevant because energy-intensive investments depend on predictable operating costs. Without this infrastructure and market design, firms may postpone clean-technology deployment even where technologies are technically available.

4.4 Carbon pricing, carbon leakage and trade exposure

The revised EU Emissions Trading System increases the carbon-cost exposure of energy-intensive industries, while the Carbon Border Adjustment Mechanism seeks to reduce carbon leakage by applying a comparable carbon-cost logic to selected imports. This combination is intended to preserve the environmental integrity of EU climate policy while protecting the competitiveness of European producers.

The sequencing of ETS reform, CBAM implementation and industrial support is strategically important. If carbon costs rise faster than clean-technology, infrastructure and market-formation conditions, investment incentives may weaken. Conversely, if carbon pricing is matched by finance, infrastructure and demand creation, it can accelerate industrial transformation.

4.5 Finance, permitting and risk-sharing instruments

The policy architecture for energy-intensive industries also depends on finance and delivery capacity. Many industrial decarbonisation projects are first-of-a-kind, capital intensive and exposed to uncertain future spreads between fossil-based and low-carbon production routes. Firms may face simultaneous uncertainty over electricity prices, hydrogen availability, carbon prices, product premiums, permitting timelines and future demand for low-carbon materials.

Public policy therefore has a market-shaping role. Grants, guarantees, contracts for difference, carbon contracts for difference, public procurement and blended finance can reduce risk where private investment is constrained by technology uncertainty or weak early demand. The policy issue is not only the total volume of public support, but whether support is sufficiently predictable, accessible and aligned with the timing of infrastructure deployment. Permitting is equally important. Industrial electrification, hydrogen production, renewable generation, CO_2 transport, storage networks, grid reinforcement and new recycling capacity require administrative procedures that can be completed within investment-relevant timescales. If permitting delays persist, the policy mix may send strong decarbonisation signals without enabling firms to implement the projects required to respond to those signals.

5. Technology pathways and deployment conditions

The policy architecture is meaningful only if it enables technology deployment at industrial scale. The most relevant pathways include electrification, renewable hydrogen, carbon capture, utilisation and storage, circularity, energy efficiency and digitalisation. Table 2 summarises their industrial function and implementation conditions.

Table 2. Technology pathways and implementation conditions.

Technology pathway	Industrial function	Key deployment condition
Electrification	Substitutes fossil-based heat and power where technically feasible.	Requires affordable clean electricity, reinforced grids, flexibility and long-term contracts.
Renewable hydrogen and low-carbon fuels	Supports high-temperature heat, feedstock substitution and selected chemical and metallurgical routes.	Requires hydrogen production, transport infrastructure, certification and bankable demand.
Carbon capture, utilisation and storage	Addresses residual and process emissions that are difficult to eliminate through electrification alone.	Requires CO_2 transport and storage networks, permitting, liability frameworks and long-term revenue models.
Circularity and resource efficiency	Reduces primary input demand, supports secondary material use and strengthens input security.	Requires standards, quality assurance, recycling capacity, industrial symbiosis and demand for secondary materials.
Digitalisation and artificial intelligence	Optimises energy use, predictive maintenance, emissions accounting and process control.	Requires data governance, skills, interoperable systems and cybersecure industrial deployment.

5.1 Electrification and clean energy procurement

Electrification is one of the most important decarbonisation routes for energy-intensive industries where electric technologies can replace fossil-fuel-based heat or power. Its industrial feasibility depends on electricity cost, grid access, flexibility, reliability and the ability to secure long-term renewable electricity contracts. The policy challenge is that electrification changes the cost structure of industrial production. Firms need confidence that electricity prices and grid constraints will not undermine the competitiveness of low-carbon production routes. This makes energy-market reform and infrastructure acceleration inseparable from industrial climate policy.

5.2 Renewable hydrogen and industrial fuel switching

Renewable hydrogen is relevant for applications where direct electrification is limited or where hydrogen can replace fossil-based feedstocks. It is particularly important for selected steel, chemical and refinery applications, but its deployment depends on cost reduction, infrastructure, certification and reliable offtake. Hydrogen policy illustrates the wider problem of first-of-a-kind industrial investment. Industrial users may not commit to hydrogen-based processes without sufficient supply and infrastructure, while infrastructure developers may not invest without credible demand. Policy instruments must therefore reduce coordination failures across the value chain.

5.3 Carbon capture, utilisation and storage

Carbon capture, utilisation and storage is relevant for process emissions and hard-to-abate applications where electrification or substitution cannot fully eliminate emissions. Cement, lime, chemicals and selected metallurgical processes are especially affected by this challenge. For CCUS to become an effective decarbonisation pathway, firms require access to CO2 transport and storage infrastructure, clear permitting, liability arrangements, monitoring frameworks and long-term revenue stability. The key issue is not only technology readiness, but system readiness.

5.4 Circularity, input security and secondary materials

Circularity is increasingly linked to industrial resilience rather than only environmental performance. Energy-intensive industries depend on primary and secondary raw materials, and the quality, availability and affordability of these inputs affect both competitiveness and decarbonisation pathways. Circular economy instruments, critical raw materials policy and ecodesign requirements can support secondary material markets, but they are effective only when recovered materials can meet industrial quality requirements. Secondary materials must be collected, processed, standardised, certified and absorbed by downstream users. This requires market-formation capacity, not only recycling targets.

5.5 Digitalisation and artificial intelligence

Digitalisation and artificial intelligence can support energy efficiency, predictive maintenance, process optimisation, emissions monitoring and traceability across industrial value chains. Their contribution is especially relevant where marginal efficiency gains, downtime reduction and real-time data can improve both cost performance and emissions performance. However, digitalisation is not a substitute for energy, infrastructure or capital investment. Its value depends on industrial data quality, cybersecurity, skills, interoperable systems and integration with operational decision-making. The policy challenge is to ensure that digital tools support measurable industrial transformation rather than remaining isolated pilots.

5.6 Sectoral deployment implications

Technology pathways must be interpreted through sectoral deployment conditions. The same pathway can have different relevance across sectors depending on process temperature, feedstock needs, product specifications, asset age, location, access to grids, access to CO2 or hydrogen networks and exposure to customers willing to pay for low-carbon materials. Table 3 summarises these differences at a policy-review level.

Table 3. Sectoral deployment implications for energy-intensive industries.

Industrial group	Main transformation priorities	Policy and deployment conditions
Basic metals	Electrification, scrap use, renewable hydrogen, process efficiency, circular inputs and carbon-management options for residual emissions.	Affordable electricity, hydrogen and grid infrastructure, scrap quality, access to strategic inputs, demand for low-carbon metals and protection against carbon leakage.
Non-metallic minerals	Fuel switching, kiln optimisation, material efficiency, recycled mineral inputs, clinker substitution where relevant and CCUS for process emissions.	CO2 transport and storage networks, permitting, product standards, procurement for low-carbon construction materials and site-specific investment support.
Chemicals	Feedstock substitution, electrification of selected processes, renewable hydrogen, circular carbon, energy efficiency and recycling of chemical inputs.	Reliable low-carbon feedstocks, infrastructure integration, regulatory coherence, customer acceptance and investment frameworks for complex value-chain transformation.
Pulp and paper	Energy efficiency, biomass and residual heat use, electrification, fibre recycling, water efficiency and circular packaging solutions.	Stable biomass and electricity conditions, circular product demand, recycling systems, water governance and investment in efficient heat and process technologies.

The sectoral reading also shows why industrial clusters and regional ecosystems matter. Energy-intensive industries often operate in geographic concentrations where infrastructure, skills, suppliers, ports, research organisations and public authorities are interdependent. Regional clusters can help aggregate demand, identify common infrastructure needs, coordinate pilots, connect technology providers with industrial users and accelerate knowledge transfer across firms.

6. Discussion: policy coherence and implementation risks

The review indicates that the EU has built a sophisticated and increasingly integrated policy framework for energy-intensive industries. The key policy direction is clear: climate neutrality must be pursued through industrial renewal, clean-technology scale-up, input security, affordable clean energy and market creation for low-carbon products. The main risk is not the absence of policy ambition, but the gap between policy design and industrial delivery. Energy-intensive industries require infrastructure before they can transform assets, demand before they can absorb green premiums, finance before they can scale first-of-a-kind projects, and regulatory simplification before they can move at the pace required by climate targets.

Policy coherence therefore depends on sequencing. Carbon pricing and border adjustment can support decarbonisation only if they are aligned with clean-energy access, hydrogen and CO2 networks, permitting, lead markets, risk-sharing instruments and product standards. If these elements develop unevenly, the policy mix may generate pressure without sufficient delivery capacity. Regional and sectoral ecosystems are also important. Industrial transformation is not implemented only at EU level. It takes place in clusters, regions, supply chains, ports, energy hubs and industrial sites where firms, public authorities, technology providers, universities and financial institutions interact. Cluster-based and mission-oriented governance can help connect demand, technology, infrastructure and investment.

6.1 Sequencing risks in the EU policy mix

The most important implementation risk is sequencing failure. Carbon pricing, reporting obligations and regulatory expectations may advance faster than clean-energy availability, grid access, hydrogen infrastructure, CO2 networks, permitting simplification and demand-side instruments. In that case, firms may experience the transition as a cost shock rather than as an investable industrial opportunity.

A second risk concerns fragmented delivery across governance levels. EU policy defines objectives, but Member States, regions, regulators, network operators, industrial firms and financial institutions determine whether projects can be executed. The transformation of energy-intensive industries is therefore a multi-level governance challenge in which legal instruments, industrial strategy and place-based implementation must be aligned. A third risk is the underdevelopment of lead markets. Even where low-carbon industrial products are technically available, firms may struggle to recover higher production costs unless customers, public buyers or regulation recognise the value of lower embedded emissions. Market formation is therefore a decisive complement to technology policy. Without it, industrial decarbonisation may remain concentrated in pilots and demonstration projects rather than scaling into routine production.

7. Analytical limitations and boundary conditions

This policy review has defined boundaries. It is an interpretative policy-review document rather than a quantitative impact assessment, econometric study or sectoral cost model. It synthesises policy instruments, technology pathways and implementation conditions, but it does not estimate investment needs, abatement costs, employment effects or firm-level competitiveness impacts.

The analysis is also deliberately European in scope. It focuses on the EU policy architecture and its implications for energy-intensive industries operating within European value chains. International factors, including China's industrial capacity, United States industrial policy, global trade measures, energy-price differentials and competition for critical inputs, are recognised as contextual pressures, but they are not modelled as independent empirical variables. Finally, the review treats technology pathways as deployment options rather than deterministic solutions. Electrification, hydrogen, CCUS, circularity and digitalisation are all relevant, but their contribution depends on sectoral fit, infrastructure readiness, investment conditions, standards, permitting, skills and demand creation. The conclusions should therefore be read as a policy-oriented synthesis designed to support further empirical research, not as a definitive assessment of the performance of any individual instrument or technology.

8. Conclusions and future research directions

This policy review concludes that the European Union is reframing the transformation of energy-intensive industries as an integrated competitiveness and decarbonisation challenge. The relevant question is no longer whether these sectors must decarbonise, but how they can do so while retaining industrial capacity, employment, supply-chain resilience and global competitiveness. The extended analysis also shows that energy-intensive industries require differentiated policy treatment. Metals, minerals, chemicals, and pulp and paper are connected by common exposure to energy and capital intensity, but their transformation pathways differ in terms of process emissions, feedstock dependence, circularity potential, infrastructure requirements and market conditions. A credible EU transition strategy must therefore combine horizontal instruments with sector-specific delivery mechanisms.

The emerging EU policy architecture combines the Competitiveness Compass, the Clean Industrial Deal, the Action Plan for Affordable Energy, carbon-pricing reform, CBAM, clean-technology manufacturing policy, critical raw materials policy, circular economy instruments and digital regulation. Its effectiveness will depend on whether these instruments translate into bankable projects, infrastructure deployment, predictable energy costs, lead markets and industrial uptake. Future research should examine the implementation gap between policy design and industrial deployment. Priority areas include the effectiveness of lead markets for low-carbon materials, the role of public-private partnerships in scaling industrial demonstrators, the interaction between CBAM and investment decisions, the market formation of secondary raw materials, and the role of regional clusters in orchestrating industrial transition. A further research direction concerns international comparison. EU energy-intensive industries operate in a global environment shaped by China's industrial capacity, United States industrial policy, trade measures, energy-price asymmetries and competition for critical inputs. Comparative research can clarify whether the European model of governed industrial decarbonisation can sustain competitiveness in an increasingly fragmented global economy.

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