Eco-Design in China

—— Value Logic and a Future-Ready Capability System

Jointly produced by Schneider Electric R&D China Council and the School of Environment, Tsinghua University.

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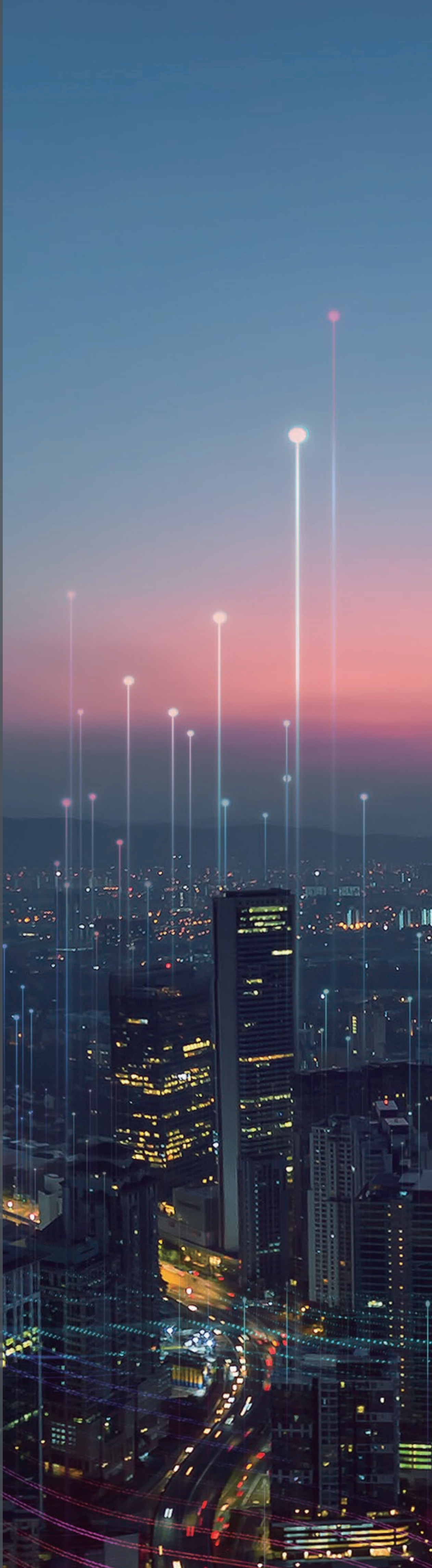

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Preface

Against the backdrop of accelerating global green transformation, Eco-design has moved from supporting environmental measures to a strategic foundation of industrial development. In China, this shift has been reinforced by the 15th Five-Year Plan, which positions green development as a defining feature of national modernization. As regulatory systems mature and sustainability expectations rise, it is increasingly clear that a product's environmental performance is largely determined at the design stage. Eco-design therefore plays a decisive role in advancing carbon reduction, pollution control, green growth, and economic resilience.

For Chinese enterprises, Eco-design is no longer merely a compliance requirement. It is now closely tied to market access, competitiveness, brand value, pricing power, and long-term business stability. Yet in practice, companies still struggle to implement it effectively—sustainability goals are not translated into concrete design requirements or decision criteria, Eco-design is introduced too late in development processes, and key decisions lack sufficient data and tool support.

This white paper, jointly published by Schneider Electric and Tsinghua University, provides practical guidance to bridge this gap. It clarifies the value logic of Eco-design, examines key implementation challenges, and presents a clear framework to support real-world application. Drawing on policy, industry, and technological trends, the report aims to help enterprises build lasting capabilities and achieve sustainable growth during the green transformation.

1 Defining Eco-Design

Why Eco-design Now?

Many companies still treat environmental protection as a production-side issue, such as emissions control, pollution treatment, material substitution, and waste management. In practice, however, environmental impact, cost structure, and long-term risk are determined before production begins, at the design stage. This chapter explains why Eco-design has become the decisive starting point for future competitiveness.

1.1 Background

From End-of-Pipe Treatment to Source-Based Design

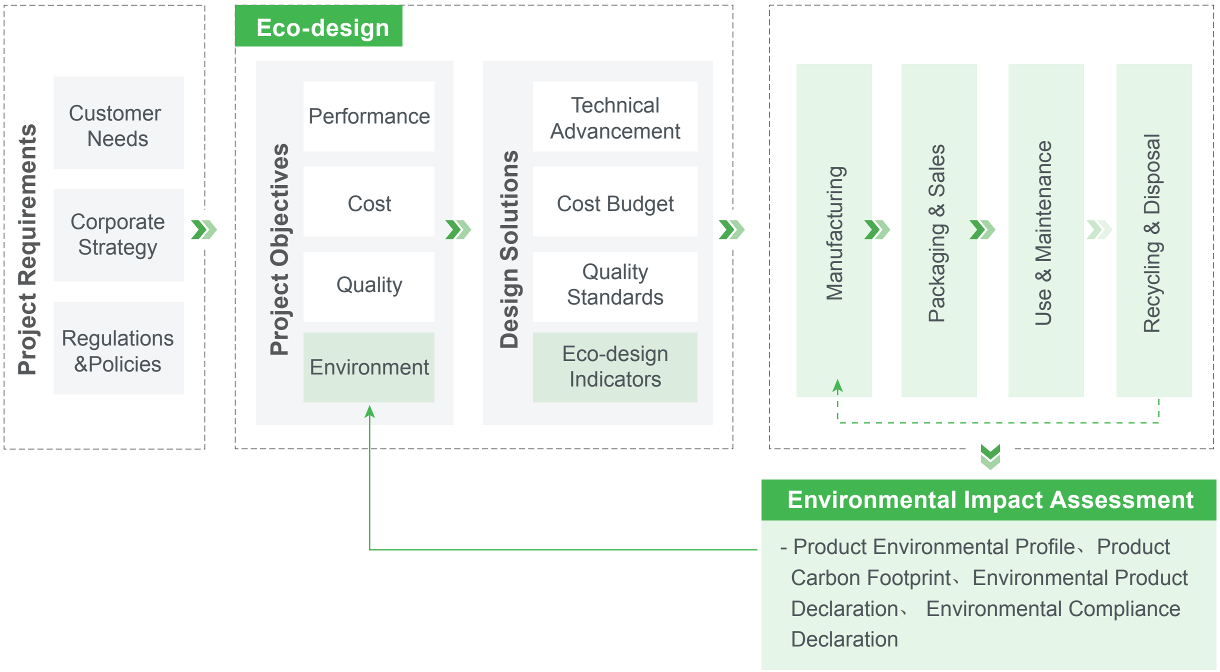
Economic expansion has intensified resource use and environmental pressure, turning ecological issues into systemic risks. Climate change, extreme weather, air pollution, water scarcity, and biodiversity loss are interlinked and increasingly affect economic operations, public health, and industrial safety. At the same time, rising material complexity, increased chemical use, redundant product structures, and growing waste streams have multiplied environmental pressure sources and raised governance costs. Environmental challenges are no longer isolated problems but structural constraints on development.

Under these conditions, governance models centered on end-of-pipe treatment are reaching their limits. Modern products rely on complex material systems and couple processes such as bonding, blending, and coating, which physically lock materials together. As a result, recycling, and disposal at end of life require high energy input and complex treatment. In parallel, environmental regulation is shifting from emission control to product-based and material-based compliance. If restricted substances such as PFAS or RoHS-listed chemicals are embedded at the design stage, downstream treatment cannot fully eliminate them, making regulatory compliance and market access impossible. Material choice, process coupling, and regulatory path dependency create irreversible outcomes that end-of-pipe solutions cannot correct.

At the same time, environmental externalities are being transferred from society to companies. Stricter regulation, multinational supply chain requirements, and resource volatility are integrating environmental impact, material compliance, and recycling costs into corporate cost structures. Extended producer responsibility requires firms to manage product take-back and reuse. Carbon border adjustment mechanisms internalize carbon costs in trade. The EU Battery Regulation mandates disassemblability at the design stage. Digital product passports impose lifecycle transparency requirements on design and procurement. Together, these mechanisms make lifecycle responsibility systematic, proactive, and unavoidable.

This shift moves environmental governance upstream. Empirical research shows that approximately 80% of a product's environmental impact and lifecycle cost are determined during the design phase, while manufacturing, use, and end-of-life stages execute decisions already embedded structurally. As environmental impacts, regulatory compliance, and lifecycle costs become binding constraints, downstream mitigation at the end-of-life stage can no longer ensure technical or economic viability.

Consequently, environmental objectives must be integrated into product design from the outset, alongside performance, cost, and quality considerations. This design logic defines Eco-design—a design approach in which environmental objectives are embedded as structural decision parameters during product development, rather than appended after technical solutions are finalized.



（ Figure 1 ）An Embedded Eco-Design Framework in Product Development

1.2 Principle

Embedding Environmental Goals into Development

Eco-design does not add environmental steps to existing processes. Its function is to lock environmental performance at the design stage through explicit goal setting and engineering constraints. It is a proactive, embedded, and engineering-driven approach that integrates environmental objectives with performance, cost, and quality to shape lifecycle outcomes from the start.

In conventional product development, the process progresses from demand definition and goal setting to solution design and manufacturing, with environmental considerations typically addressed late, at the use or end-of-life stage. Eco-design works by moving environmental goals upstream and embedding them at critical decision points, where they guide material selection, structural design, process routes, and lifecycle strategies.

At the demand stage, Eco-design requires early identification of lifecycle environmental constraints alongside customer needs and business strategy. These constraints include material restrictions, recyclability requirements, energy efficiency standards, and supply chain sustainability criteria. This defines the environmental boundary conditions of the product.

At the goal stage, environmental objectives are integrated with traditional targets such as performance, cost, and quality into a multi-objective system. Environmental goals are outcome-oriented, specifying measurable results such as lifecycle carbon footprint, water use, or resource intensity. They function as design constraints, not as post-design checks.

At the solution stage, environmental goals are translated into concrete Eco-design indicators. These indicators define engineering requirements that guide design decisions, such as material simplification, modularity and disassembly, reduced process energy, durability and repairability, and minimized packaging. They allow teams to evaluate trade-offs systematically and select solutions that balance technical, economic, and environmental performance.

Eco-design should not be confused with related concepts. Green manufacturing focuses on production processes and cannot alter structural impacts fixed by design. The circular economy depends on disassembly, material purity, and remanufacturing, all of which must be enabled during design. ESG emphasizes governance and disclosure, while Eco-design determines the physical basis of environmental performance within ESG frameworks.

Eco-design is not a post-process improvement, but a structured design approach. Environmental objectives are first defined as explicit goals, then translated into measurable Eco-design indicators, and finally implemented through concrete design solutions. Through this sequence, lifecycle environmental performance is determined at the design stage.

1.3 Framework

From Environmental Goals to Design Execution

As sustainability requirements intensify, Eco-design has evolved from a localized improvement tool into a comprehensive design paradigm. Its purpose is to decouple value creation from environmental impact through deliberate design decisions, rather than downstream mitigation.

First, Eco-design is guided by a green value orientation. Environmental performance is not an optional enhancement but a core design objective, equal to functionality and economic performance. Designers must treat environmental outcomes as inherent variables in solution generation and decision-making from the beginning of the lifecycle.

Second, Eco-design relies on a systematic and integrated approach. Traditional design often assumes trade-offs between environmental, cost, and performance goals. Eco-design instead seeks overall optimization by coordinating decisions across materials, structures, processes, and usage patterns. This integration enables structural improvements in environmental performance rather than isolated fixes.

Third, Eco-design depends on clear, measurable, and verifiable indicators to ensure implementation. Derived from environmental goals, these indicators act as engineering constraints, covering material safety, energy efficiency, recyclability, structural simplification, disassembly, durability, and packaging reduction. Quantitative tools and indicator-based management translate abstract goals into executable engineering tasks, making Eco-design operational rather than conceptual.

In summary, Eco-design is not an extension of traditional design but a lifecycle-oriented methodology. Guided by explicit environmental values, structured through systems thinking, and executed via measurable indicators, Eco-design enables the coordinated optimization of environmental performance, product function, and economic value. It provides a practical pathway for companies to reshape their value creation model under sustainability constraints.

2 The Value Logic of Eco-Design in China

Why It Matters?

Chinese companies operate under tightening regulation, rapid industrial change, and fragmented markets. Environmental responsibility is no longer external pressure; it is becoming an internal capability. Eco-design has moved beyond traditional environmental management and now directly affects product performance in the market. Eco-design influences whether a product can enter the market, expand its sales, command a premium price, and remain competitive over time. In practical terms, it increasingly determines whether a product can be sold, sold at scale, sold at a higher price, and continue to sell under changing policy and technology conditions. This chapter explains the value logic of Eco-design from perspectives of policy, industry, market, and risk.

2.1 Policy and Institutional Drivers

Market Entry

As China's regulatory system continues to tighten and align with global standards, **Eco-design has become a core condition for market access.** In recent years, laws such as the "Circular Economy Promotion Law" and the "Solid Waste Pollution Prevention and Control Law," along with various mandatory regulations and standards, have shifted environmental friendliness from a guiding principle to a strict legal requirement. Policies now demand more from product design, including recyclability, disassemblability, material environmental properties, and energy efficiency standards. If these requirements are not addressed at the design stage, products may be denied market entry or face recalls, penalties, and cross-regional liability after launch. Regulatory enforcement has therefore shifted upstream, making design the primary checkpoint for compliance.

> Eco-Design–Based Market Access Constraints in Green Certification Systems
>
> Within green product certification systems, Eco-design-related criteria have become mandatory conditions for market access. Certification bodies assess compliance with eco-design requirements based on green product evaluation standards, which are typically structured around five categories: resource, energy, environmental, quality, and low-carbon attributes. Each category is supported by quantifiable, testable, and verifiable indicators.
>
> Most indicators are directly derived from eco-design requirements and impose explicit engineering-level constraints. These include material reduction and recyclability under resource attributes, pollutant emission control and hazardous substance restrictions under environmental attributes, and minimum energy efficiency levels under energy attributes. Compliance is required at both the design and implementation stages. Failure to meet any key indicator results in certification denial and exclusion from relevant markets and procurement systems.
>
> —— Zhenghui SHAO, Director of Product (VI) Certification Management Department, China Quality Certification Center

Multiple authorities are pushing environmental requirements to the source. The Ministry of Industry and Information Technology promotes green design, the Ministry of Ecology and Environment strengthens carbon and pollution controls, the Ministry of Commerce tightens controls on restricted substances and strategic materials in trade, and the State Administration for Market Regulation expands green certification and energy labeling. Together, these measures form a full-chain regulatory system covering design, production, distribution, and trade.

As a result, compliance is increasingly decided before production begins. Eco-design has become the earliest and most critical layer of regulatory compliance. Without source-based design capability, products face rising risks of being blocked from the market.

2.2 Industry Transformation Drivers

Market Expansion

Industry restructuring is redefining product competitiveness and raising the threshold for Eco-design. Both technological evolution and policy-driven transformation are making Eco-design a key factor in market expansion.

From a technology perspective, automation, energy transition, and digitalization are reshaping product requirements. Modular design, higher energy efficiency, repairability, and upgradability are becoming standard expectations. While not always labeled as environmental goals, these trends reduce resource use and extend product life, aligning closely with Eco-design principles. As a result, Eco-design is increasingly embedded in core technology choices.

From a policy perspective, green procurement and green supply chain policies are turning Eco-design into a selection criterion. Government procurement, state-owned enterprises, and leading firms now apply environmental standards when choosing suppliers. In sectors such as green construction, energy-efficient appliances, low-carbon ICT equipment, and data centers, products lacking Eco-design are likely to lose access to major projects, bulk orders, and distribution channels.

Eco-design is therefore no longer only a compliance issue. It has become a condition for participating in key markets and supply chains. **Companies with Eco-design capabilities are better positioned to secure and expand market share during industry restructuring.**

> **Eco-Design as a Requirement for Green Procurement**
>
> Eco-design requirements are increasingly incorporated into procurement access criteria as part of green procurement systems. With technological progress and the influence of international trade rules, the requirements for Eco-design have gradually increased. Some Eco-design requirements are expected to become fundamental criteria for higher entry thresholds in the “green procurement system,” such as product energy efficiency indicators, carbon footprint, restrictions on hazardous substances, and recycled content. These quantifiable indicators are easy to distinguish and likely to become thresholds for market access to products. These indicators are measurable, comparable, and verifiable, making them suitable for use as procurement thresholds. As a result, eco-design is shifting from a value-added consideration to an institutional requirement for market and procurement access.
>
> —— Dongfeng GAO, Research Fellow, China National Institute of Standardization

2.3 Market and Brand Drivers

Value Premiums

As consumption upgrades and brand competition intensify, Eco-design is shifting from a cost factor to a source of value. Its commercial impact is reflected in brand premiums and valuation premiums.

Consumer demand for sustainable products is rising, particularly in China and the Asia-Pacific region. **Over 90% of consumers are willing to pay more for products with credible sustainability attributes**[1]**.** Eco-design enables differentiation through material safety, durability, repairability, and transparency. Take Patagonia[2] as an example. Its Eco-design-driven material and structural strategies not only reinforce its brand narrative but also significantly increase customer loyalty and purchase conversion. These design choices strengthen brand credibility and support higher perceived value.

At the same time, capital markets are increasingly factoring Eco-design capability into company valuation. Mandatory environmental disclosure and the expansion of green finance link product design choices to financing conditions, investor confidence, and long-term valuation. **Studies show that companies optimizing material systems through Eco-design can improve profitability and operational efficiency by 6%**[3]**.**

Eco-design therefore supports value creation both in the market and in capital allocation. It allows products not only to sell, but to sell at a higher price.

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[1] National Business Daily. Survey report on green and low-carbon trends in China's consumer market (2024-2025).

[2] Poonkulali Thangavelu. The Success of Patagonia’s Marketing Strategy; 2025.

[3] Jensen, B.; Megan Stoneburner; Catharina Martinez-Pardo; Jocelyn Wilkinson; Haafizah Khodabocus; Lidia Durbiano; Mireille Faist; Stefan Frehland; Philipp Meister; Marcial Vargas-Gonzales. Sustainable Raw Materials Will Drive Profitability for Fashion and Apparel Brands; Boston Consulting Group, Textile Exchange, and Quantis, 2023.

2.4 Prospective Risk Drivers

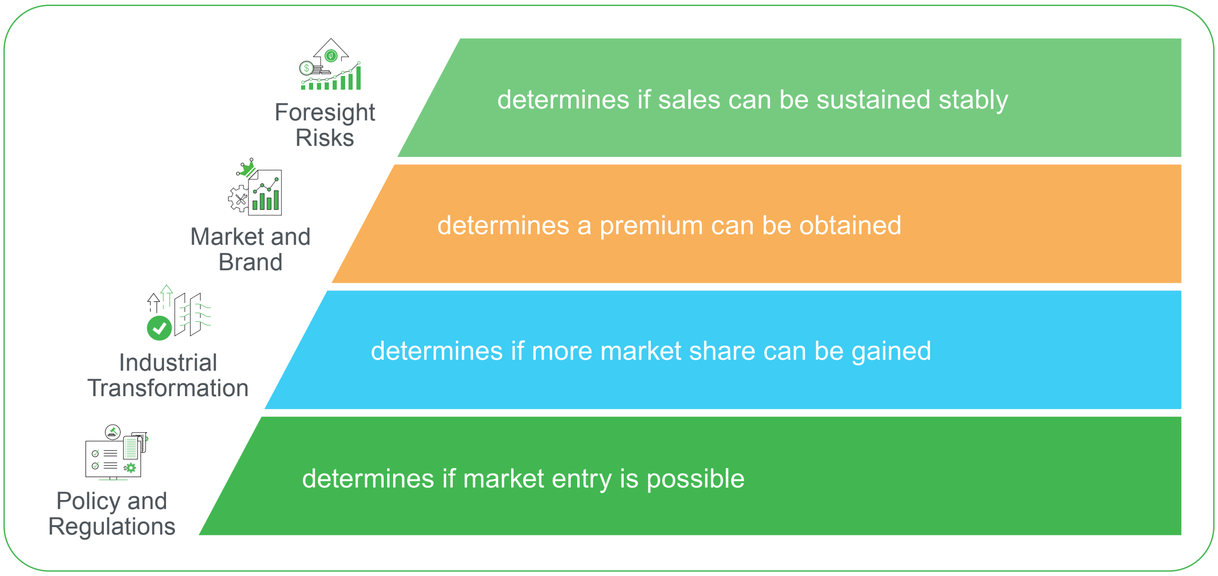
Long-Term Competitiveness

A key value of Eco-design lies in its ability to manage future risk. By addressing environmental and resource constraints during product development, companies can reduce exposure to regulatory, supply chain, and market disruptions.

Environmental regulations, material restriction lists, and energy efficiency standards are evolving rapidly. Products without Eco-design may face sudden bans, recalls, or supply chain exclusion after entering the market. For example, the global ban on perfluorinated substances (PFAS) has caused previously competitive functional materials to lose their legitimacy in various regions[4]. Similarly, the risk associated with rare earth reliance in electric motor technology has led some car manufacturers to switch to electrically excited synchronous motors ahead of schedule to mitigate supply chain uncertainties[5].

Eco-design also improves durability, repairability, and resource efficiency, reducing long-term maintenance costs, material price volatility, waste treatment costs, and supply disruptions. In effect, it embeds future regulatory and resource risks into present design decisions.

By doing so, Eco-design helps products remain viable under changing policy and market conditions. **It enables companies to sustain sales over time, avoid abrupt technical dead ends, and maintain stable competitiveness over the medium to long term.**



(Figure 2) Multi-Level Drivers Through Which Eco-design Determines Sustainable Business Value

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[4] 3M to Exit PFAS Manufacturing by the End of 2025. 3M News Center.
[5] BMW Group. BMW high-performance electrically excited synchronous motor system won the "2022 Global New Energy Vehicle Innovation Technology" award.

3

Current Status and Challenges of Eco-Design in China

What Blocks It?

Chapter 2 shows that Eco-design increasingly determines whether products can enter the market, expand sales, and remain competitive over time. In practice, however, these advantages do not emerge. Many companies face structural barriers that prevent Eco-design from translating into real product competitiveness. These barriers appear across the full chain from strategy to execution. This chapter examines key bottlenecks: strategy, objectives, mechanisms, decision-making, and implementation.

3.1 Strategic Level

Gaps in Forward Planning and Lifecycle Perspective

In most companies, Eco-design has not yet become a strategic priority. It is still handled as a response to regulation or customer requirements. Faced with fast-changing and fragmented green policies, companies often lack early judgment on regulatory direction. As a result, design adjustments are made late, close to enforcement deadlines, increasing the risk of re-design, production disruption, and recalls. Short-term compliance pressure leaves little room for systematic resource allocation.

At the same time, Eco-design is often narrowly understood as material substitution, emission reduction in production, or improvement of isolated indicators. Lifecycle impacts are rarely assessed as a whole. This leads to environmental load shifting between stages, for example, lower production emissions paired with higher use-phase energy demand[7], or greener materials that complicate recycling[6]. Local optimization fails to improve overall lifecycle performance and does not meet supply chain requirements for comprehensive environmental assessment.

The lack of a systematic strategic perspective is further reflected in internal misalignment. Departments pursue separate green targets based on their own responsibilities, without coordination at the company level. Procurement may prioritize green materials without considering manufacturing constraints, while R&D pursues lightweighting conflicts with durability targets set by after-sales teams. Without an integrated strategy, these actions do not reinforce each other and may even conflict, preventing Eco-design from supporting long-term competitiveness.

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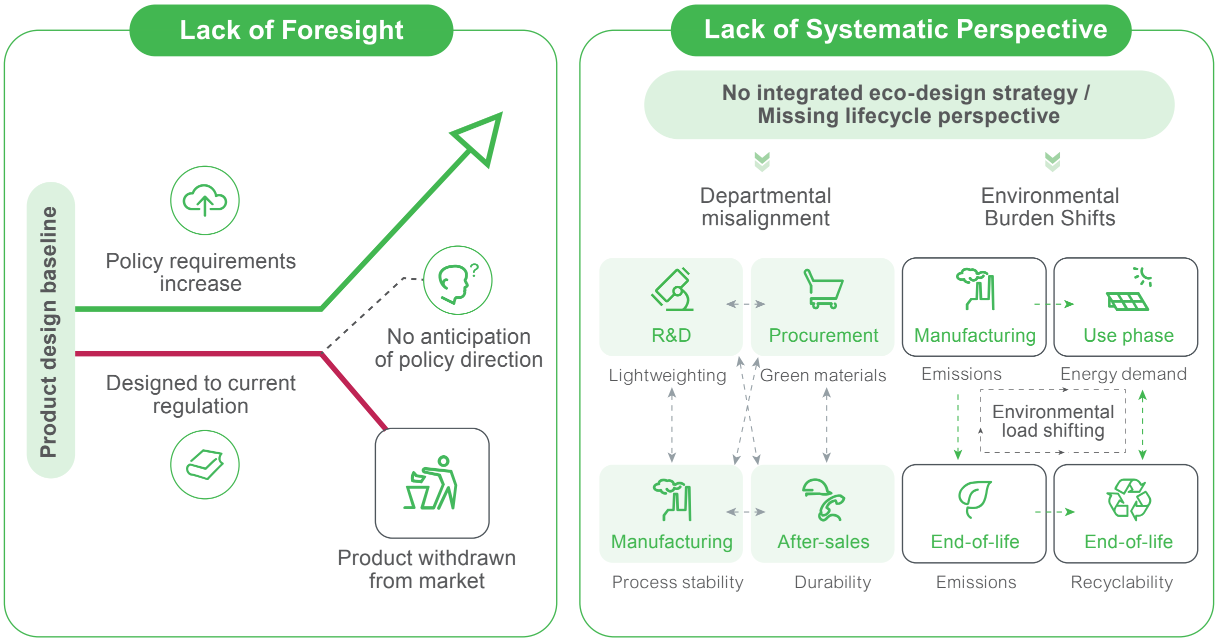
[6] UNEP. Everything you need to know about plastic pollution. 2023.
[7] European Environment Agency. Microplastics from textiles: towards a circular economy for textiles in Europe. 2022.



(Figure 3) Policy Risks and Systemic Failures Caused by Strategic Gaps in Eco-Design

3.2 Objective Level

Carbon-Centered Goal Setting

Under China's "dual carbon" targets, carbon reduction has become the dominant environmental objective for many companies, which is often referred to as "Carbon-Tunnel Vision". While important, this focus has created a narrow management approach. Other environmental impacts, such as water use, pollution, toxicity, and biodiversity, are often overlooked, leading to unbalanced environmental performance.

This single-indicator approach increases the risk of environmental burden shifting. Materials with lower carbon footprints may increase land use pressure[8,9], and some low-emission technologies during use may cause ecological damage during resource extraction[10]. Carbon targets may be met, but overall environmental value does not improve.

Supply chains are also moving beyond carbon-only requirements. More buyers now request multi-dimensional lifecycle data rather than isolated carbon metrics. A narrow carbon focus can therefore limit access to supply chains rather than support expansion.

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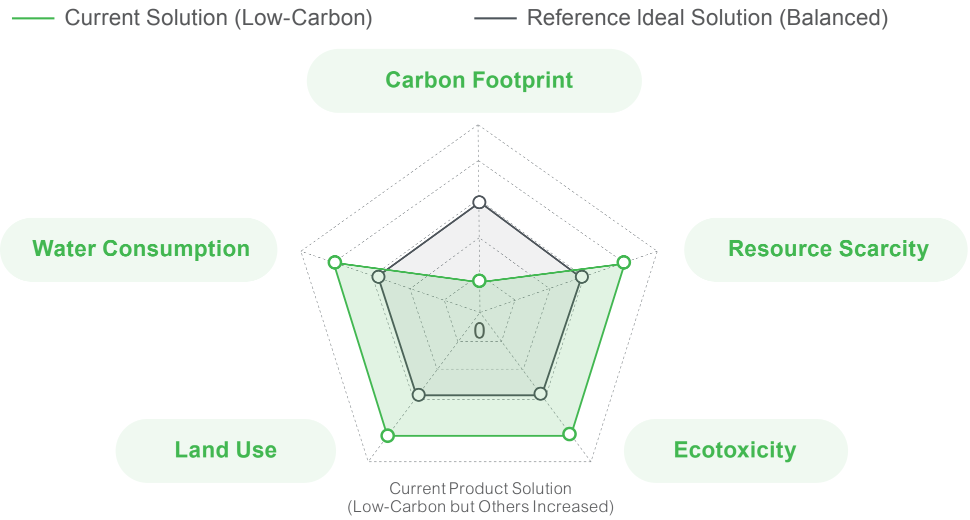
[8] Bishop, G.; Styles, D.; Lens, P. N. L. Environmental Performance Comparison of Bioplastics and Petrochemical Plastics: A Review of Life Cycle Assessment (LCA) Methodological Decisions. Resources, Conservation and Recycling 2021, 168, 105451.

[9] Zheng, J.; Suh, S. Strategies to Reduce the Global Carbon Footprint of Plastics. Nat. Clim. Chang. 2019, 9 (5), 374–378.

[10] United Nations Conference on Trade and Development. Commodities at a Glance: Special Issue on Strategic Battery Raw Materials; Commodities at a Glance; UN, 2020.

From a market perspective, consumers are increasingly skeptical of one-sided green claims. Products that emphasize a single environmental attribute are more likely to be questioned as greenwashing, reducing willingness to pay, and weakening the ability to build price premiums.



Note: the center of the radar chart is zero burden, moving outwards indicates higher (worse) environmental burden. This chart illustrates how focusing solely on metrics by companies can lead to burden shifting to other environmental dimensions such as water, land, and toxicity.

(Figure 4) Environmental burden shifting under a single low-carbon goal.

Environmental Bias Resulting from Single Carbon Indicators

From our certification practice, we often see that companies lack a clear understanding of the potential for improvement in their products. For example, textile companies tend to focus only on fabric categories, neglecting the fact that improving material utilization can significantly reduce water usage and emissions during production. Similarly, furniture and tire companies may overlook the importance of extending product lifespans in enhancing durability and reducing environmental impact.

—— Prabhu Ramkumar, Head of Sustainability, TÜV SÜD North Asia,
TÜV SÜD Certification and Testing (China) Co., Ltd.

Formation Mechanism of the Carbon Tunnel Effect

Based on our industry research and observations, the "carbon tunnel effect" is common and prominent among Chinese enterprises (and even global companies). This tendency is largely shaped by stage-based management and policy signals. Under the dual-carbon framework, policies, funding mechanisms, and performance metrics are predominantly aligned with carbon reduction, directing corporate resources and attention toward carbon-focused actions while limiting broader environmental integration. This focus was necessary in the early stages, but it has indeed resulted in a lack of a systemic perspective.

A single-objective focus increases the risk of burden shifting to other environmental dimensions. For example, carbon-oriented measures may overlook the potential impacts of technology and products on local water security and biodiversity. Therefore, in the future, corporate environmental management must avoid this "whack-a-mole" phenomenon and promote a systemic transition from "single-point carbon reduction" to "multi-dimensional synergistic efficiency."

—— Gang LIU, Professor, School of Urban and Environmental Sciences, Peking University

3.3 Mechanism Level

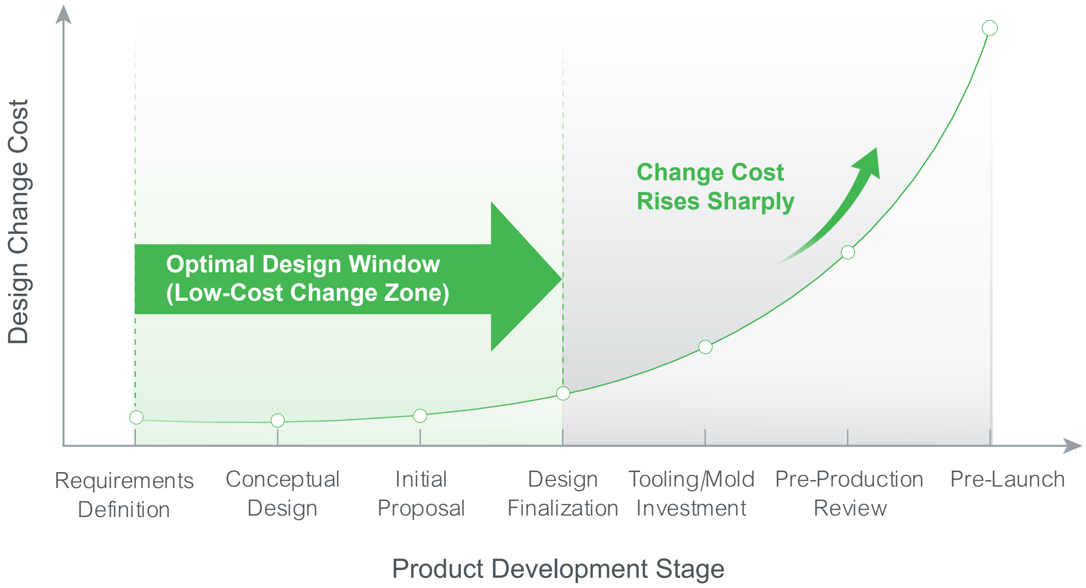
Late Environmental Assessment

Eco-design is based on the principle that environmental impact is determined by design. In many companies, however, environmental assessment still takes place after key design decisions are fixed, or even near product finalization.

Once materials, structures, and suppliers are locked in, environmental issues become costly to correct. Design changes often require modification, process adjustment, supplier replacement, or re-certification. Faced with high change costs and sunk investments[11], companies tend to avoid major revisions, limiting Eco-design to minor downstream fixes.

Late assessment also prevents early identification of regulatory risks. Materials or design choices that later face restrictions are often discovered too late, increasing commercial uncertainty.

This reversed process removes the opportunity to compare design options at low cost and makes it difficult to optimize environmental performance alongside cost and feasibility. As a result, Eco-design fails to function as a reliable tool to secure long-term product viability.



(Figure 5) The Critical Window for Eco-Design—Design Stages and Change Cost

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[11] Gregory Tassey. The Economic Impacts of Inadequate Infrastructure for Software Testing; National Institute of Standards and Technology: Gaithersburg, MD, USA, 2002.

Why Product Environmental Impact Assessment Fails to Function as Decision Support in Eco-Design

Our research indicates that the limited decision-support role of product environmental impact assessment in eco-design is not primarily due to methodological immaturity, but to the absence of enabling conditions required for integration into design decision-making. In most enterprises, environmental impact assessment is still treated as a post hoc analytical or accounting task, rather than as an input to design processes. As a result, tools such as life cycle assessment (LCA) remain weakly connected to product development decisions.

First, data availability at the design stage is insufficient. Most companies can only provide data at the factory or energy level, while design-relevant information at the material, process, and structural levels is largely missing. In addition, supply-chain environmental data is fragmented and poorly traceable, forcing assessments to rely heavily on generic databases or assumed parameters. This limits the applicability of assessment results to specific design options and reduces their usefulness for scheme comparison, material selection, and structural optimization.

Second, environmental impact assessment is typically applied late in the development process. Because assessments are mainly used for compliance, disclosure, or reporting, they are often conducted after essential design choices have been fixed. At this stage, material systems and structural pathways are difficult to adjust, preventing environmental information from influencing key decisions such as option selection or trade-off analysis.

Third, existing assessment methods remain weakly linked to concrete design actions. In LCA-based practice, design changes such as material substitution, structural modification, or process adjustment are often not sufficiently differentiated or parameterized. As a result, assessment outcomes cannot be clearly mapped back to specific engineering decisions, limiting feedback to designers and weakening the demonstrable effectiveness of Eco-design interventions.

—— Yutao WANG, Professor, Department of Environmental Science and Engineering, Fudan University

3.4 Decision-Making Level

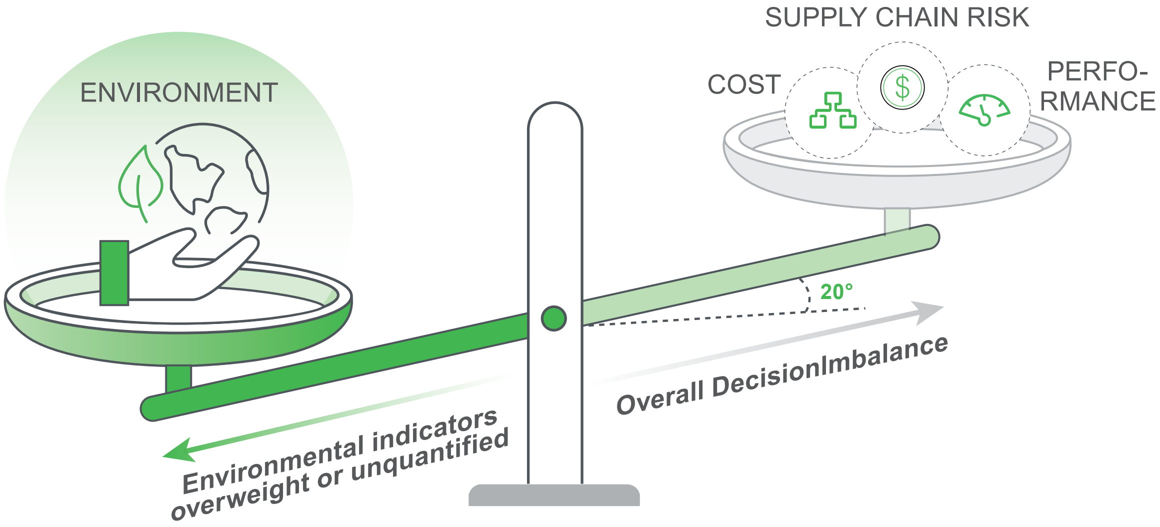
Lack of Multi-Objective Trade-Off Mechanisms

Eco-design decisions require both environmental insight and business evaluation. In practice, many green projects rely on qualitative judgment rather than quantitative analysis. Without structured decision frameworks, companies struggle to balance environmental performance, cost, supply chain feasibility, and operational impact.

Material substitutions and design alternatives are often assessed without clear comparison across lifecycle cost, resource use, recyclability, and risk exposure. As a result, some technically promising solutions lack a clear business case and face resistance during implementation. Projects such as highly automated or localized green factories may appear advanced but encounter cost and operational challenges without prior analysis12.

Over time, this 'green intuition' erodes internal confidence. When green projects consume resources without visible returns, Eco-design is seen as a cost burden rather than a value driver. It is pushed to the margins instead of being treated as a strategic lever.

Without quantitative decision support, Eco-design cannot demonstrate its commercial logic. This limits its role in growth, wastes resources, and prevents companies from building sustainable competitive advantages.



(Figure 6) Decision Imbalance in Eco-Design

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[12] adidas deploys Speedfactory technology at Asian suppliers by end of 2019 - adidas Group. 2019.

3.5 Implementation Level

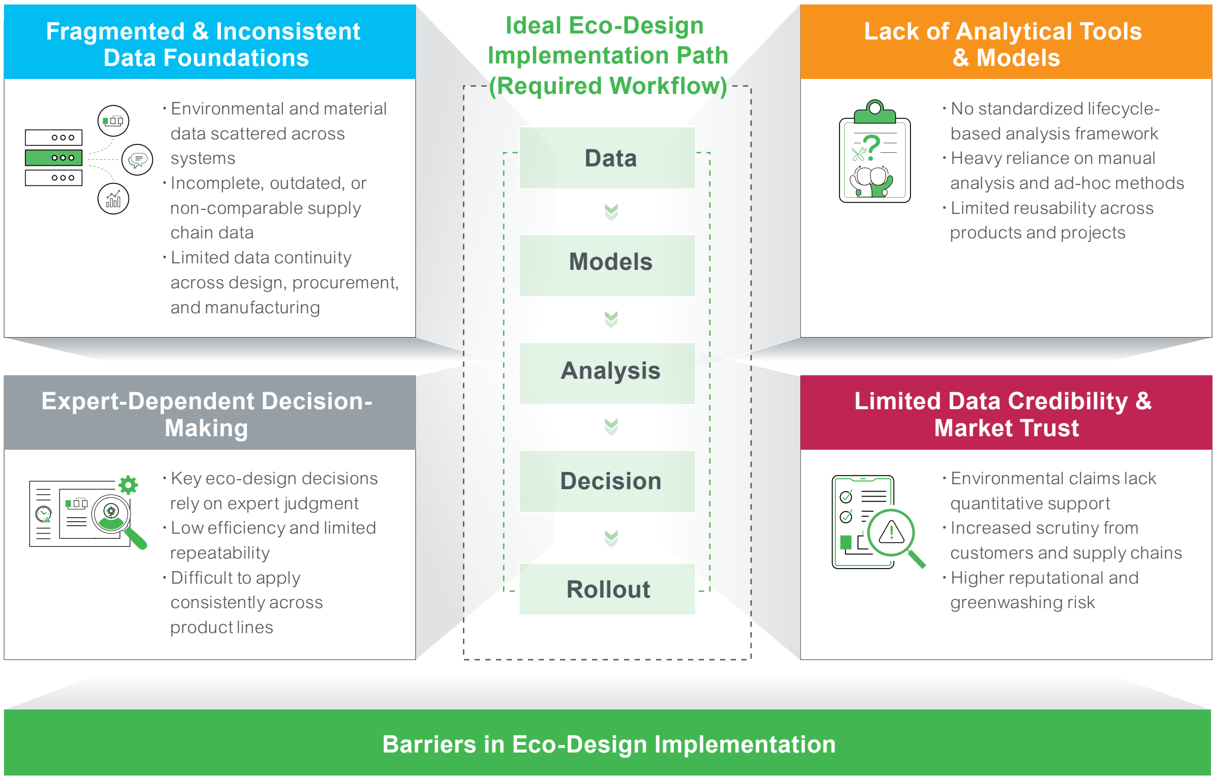
Data and Tool Constraints

Effective Eco-design depends on reliable data and analytical tools. This includes material attributes, supply chain impacts, and lifecycle models. In many companies, these foundations are incomplete. Environmental data is fragmented, outdated, and poorly shared across design, procurement, and manufacturing.

In the absence of robust data and tools, Eco-design relies heavily on expert judgment rather than standardized methods. This reduces efficiency and prevents consistent evaluation across product lines. Pilot projects cannot be scaled into company-wide practices.

Weak data capability also affects market credibility. Supply chains increasingly require transparent and verifiable environmental data. Without quantitative support, green claims are harder to validate and face higher scrutiny. Consumers also question unsupported claims, increasing reputational risk.

More critically, limited tools slow down the response to market and policy changes. When each Eco-design decision depends on manual analysis, companies cannot iterate quickly or apply Eco-design across broader portfolios. This restricts Eco-design from becoming a systematic driver of growth and limits its impact on overall competitiveness.



(Figure 7) Barriers in Eco-Design Implementation at the Execution Level

Data and Tool Constraints in Eco-Design Implementation

Based on our certification practice, many companies lack the data foundations and analytical tools required to support effective eco-design implementation. While product environmental footprint studies can help structure supply chain information, identify environmental hotspots, and inform design priorities, limited experience and capability in footprint quantification prevent these tools from being applied consistently or at scale.

Additionally, incomplete or unverifiable material declarations, together with insufficient BOM granularity, constrain the identification of substances of concern and recycled content. As a result, Eco-design decisions often rely on manual judgment rather than systematic analysis, limiting comparability across products and reducing the effectiveness of design-stage optimization.

—— Prabhu Ramkumar, Head of Sustainability, TÜV SÜD North Asia,
TÜV SÜD Certification and Testing (China) Co., Ltd.

4 The Implementation Framework for Eco-Design in China

How to make it work?

Eco-design becomes effective only when strategy, objectives, processes, decision-making, and tools are connected in a closed loop. Without this linkage, Eco-design remains a concept rather than an operational system. This chapter presents an implementation framework designed to be executable, repeatable, and scalable. The framework is built around five principles:

- **Forward-looking:** anticipate regulatory, technology, and market changes.
- **Comprehensive:** manage environmental impact across the full lifecycle.
- **Embedded:** introduce environmental constraints early in product development.
- **Feasible:** balance environmental outcomes with cost, technology, and supply chain limits.
- **Scalable:** rely on standardized methods, data, and tools rather than individual expertise.

4.1 Strategic Level

Forward-Looking and Systematic Management

Effective Eco-design requires coordination at a strategic level. Without early judgment on trends and clear internal alignment, companies are forced into reactive responses, and Eco-design remains fragmented.

First, companies need to shift from reactive compliance to forward planning. This requires continuous monitoring of regulatory trends, industry changes, and competitor practices, and translating them into clear Eco-design priorities for the next three to five years. For emerging requirements such as material restrictions, disassembly rules, digital product passports, and carbon thresholds, technical routes and alternatives should be assessed before formal implementation. Early planning reduces redesign costs, inventory risk, and market access disruption.

Second, Eco-design must be treated as a system-wide issue rather than a set of isolated actions. It should be integrated into R&D planning, supply chain strategy, manufacturing decisions, and business targets. For example, Schneider Electric has set the goal of "100% of new products adopting Eco-design methods"13, Philips aims for "all new products to meet Eco-design standards by 2025"14, and Volvo Group holds business units accountable for environmental performance15. Environmental requirements need to be embedded into product development milestones and performance evaluation, so that Eco-design becomes a stable input to business operations rather than an ad hoc adjustment.

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[13] Schneider. Sustainability Impact Results Q2 2025; Schneider.
[14] 2023 Annual Report; Royal Philips, 2023.
[15] 2023 Annual Report; VOLVO GROUP, 2024.

Third, Eco-design requires formal cross-functional governance. Design, R&D, procurement, manufacturing, quality, and sustainability teams must share data and participate in joint decisions. This requires clear roles, defined decision rights, and stable coordination mechanisms. Without governance structures, Eco-design depends on individual initiative cannot be sustained.

A forward-looking strategic mechanism determines whether Eco-design functions as an early planning tool or remains a late-stage response.

4.2 Objective Level

Multi-Dimensional Environmental Goals

Eco-design requires clear and balanced environmental objectives. A narrow or incomplete goal system can misdirect design decisions and shift environmental burdens between lifecycle stages.

First, companies need to move beyond single carbon indicators. In addition to carbon emissions, objectives should cover water use, pollution, toxicity, impact of biodiversity, use of scarce resources, and recyclability. Multi-indicator management is increasingly required by global supply chains.

Second, environmental objectives must be set from a lifecycle perspective. Goals should cover raw material extraction, manufacturing, transport, use, and end-of-life. This prevents improvements in one stage from causing higher impacts elsewhere and helps identify environmental hotspots that design can address.

Without multi-dimensional, lifecycle-based goals, Eco-design cannot guide effective design decisions. Schneider Electric has invested considerable time and resources to systematically review global policies, regulations, and standards for electronic and electrical products. They have integrated environmental and Eco-design goals to comprehensively evaluate the design of relevant products.

Beyond Carbon: A Life Cycle–Based Multi-Dimensional Approach to Environmental Management

As carbon accounting frameworks mature, carbon indicators have become widely used in corporate environmental management due to their quantifiability and comparability. While carbon-focused management can support short-term emission reduction planning, it does not adequately capture other environmental impacts, including water use, land occupation, toxicity, and biodiversity, and may lead to burden shifting across environmental media, regions, or life-cycle stages.

Evidence shows that carbon-oriented strategies do not always result in overall environmental improvement. Materials with low use-phase emissions may pose recycling challenges; bio-based materials can increase land-use pressure; and some recycled materials may raise energy use or pollution during processing. These cases highlight the limitations of single-indicator management.

As supply chains, regulatory systems, and environmental policies increasingly emphasize multi-dimensional environmental performance, carbon-only management approaches are becoming insufficient. Establishing a life cycle–based environmental management and eco-design system that integrates multiple environmental indicators provides a structured pathway for long-term environmental performance improvement.

—— Yutao WANG, Professor, Department of Environmental Science and Engineering,
Fudan University

4.3 Mechanism Level

Proactive Design Processes

Eco-design only creates value when it influences decisions while change is still possible. Many companies still assess environmental impact after key design choices are fixed, limiting Eco-design to corrective actions.

First, **environmental constraints must be introduced early.** Eco-design should be involved during requirement definition, concept development, and material selection—not after structures, molds, and suppliers are finalized. Early definition of environmental goals, material options, and restriction lists ensures that environmental factors influence design comparisons.

Second, **critical decision windows must be clearly defined.** Companies should set mandatory Eco-design checkpoints at key milestones such as concept approval, design freeze, and supplier selection. For example, recyclability must be assessed before concept finalization, and material compliance verified before design freeze. This prevents costly late-stage changes.

Third, **execution must be standardized.** Eco-design should be a required process, supported by standard checklists, templates, and design guides. Standardization reduces reliance on individual expertise and enables consistent application across teams and projects.

4.4 Decision-Making Level

Data-Based Trade-Offs

Eco-design decisions must be based on data rather than intuition, enthusiasm, or traditional experience. Without quantitative support, green projects face cost uncertainty and weak business justification.

First, companies need a unified decision data structure covering environmental impact, cost, performance, supply chain risk, recyclability, and compliance exposure. Decisions without this data cannot be properly compared or validated.

Second, decision-making should be model-based. By linking design parameters to environmental and cost outcomes, companies can compare alternatives during design rather than after completion. Changes in materials, structures, or processes should directly translate into comparable results for emissions, resource use, recyclability, and cost. This turns environmental indicators into real design inputs.

Third, green decisions must be traceable. Key decisions should be documented, reviewable, and auditable. This builds trust that Eco-design choices are based on evidence rather than preference.

4.5 Implementation Level

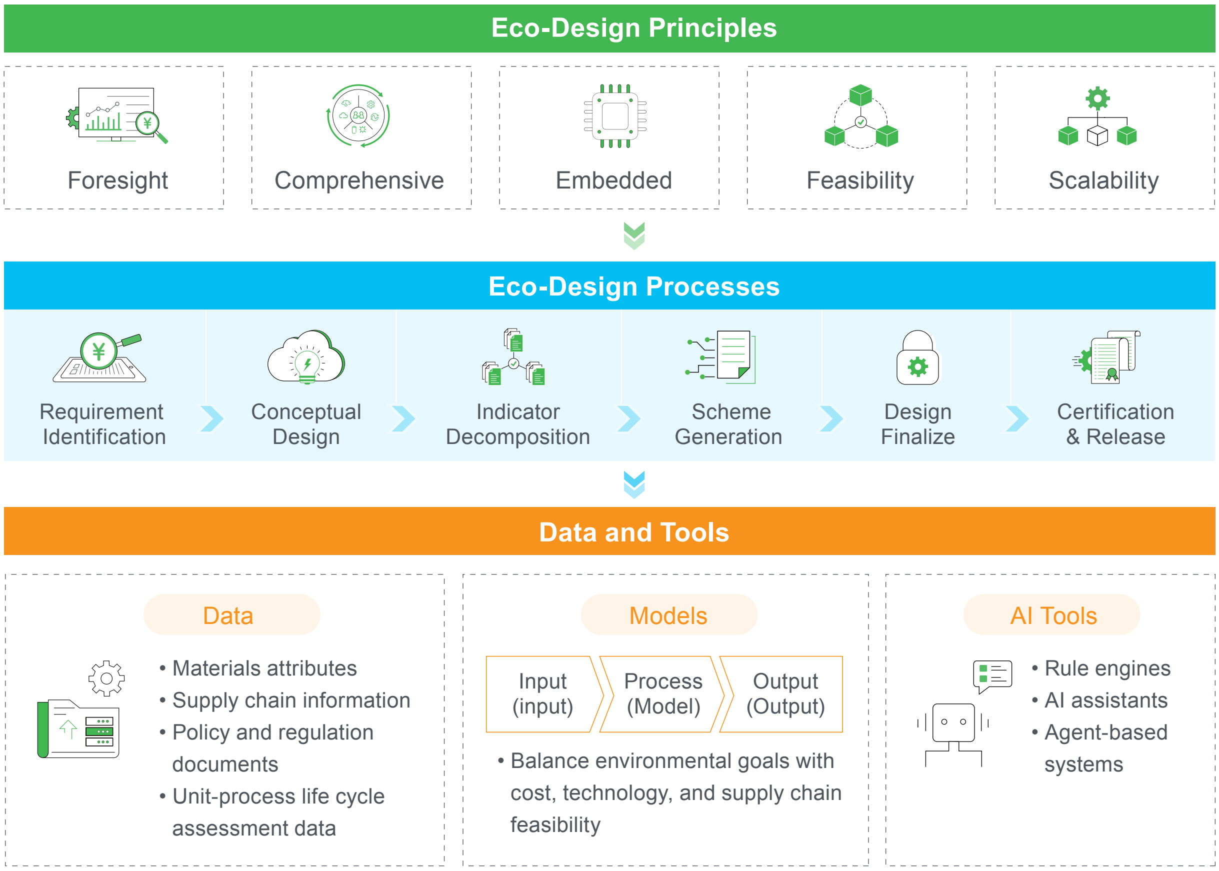
Digital and Intelligent Tools

Effective Eco-design requires stable data systems and reliable tools. In practice, many companies suffer from fragmented data, weak tooling, and expert-dependent decision-making. As a result, Eco-design remains difficult to scale, and green claims lack credibility. Digitalized and intelligent engineering foundations are critical to resolving these structural barriers.

Digital systems provide the foundation. By integrating material data, regulatory requirements, and supply chain information, companies can support real-time environmental evaluation during design, rather than post-project analysis. Digitalization improves efficiency and provides verifiable support for environmental claims.

Intelligent tools build on this foundation. Automated analysis of regulations, standards, and technical documents can convert complex requirements into clear design rules, reducing interpretation errors. Intelligent agents can flag compliance risks, compare design options, and generate optimization suggestions within defined parameters. This reduces omission risk and improves consistency across projects.

Digital systems address data availability and flow. Intelligent tools address interpretation and application. Together, they allow Eco-design to operate as a repeatable and scalable system rather than a manual, expert-driven process.



(Figure 8) The Eco-Design Implementation Framework

Eco-Design as a Systematic Practice Across Corporate Strategy, Product Life Cycle, and Industry Ecosystems

Enterprises that effectively implement Eco-design adopt a systematic approach that extends from corporate strategy to the full product life cycle and further into the industry ecosystem, rather than focusing on isolated improvements.

At the strategic level, sustainability is embedded as a long-term management objective rather than a marketing consideration. At the product level, Eco-design is integrated into life-cycle management, with environmental impacts addressed at the design stage and managed across raw material sourcing, manufacturing, use, and end-of-life. At the industry level, enterprises promote Eco-design practices across supply chains and participate in collaborative platforms to support sector-wide green transformation.

In practice, eco-design functions as a design-based management tool that restructures the relationships among enterprises, users, supply chains, and environmental systems, enabling coordinated economic and social performance and environmental outcomes.

—— Yutao WANG, Professor, Department of Environmental Science and Engineering, Fudan University

5 Opportunities and Future Directions for Eco-Design in China

Where to go next?

As policies advance, industries rapidly reshape, and supply chain thresholds rise, Eco-design is shifting from a compliance requirement to a strategic opportunity. From products to systems to services, the competitive dimension businesses face is undergoing profound transformation. This chapter will focus on opportunities and future directions, helping companies identify key capability breakthroughs for the next phase in an uncertain era.

5.1 Opportunities

The Strategic Window for Eco-Design in China

5.1.1 Policy Opportunities: From Pilot Incentives to Lifecycle Requirements

Policy momentum is moving from encouragement to enforceable requirements. The trend is toward rules that are lifecycle-based, auditable, and tied to engineering choices made during R&D. This pushes environmental governance upstream—from end-of-pipe treatment to product definition, material selection, and structural design.

First, **requirements are becoming mandatory.** Eco-design is increasingly linked to formal compliance systems (laws, standards, certifications, and producer responsibility rules). For many products, design-stage choices now affect approval, market access, and footprint accounting. Firms that treat Eco-design as a late adjustment will face higher redesign and compliance costs.

Second, **requirements are becoming more specific.** Policy is moving from broad targets (e.g., recycling rates or energy use) to design-relevant constraints, such as restricted substances, recycled-content ratios, disassembly rules, and structural standards. The direction is toward rules that can be checked, calculated, and verified.

Third, **requirements are expanding from single points to lifecycle control.** Policy focus is extending across design, manufacturing, logistics, use, and end-of-life, with emphasis on emissions reduction and circularity. Tools and methods such as lifecycle assessment, product carbon footprints, and remanufacturing pathways are increasingly used to support enforcement and evaluation. This pushes companies from local fixes to system-level optimization.

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[16] Xinhua News Agency National High-end Think Tank Academic Committee. (2025, November 24). Joining hands towards eco-friendly modernization —Theoretical contributions and practical guidance of Xi Jinping's thoughts on ecological civilization for global sustainable development.

Fourth, transparency requirements are rising. Digital passports, carbon accounting systems, and digital monitoring under producer responsibility frameworks increase the demand for traceable product data. Companies will need material databases, footprint data management, and product-level traceability to operate in “traceable and auditable” environments.

Policy is moving toward Eco-design requirements that are binding, detailed, lifecycle-based, and data-backed. Companies that build Eco-design into R&D and data systems earlier can reduce later correction costs and avoid being blocked by new thresholds.

Environmental Goal System Based on Synergistic Control of Pollution and Carbon Emissions

With the advancement of the dual-carbon strategy, environmental management is shifting from separate approaches to pollution control and carbon reduction toward integrated management. This approach recognizes the shared sources and strong linkages between air pollutants and greenhouse gas emissions. The synergistic control of pollution and carbon emissions emphasizes coordinated reduction pathways to achieve co-benefits, aligning conventional pollutant abatement with climate mitigation objectives. It is not only a great opportunity for future corporate development, but also a crucial lever to promote the comprehensive green transformation of economic and social development and drive a qualitative improvement in ecological environmental quality from incremental change to transformational change.

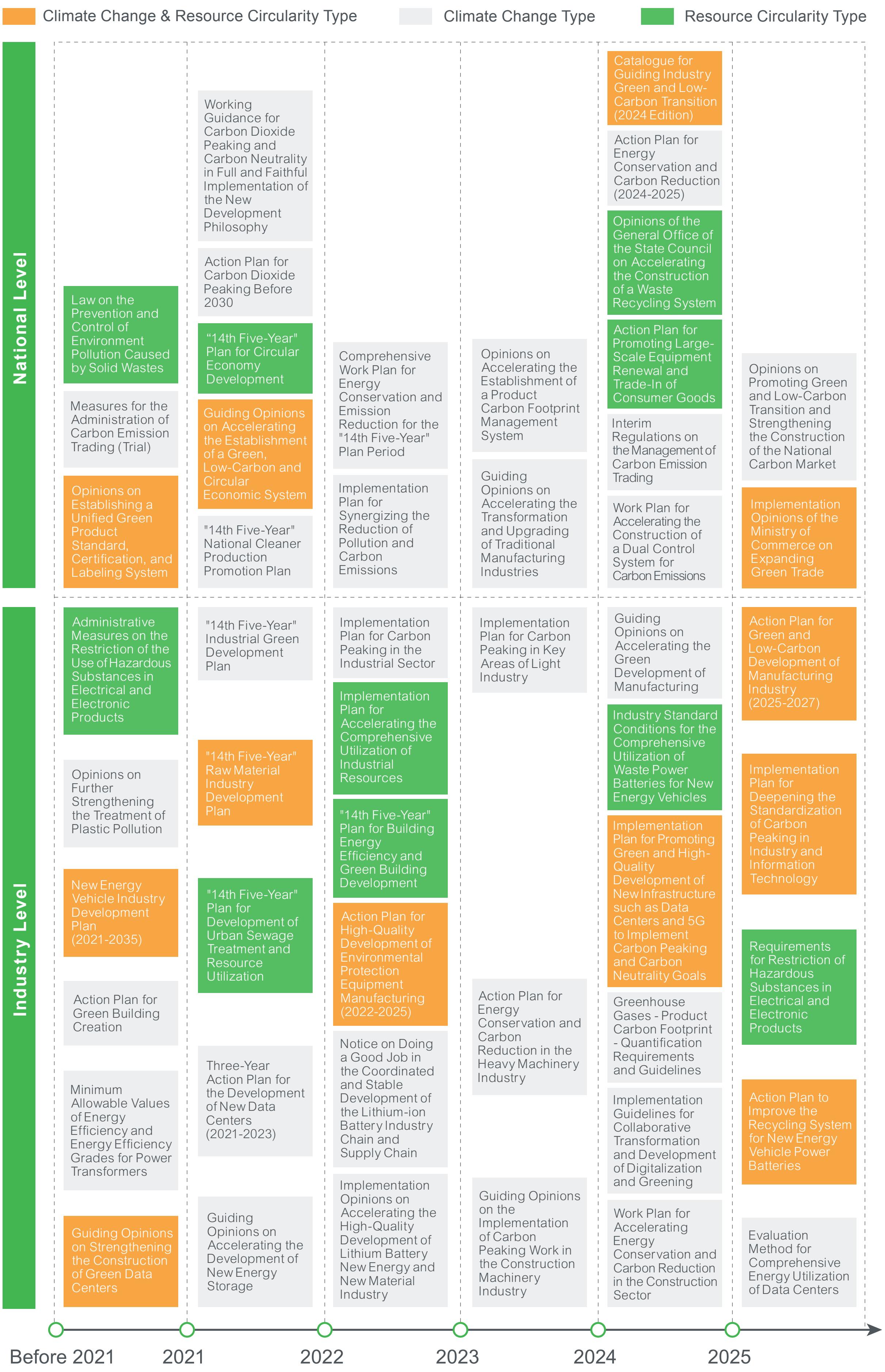
—— Minghui XIE, Director/Research Fellow, Research Center for Environmental Management, Chinese Research Academy of Environmental Sciences

Trends in Eco-Design Life Cycle Management and Supply Chain Collaboration

During the 15th Five-Year Plan period, product Eco-design regulation is increasingly centered on carbon emission control, with a focus on establishing life-cycle management requirements covering raw materials, manufacturing, and distribution. Policy instruments such as product carbon footprint standards and carbon labeling are being applied to support the implementation of China’s carbon targets and alignment with emerging international green trade rules.

At the same time, Eco-design is expanding from firm-level application to industry- and supply-chain-level coordination. Greater coordination among upstream and downstream enterprises is being promoted in areas such as eco-design practices and recycling systems. Supply-chain-wide digital traceability of eco-design information is becoming a key enabling infrastructure.

—— Yun TENG, Senior Engineer, China Electrical Equipment Industry Association.



🟧 Climate Change & Resource Circularity Type
⬜ Climate Change Type
🟩 Resource Circularity Type

	National Level	Industry Level
Before 2021	🟩 Law on the Prevention and Control of Environment Pollution Caused by Solid Wastes ⬜ Measures for the Administration of Carbon Emission Trading (Trial) 🟧 Opinions on Establishing a Unified Green Product Standard, Certification, and Labeling System	🟩 Administrative Measures on the Restriction of the Use of Hazardous Substances in Electrical and Electronic Products ⬜ Opinions on Further Strengthening the Treatment of Plastic Pollution 🟧 New Energy Vehicle Industry Development Plan (2021-2035) ⬜ Action Plan for Green Building Creation ⬜ Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Power Transformers 🟧 Guiding Opinions on Strengthening the Construction of Green Data Centers
2021	⬜ Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy ⬜ Action Plan for Carbon Dioxide Peaking Before 2030 🟩 "14th Five-Year" Plan for Circular Economy Development 🟧 Guiding Opinions on Accelerating the Establishment of a Green, Low-Carbon and Circular Economic System ⬜ "14th Five-Year" National Cleaner Production Promotion Plan	⬜ "14th Five-Year" Industrial Green Development Plan 🟧 "14th Five-Year" Raw Material Industry Development Plan 🟩 "14th Five-Year" Plan for Development of Urban Sewage Treatment and Resource Utilization ⬜ Three-Year Action Plan for the Development of New Data Centers (2021-2023) ⬜ Guiding Opinions on Accelerating the Development of New Energy Storage
2022	⬜ Comprehensive Work Plan for Energy Conservation and Emission Reduction for the "14th Five-Year" Plan Period ⬜ Implementation Plan for Synergizing the Reduction of Pollution and Carbon Emissions	⬜ Implementation Plan for Carbon Peaking in the Industrial Sector 🟩 Implementation Plan for Accelerating the Comprehensive Utilization of Industrial Resources 🟩 "14th Five-Year" Plan for Building Energy Efficiency and Green Building Development 🟧 Action Plan for High-Quality Development of Environmental Protection Equipment Manufacturing (2022-2025) ⬜ Notice on Doing a Good Job in the Coordinated and Stable Development of the Lithium-ion Battery Industry Chain and Supply Chain ⬜ Implementation Opinions on Accelerating the High-Quality Development of Lithium Battery New Energy and New Material Industry
2023	⬜ Opinions on Accelerating the Establishment of a Product Carbon Footprint Management System ⬜ Guiding Opinions on Accelerating the Transformation and Upgrading of Traditional Manufacturing Industries	⬜ Implementation Plan for Carbon Peaking in Key Areas of Light Industry ⬜ Action Plan for Energy Conservation and Carbon Reduction in the Heavy Machinery Industry ⬜ Guiding Opinions on the Implementation of Carbon Peaking Work in the Construction Machinery Industry
2024	🟧 Catalogue for Guiding Industry Green and Low-Carbon Transition (2024 Edition) ⬜ Action Plan for Energy Conservation and Carbon Reduction (2024-2025) 🟩 Opinions of the General Office of the State Council on Accelerating the Construction of a Waste Recycling System 🟩 Action Plan for Promoting Large-Scale Equipment Renewal and Trade-In of Consumer Goods ⬜ Interim Regulations on the Management of Carbon Emission Trading ⬜ Work Plan for Accelerating the Construction of a Dual Control System for Carbon Emissions	⬜ Guiding Opinions on Accelerating the Green Development of Manufacturing 🟩 Industry Standard Conditions for the Comprehensive Utilization of Waste Power Batteries for New Energy Vehicles 🟧 Implementation Plan for Promoting Green and High-Quality Development of New Infrastructure such as Data Centers and 5G to Implement Carbon Peaking and Carbon Neutrality Goals ⬜ Greenhouse Gases - Product Carbon Footprint - Quantification Requirements and Guidelines ⬜ Implementation Guidelines for Collaborative Transformation and Development of Digitalization and Greening ⬜ Work Plan for Accelerating Energy Conservation and Carbon Reduction in the Construction Sector
2025	⬜ Opinions on Promoting Green and Low-Carbon Transition and Strengthening the Construction of the National Carbon Market 🟧 Implementation Opinions of the Ministry of Commerce on Expanding Green Trade	🟧 Action Plan for Green and Low-Carbon Development of Manufacturing Industry (2025-2027) 🟧 Implementation Plan for Deepening the Standardization of Carbon Peaking in Industry and Information Technology 🟩 Requirements for Restriction of Hazardous Substances in Electrical and Electronic Products 🟧 Action Plan to Improve the Recycling System for New Energy Vehicle Power Batteries ⬜ Evaluation Method for Comprehensive Energy Utilization of Data Centers

(Figure 9) Evolution of China's Eco-Design Policies and Industry Action

5.1.2 Industry Opportunities: From Compliance to System Upgrades

As policy becomes more lifecycle-focused, industries are adjusting in ways that change what “good Eco-design” means. Three shifts are common: standards move upstream into product definition and structural design; value chains move from linear flow to closed-loop coordination; infrastructure shifts toward low-carbon and circular models. Different industries face different constraints and timelines, which creates room to build differentiated capabilities.

Electronics and electrical products are moving beyond energy efficiency toward circular design requirements: modular disassembly, interface standardization, restricted substance control, and recycled-content management. Repairability and substitution are increasingly treated as design inputs. Firms with platform architecture, reuse of modules, and material rule databases are better positioned.

New energy (solar, wind) is shifting from “capacity growth” to “quality and efficiency.” On the manufacturing side, design is moving toward material selection, structural decoupling, and recovery of scarce metals to meet decommissioning and footprint requirements. On the application side, projects increasingly link energy deployment with land and ecosystem constraints. Equipment and systems that support recyclability, material control, and site compatibility will face stricter expectations.

Electric vehicles (EVs) and lithium batteries are entering a phase where recycling systems and lifecycle carbon management affect competitiveness. Vehicle design needs to plan for disassembly and downstream treatment; battery design needs to include recycled-content constraints, footprint accounting, and lifecycle safety early. Companies that connect design, production, use, second life, and recycling operations will be more resilient under supply chain and trade audits.

Other industries show similar movement. Data centers are transitioning from PUE management to integrated energy node design focusing on liquid cooling, waste heat utilization, and green power consumption. The power equipment industry is advancing standards in dielectric replacement, remanufacturing, and lifecycle management. The mining and metallurgy industries are incorporating waste-free mining, tailings utilization, and ecological restoration at the project’s source. The construction industry is restructuring design standards around ultra-low-energy buildings, modular structures, and full lifecycle carbon limits.

Diverging Eco-design requirements across industries create a narrow window for firms to build differentiated capabilities and long-term technical barriers. Early movers can advance design upstream to reduce costs, stabilize supply chains, overcome green trade barriers, and capture higher value-chain positions. Once industry pathways solidify, capability gaps will rapidly widen and become hard to close.

🟩 Important 🟦 Moderately important ⬜ General

Industry	Materials	Packaging & Operations	Lifespan Extension	Energy Efficiency	Circularity	Environmental Impacts
Traditional Electronics & Appliances	RoHS Limits	/	Lifespan	Energy Efficiency Grade	Recycling Utilization Rate	/
New Energy	/	/	Lifespan	Electric Transport Consumption	Battery Recovery Rate	Carbon Footprint
Data Centers	/	Green Power Proportion	/	PUE WUE Utilization Rate	/	Carbon Emissions
Power Equipment	/	Gas Leakage Rate	Lifespan	Energy Efficiency Grade	Recovery Rate	/
New Energy Vehicles	Proportion of Recycled Materials	/	/	/	Battery Recycling & Second-life	Lifecycle Carbon Emissions
Lithium Batteries	Recycled Metal Content	Safety Indicators	Cycle Life	/	/	Energy Carbon Footprint
Electronics & 3C	HazMat Limits Modularity	/	Product Repairability Index	Energy Efficiency Grade	Recovery Rate	/
Mining & Metallurgy	/	Ultra-low Emission Compliance	/	Energy/ Carbon Intensity	Bulk Waste Utilization	Mine Restoration Rate
Petrochemicals	Proportion of Green Products	VOCs Leakage Rate	/	/	Resource Recycling	Carbon Intensity
Water & Environmental Protection	Material Corrosion Resistance	/	/	Self-Gen Rate Equip.Efficiency	Water Recycling Res. Recovery	/
Construction & Real Estate	Proportion of Green Materials	/	/	Operational Energy Consumption	/	Embodied Carbon Prefab Rate
Manufacturing & Heavy Industries	Low-Carbon Materials	/	Disassembility	Renewable Energy Usage	Heat Recovery Recyclable Materials	Carbon Footprint Emission Control

Note: Based on policy relevance, supply chain impact, and stakeholder concerns.

(Figure 10) Overview of Eco-Design Requirements Across Industries in China

Product-Oriented Focus in China's Eco-Design Regulation

Since the release of the "Guidelines for Promoting Eco-Design of Industrial Products" by the Ministry of Industry and Information Technology, the National Development and Reform Commission, and the Ministry of Environmental Protection in January 2013, China has made long-term efforts in Eco-design regulation. These efforts include conducting pilot programs for industrial product Eco-design, developing Eco-design standards for key products, creating green design products, and laying a solid foundation for Eco-design, leading to positive progress.

With changes in cross-border trade policies, the importance of Eco-design has become even more pronounced. In the next 3-5 years, China's Eco-design regulation is likely to focus on key cross-border trade products such as household appliances, automobiles, and batteries. It will integrate high-priority information such as carbon footprints and recycled materials, and leverage digital tools to encourage companies to invest more in the design phase and enhance the level of product Eco-design.

—— Dongfeng GAO, Researcher, China National Institute of Standardization

5.2 Outlook

Future Directions for Eco-Design

5.2.1 Business System: From Products to Systems and Services

As regulatory pressure increases and industry competition shifts, Eco-design is moving beyond isolated product improvements toward shaping how companies design systems and deliver services. Its role in business is expanding from risk control to determining how value is created and maintained over time.

In the first stage, companies need to establish a product-centric Eco-design capability. The focus is on eliminating environmental risks at the source while improving core product performance. This requires embedding environmental requirements early in product definition and concept review, and building measurable Eco-design indicators that link carbon emissions, resource use, hazardous substances, durability, and recyclability to specific engineering parameters. By enabling early-stage impact assessment and design option comparison, Eco-design helps products achieve stable compliance and sustained market competitiveness.

In the second stage, the scope of Eco-design expands from individual products to system-level performance. As companies shift from product suppliers to providers of integrated green solutions, Eco-design must move beyond single-product optimization toward cross-module, cross-process, and cross-scenario integration. Through modular architectures, coordinated manufacturing and supply-chain optimization, digital operation platforms, and integrated recovery systems, companies can deliver lifecycle-oriented system solutions and move up the value chain.

In the third stage, Eco-design becomes embedded in service-based business models, forming a service-centric system. Supported by closed-loop lifecycle data and long-term responsibility management, companies gradually shift from one-off product sales to Product-as-a-Service (PaaS) models based on sustainable performance. Environmental gains achieved through improved durability, repairability, upgradability, and recyclability are translated into lower operating costs, higher service reliability, and stronger customer retention. Service-based Eco-design marks the shift from improving products to optimizing full lifecycle value, enabling long-term alignment between environmental and commercial performance.

Overall, the evolution of a company's Eco-design business system will progress from enhancing product green performance to providing industry green capabilities, and then to a service-based business model driven by lifecycle performance. As companies deepen their Eco-design capabilities across these three stages, their competitive boundaries, organizational structures, and value creation methods will undergo systemic changes.

Key Features of Advanced Practices in Corporate Eco-Design

> Enterprises that demonstrate advanced Eco-design practices typically share the following key feature: they adopt a product life cycle perspective, focusing not only on product profitability but also on the Eco-design performance of the product. During the design and production stages, they consider aspects such as product maintenance, repair, refurbishment, and reuse, and are willing to provide related support services for these efforts.
>
> —— Prabhu Ramkumar, Head of Sustainability, TÜV SÜD North Asia,
> TÜV SÜD Certification and Testing (China) Co., Ltd.

5.2.2 Technical System: From AI Tools to Agentic Workflows

As Eco-design expands from R&D into manufacturing, supply chains, operations, and recycling, the scale of data, model requirements, and process complexity increases rapidly. Traditional approaches based on experience and manual judgment are no longer sufficient to support high-frequency iteration or lifecycle-level optimization. Eco-design therefore requires a technical system that allows data, rules, and tools to be accessed, combined, and evaluated during design.

The first stage focuses on establishing foundational AI (Artificial Intelligence, AI) capabilities at the functional level. Core Eco-design tasks involve large volumes of structured and unstructured data, including material environmental attributes, process energy use, structural performance, supplier information, quality and lifetime data, and recovery pathways. Each function must digitize and model its own data, rules, and tools so that they can be accessed and invoked by agentic workflows as below. R&D teams need to platform structural models, simulation tools, and experimental data; manufacturing functions must structure process routes, energy data, and quality control records; supply chain teams must standardize bills of materials, supplier environmental data, and compliance records; and operations and recycling functions must establish traceable lifecycle databases. Through open interfaces, unified data formats, callable rule sets, and automatable process scripts, these functions become AI-ready, providing a computable, searchable, and composable technical foundation for Eco-design.

The second stage builds enterprise-level agentic workflows that enable cross-functional coordination by large language modes (LLMs). Only once departmental data and tools are AI-callable can multi-agent systems based on LLMs operate effectively. Within a defined Eco-design logic and rule framework, agents can automatically access tools and databases across R&D, manufacturing, supply chains, and recycling, forming an end-to-end Eco-design orchestration capability. Beyond this, agents can invoke existing simulation tools, process databases, quality records, and supply chain systems across functions, transforming Eco-design analysis and decision-making from manual integration into automated and continuous workflows. After product objectives and constraints are defined, LLM-based agentic systems can generate design pathways, experimental options, and supply chain scenarios, with engineers responsible for judgment, validation, and final confirmation. Designers are thus released from repetitive data integration and computation tasks, allowing them to focus on critical decisions, boundary checks, and final validation.

Through the development of a digital- and intelligence-enabled eco-design technology framework, enterprises can build a coherent capability system that evolves from "tools being callable by AI" to "processes being orchestrated by intelligent agents." This enables eco-design to truly exhibit the characteristics of being forward-looking, multi-objective, embeddable, integratively feasible, and scalable. Against the backdrop of accelerating regulations, increasing product complexity, and expanding lifecycle responsibilities, this technology framework will become a critical enabler for enterprises to sustain eco-design practices over the long term.

Structural Bottlenecks in the Eco-Design Technology System

Eco-design has rapidly shifted from "concept advocacy" to "mandatory requirements," but most companies' design systems have yet to complete this transition. Due to limitations in data foundations, tool systems, and engineering methods, existing Eco-design practices still rely on expert experience, with minimal improvements after evaluations. As a result, Eco-design has struggled to truly integrate into the design process, remaining far from being computable, replicable, and scalable.

The main breakthroughs in the next five to ten years will not lie in a specific tool or algorithm, but rather in a comprehensive shift in design paradigms. AI-generated Eco-design assistive tools will automate parts of the process, facilitating life cycle assessments, material selection, and ecological risk identification. This will move the field from post-design validation analysis to "accompanying computation" throughout the entire design process, turning eco-performance into a fundamental constraint that exists alongside cost, performance, and safety during real-time solution generation and parameter optimization. Additionally, Eco-design will shift from product-oriented optimization to a system-level, industry-level, and multi-scenario collaborative framework, expanding eco-performance from individual products to the complete results of final product portfolios, operational strategies, application scenarios, and environmental contexts.

Furthermore, traditional models that rely on static standards and stable assumptions are gradually becoming ineffective. In the future, Eco-design will evolve into a dynamic adaptive system based on real-time data and environmental feedback, becoming a key system capability in the green transformation of enterprises.

—— Yutao WANG, Professor, Department of Environmental Science and Engineering, Fudan University

Next-Generation Technology Paradigm for Eco-Design

"AI for Science" and "AI for Design" will play a crucial role in the development trajectory of ecological upgrade technologies over the next 5-10 years, ultimately leading to technological breakthroughs in "product ecosystem digital twins and AI collaborative design." This has already been reflected in material selection, research, and design, and will likely be embodied in Eco-design at a more macro scale in the future. Such technological platforms will not be single-point tools but will integrate multi-source ecological data (such as geographic information, resource flows, carbon footprint chains) into intelligent systems embedded within the design process. These systems will include dynamic data infrastructures, AI-assisted decision-making, and system-level coupling optimization, transforming Eco-design from a "compliance tool" to a core engineering capability that drives product innovation and systemic emission reductions. Ultimately, the system will become computable, replicable, and scalable.

—— Dongfeng GAO, Professor, School of Urban and Environmental Sciences, Peking University

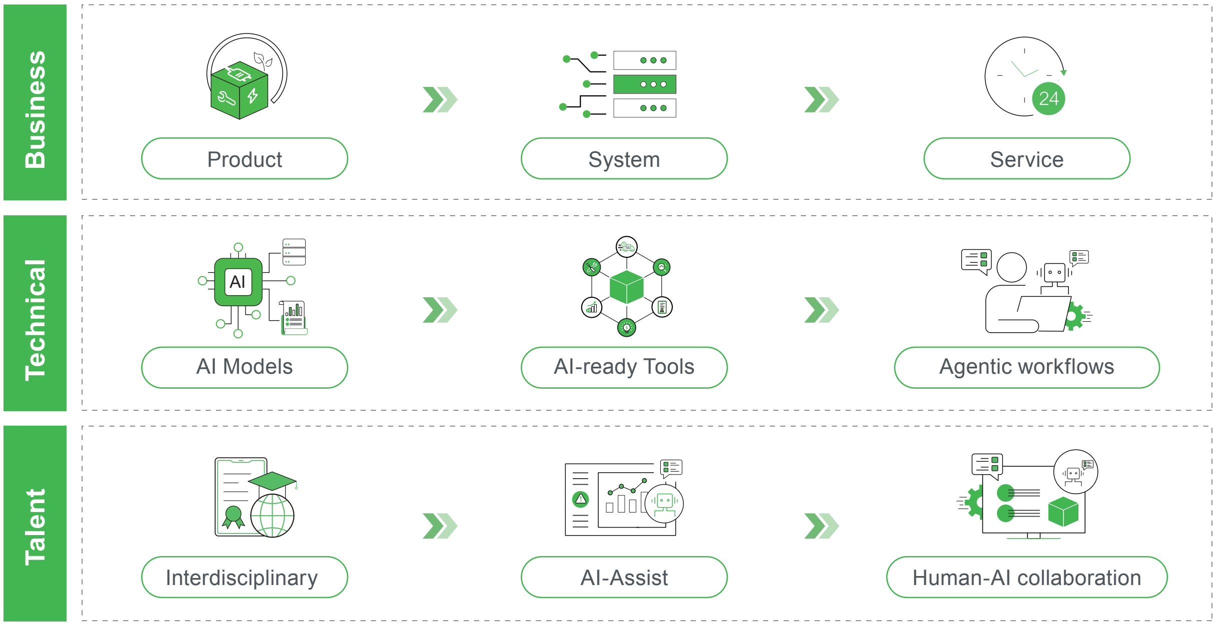
5.2.3 Talent System: From Interdisciplinary Basics to AI Collaboration

As Eco-design becomes more data-driven and system-wide, talent requirements shift from single-discipline engineering to decision roles that combine environmental understanding, engineering logic, and AI applications. Tools and platforms alone are not sufficient. Eco-design depends on people who can define constraints, judge trade-offs, and validate results as AI systems participate in routine analysis.

A core interdisciplinary foundation remains essential. Eco-design requires understanding how material choices affect environmental impact, how structures influence system performance, how process routes drive energy use, and how impacts shift across lifecycle stages. These mechanisms cannot be inferred reliably by models alone. AI-generated options and predictions still require expert judgment to check boundaries, test assumptions, and detect unintended impact shifts.

At the same time, Eco-design increasingly relies on data and models. Companies need talent that understands how environmental data is generated, how models translate design parameters into results, and where uncertainty enters the analysis. This includes managing data quality, interpreting model outputs, and recognizing sensitivity and limits. Without this capability, quantitative results cannot support real design decisions.

As intelligent agents become part of daily workflows, teams must also know how to work with AI. This means defining questions in computable terms, structuring inputs, and verifying outputs against engineering and environmental logic. Human roles focus on setting objectives, constraining solution space, identifying bias or risk, and approving final decisions. In this setup, AI supports analysis and coordination, while responsibility and judgment remain with people.



（ Figure 11 ）Outlook of China's Eco-Design

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