

THE AWAKENING OF THE FORCE

HOW INFRASTRUCTURE STAKEHOLDERS CAN TURN TRANSITION AMBITIONS INTO REALITY, STRENGTHENING EUROPE'S LONG TERM COMPETITIVENESS, SOVEREIGNTY AND RESILIENCE

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A leading Think Tank for the infrastructure sector, InfraVision was created in March 2024, leveraging on four years of research, and is now open to all stakeholders. For companies, investors and individuals looking to strengthen the position of the infrastructure asset class as a building block of the society of tomorrow.

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FOREWORD

Infrastructure investment is an exercise in long-term responsibility. The assets we finance provide services on which communities depend every day, while the decisions taken around them shape economic and social outcomes for decades. At Vauban Infrastructure Partners, we therefore approach infrastructure not only as an asset class, but as a set of essential systems with lasting public consequences. This perspective requires us to consider how these systems can continue to serve communities as their needs, constraints and operating environments change.

Created in 2024, InfraVision was designed as a platform through which the infrastructure ecosystem could share knowledge, confront perspectives and anticipate the forces reshaping the sector. In 2026, it entered a new stage of development. Its community now includes 39 corporate members from across the infrastructure value chain, together with public authorities, academics and other contributors. This expansion strengthens its ability to connect research with operational experience and to examine infrastructure challenges across sectors rather than from the standpoint of a single asset or institution. By widening its membership, InfraVision also creates a common forum for issues that no participant can address alone.

This year's program focuses on the critical role of infrastructure in enabling Europe's major transitions, particularly the environmental and digital transformations. How Europe develops, upgrades and operates its infrastructure will have far-reaching implications for its competitiveness, resilience and sovereignty, shaping its ability to deliver these transitions while maintaining reliable and affordable essential services. Drawing on contributions from experts and infrastructure stakeholders, this report examines how Europe can translate its transition ambitions into effective delivery. It explores how policy objectives interact with the physical networks, institutional frameworks, capital and capabilities required to transform complex infrastructure systems at the necessary scale and pace.

InfraVision's development is also reflected in its 2026 student competition, "Designing infrastructure systems under uncertainty". Students from different disciplines were invited to design projects able to withstand changes in demand, technology, regulation and resource availability, rather than optimize them for a single forecast. The competition received 89 submissions from 75 institutions representing 32 countries. We are pleased to present the three laureates in this report and to share the perspectives of a generation that will inherit, operate and continue to transform the systems being designed today.

Gwenola Chambon,
Co-founder and CEO of Vauban Infrastructure Partners, and President of InfraVision

EXECUTIVE SUMMARY

Every major economic transformation has been built on infrastructure. Canals, railways, electricity grids, roads and telecommunications networks did more than support successive waves of development: t**hey turned new technologies and economic possibilities into systems that could operate at scale**, shaping where transformation occurred, how quickly it spread and how widely its benefits were shared.

Today, i**nfrastructure must perform that role under great pressure.** Europe is simultaneously managing the energy and ecological transitions, digitalization, economic resilience, social dynamics and renewed strategic autonomy. While these transformations have different drivers and objectives, **they are increasingly interdependent:** progress in one often depends on progress in the others. Together, they are placing new and overlapping demands on the networks, assets and capabilities on which Europe's economy depends.

In this context, **infrastructure has become a decisive factor in Europe's ability to deliver.** Its availability, quality and resilience will determine how quickly new industries can scale, where investment flows and whether the benefits of transformation are broadly shared. New technologies and investment projects increasingly depend on access to grids, connections, permits and effective institutional coordination. Yet Europe must expand and modernize an **infrastructure base that is already aging, congested, increasingly exposed to climate and geopolitical risks,** and insufficient to meet future demand.

Infrastructure is therefore both an i**nvestment imperative and a strategic economic opportunity.** Europe needs more infrastructure, better infrastructure and, critically, better-chosen infrastructure – not only to enable its transitions, but also to capture the economic value they create. **Clean energy illustrates the scale of that opportunity:** the global market for selected clean-energy technologies reached around $1.2 trillion in 2025 and could approach $2 trillion under current policies, or nearly $3 trillion under stated policies, by 2035.

The energy and environmental transition brings this infrastructure imperative into its sharpest focus. Europe must reshape capital-intensive, long-lived systems at unprecedented scale and speed, while adapting them to a changing climate and preserving the affordability and reliability of essential services. This challenge is compounded by the **growing interdependence of the green and digital transitions.** Digital technologies are becoming critical to decarbonizing and optimizing power systems, transport, buildings and industry, while their rapid expansion is itself increasing demand for electricity, network capacity and critical resources. Finally, Europe must deliver the green transition **in a way that strengthens competitiveness, resilience and sovereignty** – ensuring infrastructure can withstand future shocks while limiting new technological and supply-chain dependencies.

Under these conditions, **the relevant risk is no longer simply the cost of inaction, but also the cost of the wrong action.** Infrastructure choices made today shape systems – and constrain future choices – for decades. Moving too slowly can perpetuate carbon-intensive configurations and increase future adaptation costs; moving too quickly in the wrong direction can lock capital into immature technologies, create stranded or redundant assets, undermine affordability, or replace one strategic dependency with another. In a context of constrained public finances and intense global competition for capital, technology and industrial capabilities, **Europe has limited room for misallocation.**

The relevant question is therefore not simply whether investment takes place, or even how quickly, but w**hether it takes place in a configuration capable of surviving technological, economic and political change.** Transition targets provide direction, coordinate expectations and express collective ambition, but they cannot determine decades in advance which technology will prevail, how quickly adoption will occur, which infrastructure must come first or when incumbent assets can safely be retired. **A robust pathway keeps the destination clear** while allowing technology, pace, sequence and the evidence for retirement to adjust as conditions become observable, while remaining consistent with interim climate objectives and cumulative-emissions constraints.

The implication is neither to wait until uncertainty disappears nor to accelerate indiscriminately. **The most relevant approach is 'governed acceleration':** move decisively where direction is durable and solutions are deployable; sequence commitment as evidence accumulates; integrate assets into the systems that make them useful; allocate risks to those able to manage them; and preserve optionality where uncertainty remains material.

For capital allocation, three conclusions follow:

- **Commitment should grow with proof.** The scale and irreversibility of investment should increase as uncertainty is converted into evidence. New capacity creates value only when the interfaces on which it depends are ready, and incumbent assets can be withdrawn only when the functions they still perform have demonstrably been replaced.

- **Sequence matters as much as destination.** Bottlenecks move as systems transform. Investing ahead of the weakest interface can strand capacity; withdrawing an incumbent service before its replacement is ready can undermine the transition itself. Speed comes from resolving constraints in the right order, not from accelerating every component simultaneously.

- **Delivery must remain economically and politically bearable.** A technically viable pathway can still fail if its costs become concentrated on users, territories or institutions unable to sustain them. Distributional choices and public acceptance are therefore part of delivery, not considerations that arise after the technical solution has been selected.

This calls for a **shift from target-setting to pathway design:** prioritizing mature and compatible solutions where deployment can begin now, preserving optionality where uncertainty remains high, and adapting investment as technologies, constraints and system needs evolve. The quality of the pathway, as much as the ambition of the destination, will determine whether the environmental transition strengthens or erodes Europe's competitiveness and sovereignty.

Getting the sequence right, however, requires **looking beyond individual assets to the systems in which they operate.** An infrastructure asset maximizes value-creation within the configuration that makes its service usable, paid for and institutionally permissible. Electrified mobility depends on vehicles, charging and electricity networks; low-carbon heat on production, networks, buildings and users; digital infrastructure increasingly on reliable power and connectivity as much as computing capacity. A technically successful asset can therefore fail economically if the system around it cannot absorb it – and a relatively modest investment in a grid, interface, standard or operating model can unlock value far beyond the asset itself.

This shifts the relevant unit of analysis from the individual asset to the 'infrasystem'. Three principles follow for investment and deployment:

- **Assess the system, not only the asset, and promote coordination.** Physical interfaces, revenue models, institutional responsibilities, users and territories need to work together. Coordination can unlock value through shared capacity, coupled resource flows, replication and common skills, but every additional connection also creates a dependency. Coordination should create value net of the risks introduced by interdependence, while tariffs, contracts or payment mechanisms must allow the enabling assets to capture enough of that value to attract financing.

- **Select for deployability, not novelty.** Technical readiness is necessary but insufficient. A solution may perform technologically and still fail to scale because networks cannot accommodate it, institutions cannot authorize it, financing arrangements cannot support it or users and territories cannot absorb it. **Deployment maturity matters as much as technological performance:** the strongest solutions are those that can be integrated, replicated and scaled while preserving valuable future options.

- **Make rules and residual risks investable.** Price signals remain essential but cannot alone address biodiversity loss and ecosystem degradation; public policy, standards and regulation also shape deployment, the treatment of committed assets and the risks private capital is expected to carry. **Long-lived investors need stable and predictable regulatory frameworks** to understand how different policies affecting the same economic equation will interact. Nor must uncertainty disappear: what remains should be made legible across contracts, regulation and financing, with the event identifiable, the bearer named, exposure capped, adjustment defined and responsibility clearly transferred. **Physical and transition climate risks should be assessed, reduced where possible and allocated to actors with the capacity to manage or absorb the remaining exposure.**

This is where Europe can turn an apparent constraint into an advantage as it combines deep pools of long-term savings with experienced infrastructure operators and investors, mature regulatory institutions, extensive capabilities in concessions and risk allocation, and a large integrated market. Its challenge is not simply to mobilize more capital, **but to create the conditions under which capital can be committed faster, more coherently and to the configurations that create the greatest long-term system value.**

The environmental transition therefore does not simply increase the need for infrastructure capital; it increases **the value of disciplined capital allocation.** Public authorities provide durable direction and credible rules; operators identify how systems perform and where constraints are moving; investors test whether the pathway, surrounding infrasystem and residual risks are sufficiently robust for long-term commitment. **None can solve the equation alone.**

This report explores the conditions under which the 'infrastructure force' can be successfully mobilized to make current transitions – in particular the environmental one – deliverable, investable and durable – while strengthening the competitiveness, resilience and sovereignty of the economies it serves.



METHODOLOGY

This report offers a forward-looking perspective on the role of infrastructure in advancing Europe's environmental and energy transitions while reinforcing its competitiveness, sovereignty and resilience. It examines these challenges in the context of broader digital, demographic, social and geopolitical transformations, with a focus on long-term investment decisions and the affordability and continuity of essential services. Sponsored by Vauban IP, the study was developed with InfraVision members and key stakeholders, in collaboration with Altermind and international academic experts

A series of events was organized to gather insights and perspectives:

- **An inaugural webinar** titled "The Awakening of the Force: how infrastructure can be a major lever to achieve the required transitions", moderated by Laurene Mahon (Former Vice Chair, CIBC Capital Markets), featuring a keynote by Mika Aaltola (Member of the European Parliament); a master class by Hazal Kaya (Researcher at Delft University of Technology) on infrastructure in transitions and the design of systemic change; and a fireside chat on infrastructure, competitiveness and influence in complex environments with Roland Kupers (Senior Research Fellow, University of Amsterdam) and Anna Creti (Professor at Université Paris Dauphine-PSL);

- **A breakfast panel** titled "Infrastructure for Sovereignty", opened by Roland Lescure (French Minister for the Economy, Finance and Sovereignty). Moderated by Julia Sieger, the discussion featured Gabriele Todesca (European Investment Fund), Nicolas Notebaert (VINCI Concessions), Anne-Christine Champion (Société Générale) and Thomas Reynaud (Groupe iliad), with a contribution from Didem Nisanci (Senior Fellow, Global Climate Policy Project, Harvard University and MIT) and a closing keynote by Susanne Nies (Helmholtz-Zentrum Berlin);

- **A series of three podcasts** titled "The Awakening of the Force", exploring the conditions for delivering sustainable infrastructure at scale and pace through three lenses:

- *Delivering sustainable infrastructure at scale and pace*: the first episode, hosted by Charlotte Kan (International Journalist and Moderator), examines what it takes to close the gap between ambition and delivery, with Roseline Legrand (Director of Concessions at Bouygues Construction) and Vincent Cuvillier (Chief Strategy Officer at Cellnex);

- *Trade-offs, risk dynamics and incentives:* the second episode, hosted by Julia Sieger (Broadcast Journalist and Moderator), explores how risks can be allocated and incentives aligned across stakeholders, with Ana Giros (Executive Vice President Strategy, Development and CSR at Equans) and Mike Nowak (Global Head of Infrastructure Coverage at Crédit Agricole CIB);

- *Incentives for infrastructure delivery*: the final episode, hosted by Aude Kersulec (Economic Journalist and Moderator), focuses on the incentives that make solutions replicable at scale, with Diego Marin (CEO of ACCIONA's Concessions Business) and Emanuela Trentin (CEO of Veolia Italy).

The analysis connects these sources across four issues: the infrastructure requirements of Europe's transitions; the design and sequencing of transition pathways; coordination, regulation and risk allocation within infrastructure systems; and the selection, integration and scaling of innovation. Throughout, assets are assessed in relation to the networks, institutions, financing arrangements, users and territories on which their performance depends. This approach supports a practical assessment of what makes infrastructure deliverable, investable and capable of retaining value under changing conditions.

In 2026, InfraVision also organized the second edition of its student competition, "Designing infrastructure systems under uncertainty", inspired by the theme "Infrastructure as a System". Multidisciplinary student teams from around the world were invited to design infrastructure projects able to withstand changes in demand, technology, regulation and resource availability, and to examine their performance across contrasting future scenarios. The competition received 89 entries from 32 countries; the winning projects, selected by a jury of experts led by architect Sadie Morgan, are presented in this report.

SUMMARY

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THE INFRASTRUCTURE IMPERATIVE: THE STRATEGIC ASSET TO SUPPORT EUROPE'S AMBITIONS, COMPETITIVENESS AND SOVEREIGNTY

Key takeaways

→ Infrastructure is the common operating system of five transitions unfolding simultaneously. Environmental, digital, demographic, social and geopolitical change are deeply interconnected, but they all ultimately depend on physical networks and the institutions, capital and capabilities surrounding them.

→ Infrastructure has become the common rate-limiter of transition. The constraint is increasingly not technological ambition or even capital availability, but the ability to permit, reinforce, connect and operate networks. Grid-connection queues and lengthening waits for power supply increasingly constrain renewable deployment and data center development. The speed of infrastructure delivery increasingly sets the speed of economic transformation.

→ The environmental transition is the sternest test because it combines unprecedented scale, a physical deadline and irreversible delay. Unlike the other transitions, decarbonization must transform an energy system accumulated over two centuries within a single generation, against a finite carbon budget. And unlike previous energy transitions, it cannot simply add a superior technology: it requires the deliberate retirement of functioning incumbent assets.

→ Markets cannot price the environmental transition into existence. Carbon is unusually amenable to pricing because it has a common unit; much of nature does not. Biodiversity and ecosystems combine uncertainty, non-linearity, irreversibility and non-fungibility, making a single monetary signal structurally insufficient. Successful transition policy therefore requires a broader architecture of prices, standards, quantities, regulation and public decision-making.

→ Europe faces a double infrastructure deficit: it needs more assets, better ones – and better chosen. The Draghi report estimates additional annual investment needs of €750–800bn across Europe's wider competitiveness agenda, including innovation, decarbonization and defense. Infrastructure is a major component of that agenda, while the existing asset base is aging, congested and increasingly exposed: 40% of EU distribution grids are over 40 years old. In mature networks, the highest marginal returns often lie less in adding standalone capacity than in removing systemic constraints through maintenance, modernization, interconnection and resilience – the next euro should go where it unlocks the greatest system value.

→ Across major economies, the environmental transition has become an industrial and strategic contest as much as a climate policy: China has made clean technologies a pillar of its growth model, while US support has combined large fiscal incentives with subsequent policy reversals. For Europe the stakes are sharpest: clean technologies are becoming a multi-trillion-dollar market, but China already dominates several key manufacturing and processing chains while European energy costs remain substantially above US levels. Europe therefore faces a double imperative: build the infrastructure needed to decarbonize, and capture enough of the associated industrial value, and strategic capabilities to avoid replacing fossil-fuel dependence with technological dependence.

More and better infrastructure to deliver the "transitions"

Infrastructure systems: the one substrate of all transitions

FIVE TRANSITIONS, ALL INTERCONNECTED

Since the late twentieth century, the world economy has entered a period in which five structural transitions have been unfolding simultaneously. This report refers to them throughout as the five transitions:

The environmental transition: the shift to low-carbon energy, resource-efficient production and ecological uses, with a physical carbon and biodiversity constraint;

The digital transition: the diffusion of connectivity, data and computing power as a layer that increasingly conditions how every other system operates;

The demographic transition: diverging population trajectories, rapid growth and urbanization across much of the developing world, aging in advanced and emerging economies, and the migrations between them;

The social transition: the recomposition of work, skills and living standards, and widening demands for access to essential services, housing, health, water and mobility;

The geopolitical transition: the fragmentation of trade, technology and security blocs, which re-prices dependence and rewards strategic autonomy.

Each follows its own imperative, but their concurrence produces change that is non-linear, accelerated and volatile, with feedback loops that can amplify both risks and benefits. These interactions are extensive and complex, most are coupled, amplifying or obstructing depending on how they are governed.

A few illustrations show the mechanism at work, taking each of the five transitions in turn as the point of entry:

- Decarbonization is a system rebuild before it is a fuel switch: electrifying transport, heating and industry requires adding or replacing some 80 million kilometers of power lines by 2040[1], the equivalent of rebuilding the entire existing global grid in fifteen years, and claims capital, land, materials and skills from every other transition.

- Access to advanced models and computing power now determines national innovation capacity, making computing a factor of sovereignty; applied AI can support climate mitigation and adaptation – the IEA estimates that widespread adoption of existing applications could cut emissions by some 1.4Gt CO_2 in 2035, around 2.6% of today's global total – yet its expansion claims growing quantities of electricity, water, land and critical materials.

- Warming falls hardest on aging societies. Heat-related mortality among the over-65s has risen by some 85% since the early 2000s, heat caused an estimated annual average of 546,000 deaths worldwide over 2012–2021, and by 2050 more than 23% of the world's population aged over 69 will live in climates of acute heat exposure, against 14% in 2020;

- Climate-related migration links three transitions at once as migrants can support economies facing demographic decline while creating political and social tensions at national and international levels[2]. Displacement produces secondary population effects that alter demographic trajectories themselves: modeling US counties through 2100, Hauer et al. estimate a 5.3–18-fold amplification of demographic change relative to direct sea-level-rise displacement alone, including changes in population size and age structure rather than additional migrants only[3].

The critical materials of the digital and environmental transitions are geopolitically concentrated: China was the

1 - IEA, *Electricity Grids and Secure Energy Transitions*, 2023.

2 -Karim and Jannati, *Climate-Induced Migration and Its Threat to National Security: Implications for Regional Stability and Geopolitics in South Asia*, 2025.

3 - Hauer M. E. et al., "Climate migration amplifies demographic change and population aging", *Proceedings of the National Academy of Sciences*, 121(3), 2024.

leading refiner for 19 of the 20 minerals analyzed by the IEA in 2025, with an average market share of around 70%, and the market share of the top three refining nations rose to 86% in 2024[4]. The 2025 Chinese export controls on rare earths and battery materials forced carmakers in the US and Europe to cut output within weeks. The IMF estimates that a fragmentation of critical-minerals trade between blocs would leave investment in renewables and electric vehicles as much as 30% lower by 2030 than in an integrated world[5].

These five illustrations carry two lessons.

- The first is that couplings work in both directions: they can accelerate a transition as well as obstruct it. Russia's invasion of Ukraine produced, through REPowerEU, a rapid reframing of European climate policy, with renewables recast as instruments of sovereignty and the Russian share of EU gas imports cut from 45% in 2021 to 12% in 2025[6].

- The second is that, however different their logics, the couplings all converge on the same material base. Ports, logistics corridors, energy interconnections, subsea cables and computing facilities are increasingly treated as instruments of strategic autonomy as much as economic assets: some 500 active subsea cables carry an estimated 99% of intercontinental data traffic and over $10tn of financial transactions daily, turning commercial infrastructure into contested terrain; above the physical layer, semiconductor export controls are splitting the digital world into two technological ecosystems with distinct hardware, software and regulatory philosophies[7] – a fragmentation driven entirely by the geopolitical transition. Where the transitions meet, they meet in infrastructure.

- These interdependencies can be orchestrated as they depend heavily on institutional settings, governance choices, distributional dynamics, and power relations within organizations and in society.

DIGITALIZATION AND CLIMATE TRANSITION: A TWIN TRANSITION

Among the five, the digital and environmental transitions are increasingly approached as a twin transition. They remain distinct in their objectives, investment requirements and capital cycles, but their delivery has become closely interconnected. Digital capabilities can help balance grids, organize mobility, steer industrial decarbonization and deliver public services, while environmental constraints increasingly shape how digital infrastructure is powered, located and expanded.

This interdependence does not make digitalization the operating layer of every transition, nor does it make its benefits automatic. Digital systems consume electricity, water, land and critical materials, while efficiency gains can be offset by rising demand through rebound effects[8]. The environmental transition therefore remains the wider physical frame: it defines the resource constraints and externalities within which digitalization, like the other transitions, must develop.

European institutions have drawn this conclusion, treating the environmental and digital transitions as mutually reinforcing rather than independent policy agendas[9], while the OECD's Twin Transition Tracker assesses territorial resilience through their combined performance[10].

EXPERT POSITION 1

Thomas Reynaud – Digital infrastructure: a question of values and sovereignty

"When discussing digital infrastructure, Europe is often misdiagnosed. The continent is not lagging behind in connectivity. On the contrary, it has developed some of the world's most advanced fiber and telecom networks, with affordable services, and it is home to major industrial players such as Ericsson and Nokia. The real mismatch lies elsewhere. Europe performs well in data transport, but it struggles to create value from it. Today, it remains heavily dependent on the US and China for the new layers of digital infrastructure: computing power, GPUs, AI platforms, and data centers.

This dependency is becoming a vulnerability, not only for competitiveness, but for the way information is accessed, processed, and protected. A large share of cloud services remains operated by non-European actors, exposing organizations to extra-European legislation and limiting Europe's ability to shape its own digital future. As AI becomes increasingly central to economic and industrial activity, control over digital infrastructure is also becoming a question of values and sovereignty."



Thomas Reynaud
CEO of iliad Group

4 - IEA, *Global Critical Minerals Outlook 2025*, 2025; IEA, *Global Critical Minerals Outlook* 2026, 2026.

5 - IMF, *World Economic Outlook: Navigating Global Divergences*, 2023.

6 - European Commission, *REPowerEU – 4 Years On*, 2026.

7 - Miller C., *Chip War: The Fight for the World's Most Critical Technology*, 2022.

8 - IEA, *Digitalisation and Energy*, 2017; IEA, *Energy and AI*, 2025.

9 - De Hert and Hinrichs, *The EU Twin Transition: Comparing Form and Substance of the Regulatory Approaches*, 2026.

10 -OECD, *Twin Transition Tracker: Assessing Regional Resilience*, 2024.11 -

CASE STUDY 1

iliad Group: Scaleway/Qarnot, succeeding in the twin transition (green & digital)

S —

Scaleway is the cloud subsidiary of French telecommunications group iliad, providing cloud, AI and high-performance computing services from nine data centers powered entirely by low carbon energy. Headquartered in Paris, with infrastructure already in place in France, Poland, Italy, and Amsterdam, and an expansion into Sweden and Germany in the coming months, the company serves over 25,000 businesses across 160 countries, including French Health Data Hub, the European Commission, and more recently LVMH, Maif or Airbus.

Scaleway operates solely under European jurisdiction and is fully European-owned, offering immunity from extraterritorial laws such as the US Cloud Act, with all data localized in Europe. In April 2026, it was selected as one of four cloud providers under the European Commission's Cloud III Dynamic Purchasing System, a €180m framework giving EU institutions access to sovereign cloud services over six years.

In July 2026, Scaleway acquired Qarnot, a French specialist in high-performance computing (HPC) for engineering, simulation and research workloads. HPC has become one of the fastest-growing segments of cloud demand, driven by industrial and financial clients running complex simulations – Qarnot's customers include MaiaSpace, Alpine Racing and Natixis – and the acquisition brings cloud, AI and dedicated HPC together within Scaleway's European platform. The same asset carries an energy dividend: Qarnot's patented direct liquid-cooling technology recovers up to 95% of the heat produced by servers and redirects it into district heating networks, public facilities and industrial sites – making the electricity that computing cannot avoid consuming, in the words of Scaleway's CEO, "create value twice"[11]. For instance, the model has been deployed in Brescia, Italy where HPC infrastructure is connected to the city's heating network in partnership with local utility A2A.

The acquisition builds on Scaleway's environmental performance: a Power Usage Effectiveness of 1.37 in 2024, compared with an industry average of 1.55, and the Transformers program, which has refurbished nearly 15,000 servers and extended their lifespan to up to 10 years, against 5 to 6 years for the rest of the industry.

11 - Scaleway, *Scaleway Acquires Qarnot, Adding Low-Carbon HPC to its European Cloud & AI Platform, press release, 10 July 2026*; Silicon Republic, *French Cloud Firm Scaleway Acquires HPC Provider Qarnot*, 10 July 2026.



AN INFRASTRUCTURE FORCE SETTING THE PACE AND THE SCALE

All five transitions run through the same physical substrate: infrastructure. Infrastructure networks determine whether new technologies, production models and patterns of consumption can move beyond isolated applications and reshape the system at scale. Each transition, whatever its imperative, materializes through integrated and interdependent systems: decarbonization through grids, interconnectors and charging corridors; digitalization through data centers, fiber and subsea cables; social and demographic change through water, housing, health and mobility systems.

This shared substrate is more than a logistical coincidence. Economic theory has long recognized that infrastructure differs from other capital in that its value lies in the spillovers it generates across every activity built upon it[12]. Anthropology reaches the same conclusion from the other direction: infrastructure is the form through which societies project and imagine their collective future[13]. The substrate, in other words, is never neutral: it shapes what passes through it.

This is why infrastructure should be understood not simply as a stock of physical assets, but as a force: the assembled capacity of assets, capital, skills, institutions and operating capabilities required to deliver a service and transform a system. A grid without the capital to reinforce it, a railway without the skills to operate it, or a fiber network without the institutions capable of coordinating deployment does not constitute the same force.

Once mobilized, this force has a transformative reach far beyond the infrastructure sector itself. When a new technology is integrated into a network, it does not simply add capacity: it triggers a process of co-evolution in which technical choices reshape behaviors, markets and institutions in turn[14] – the deployment of charging networks alters vehicle purchases, which changes load patterns, which forces tariff and market redesign. The breadth of this influence is measurable: UNOPS estimates that infrastructure conditions the achievement of 92% of the 169 targets underpinning the SDGs[15].

Symmetrically, a shock to one infrastructure asset rarely stays isolated – it ripples through electricity, transport, water and communications alike[16]. In low- and middle-income countries, the direct and indirect costs of these disruptions for households and firms amount to an estimated USD390bn per year. Power outages give a contemporary measure of this dependence at every level of development: the Iberian blackout of 28 April 2025 cost Spain an estimated 0.02% of GDP in a single day (Case Study 2), while load-shedding cost South Africa an estimated 1% to 3% of GDP in 2022 according to the national central bank[17].

12 - Frischmann B. M., *Infrastructure: The Social Value of Shared Resources*, 2012.

13 - Larkin B., "The Politics and Poetics of Infrastructure", *Annual Review of Anthropology*, 42, 2013, pp. 327–343.

14 - Foxon T. J., "A Coevolutionary Framework for Analysing a Transition to a Sustainable Low Carbon Economy", *Ecological Economics*, 70(12), 2011, pp. 2258–2267.

15 - UNOPS, *Infrastructure Underpinning Sustainable Development*, 2019.

16 - Hallegatte S. et al., *Lifelines, World Bank*, 2019.

17 - CaixaBank Research, 2025; Van Rensburg and Morema, *South African Reserve Bank*, 2023.

18 - ENTSO-E, Final Report on the 28 April 2025 Blackout in Spain and Portugal, 20 March 2026

CASE STUDY 2

Cellnex: Infrastructure resilience, the example of the Iberian blackout

As extreme weather events and grid disruptions become more frequent, long-life infrastructure resilience is becoming a central concern. Cellnex, Europe's largest independent operator of wireless telecommunications infrastructure, experienced this directly during the Iberian blackout on April 28, 2025.

Cellnex's critical broadcast and emergency networks remained operational. From its Torrespaña site in Madrid, the company maintained public radio, television broadcasting, as well as emergency communications, keeping citizens informed and response teams connected throughout the outage. While much of the consumer network relied on short-duration batteries, these critical sites were supported by a more robust combination of batteries, generators and alternative energy-supply arrangements put in place through earlier investment.

This event accelerated Cellnex's resilience investments. In January 2026, Cellnex and Telefónica agreed to equip over 2,000 mobile sites in Spain with batteries and generators. The program expanded in July 2026 to 3,800 sites, scheduled for completion by June 2027, each guarantees at least two hours of power autonomy. The equipment is provided under an "Energy as a Service" model, in which Cellnex owns, installs and maintains the backup systems.

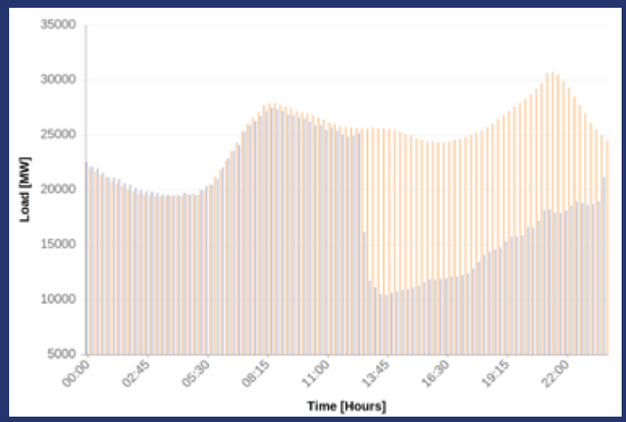
The same resilience thinking is being applied more widely. Cellnex is developing a "Battery as a Service" model to use site batteries to help stabilize the electricity grid. In July 2026, Cellnex Netherlands partnered with the Netherlands Red Cross to create a nationwide emergency communications network, making its infrastructure available for the Red Cross's crisis-response equipment so that responders stay reachable across regions during floods, prolonged outages, and other large-scale emergencies. Through these initiatives, resilience is shifting from a post-crisis repair to a core design and investment criterion, highlighting its role as a strategic priority rather than a reactive fix.

Asset-level resilience and system-level reliability are complementary. Batteries and generators preserve service during an outage, while suitably equipped assets can also provide grid services. They do not remove the need for effective system-wide voltage and reactive-power control. ENTSO-E's final investigation into the April 2025 Iberian blackout identified interacting failures involving oscillations, voltage regulation and generation disconnections[18]. The lesson is to secure both continuity at critical sites and the operating capabilities that keep the wider electricity system stable.

FIGURE 1

Total load in Spain (day-ahead total load forecast vs actual total load) on 28 April 2025

Source: ENTSO-E transparency platform.



Because infrastructure is durable, capital-intensive and embedded in technical and institutional systems, it sets the ceiling on the pace and scale of all transitions:

Electricity grids have become the main bottleneck to renewable integration: more than 2,500 GW of renewable, storage and large-load projects are stalled in grid connection queues worldwide[19];

The "time-to-power" for a new American data center has stretched from about one year to more than seven within three years[20], while the unit cost of delivering large-scale grid infrastructure has risen roughly sixfold since the last major build-out, driven by permitting delays, labor constraints and supply-chain bottlenecks[21]. For instance, waits reach seven years in Northern Virginia, the world's largest data center market, and Dublin operated under a de facto connection moratorium for years.

A recent study, driven by Hazal Kaya, of grid capacity planning in the Netherlands offers a useful lens for the analysis of infrastructure transitions. It shows how a Distribution System Operator (DSO), as a regulated monopoly, becomes caught between decarbonization pressures and its own entrenched constraints – aging assets, the regulatory duty to guarantee universal access, and the ingrained expectation of unlimited electricity. These lock-ins reinforce one another, producing congestion and delayed investment.

The conclusion is stark: the pace of all five transitions is now set less by technology, capital or political ambition than by the rate at which shared infrastructure can be permitted, financed, connected and built. **Infrastructure is both the backbone of the transitions and their common rate-limiter.**

EXPERT POSITION 2

Hazal Kaya – Infrastructure dynamics: from sectoral assets to systemic bottlenecks

"Infrastructure is increasingly recognized as a strategic asset for Europe, underpinning its competitiveness, sovereignty, and sustainability ambitions. These systems have traditionally been optimized for efficiency and reliability, but sustainability objectives now call for new technologies, circular processes, and cross-sectoral solutions. This creates a growing tension between the scale of the transition required and the realities infrastructure operators face on the ground. Established sustainability pathways often assume that capacity can simply be expanded when needed; in reality, infrastructure systems are already constrained in space, energy, and labor. And despite growing interdependencies between energy, water, transport, and digital systems, infrastructure sectors continue to operate largely in silos."

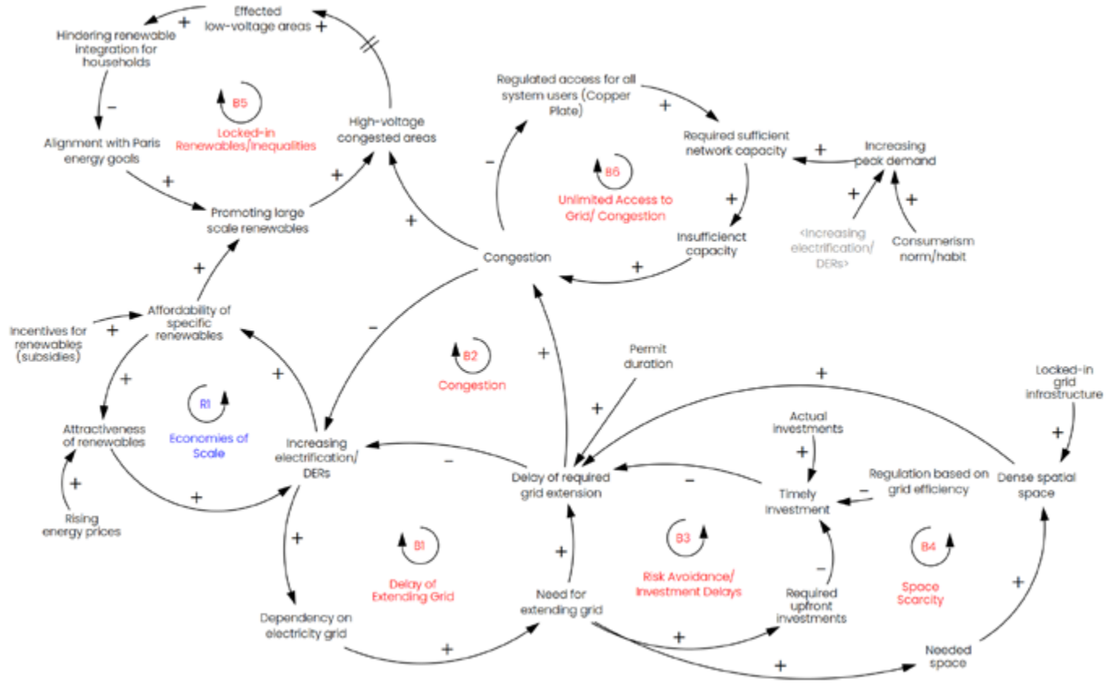


Hazal Kaya
PhD researcher at Delft University of Technology

FIGURE 2

Feedback loops: system dynamics of infrastructure

Source: Kaya et al., 2026



19 - IEA, *Electricity 2026*, 2026.

20 - Blackstone, *2026 Investment Perspectives*, 2026.

21 - BCG, *The Energy Transition's Next Chapter*, 2025.

A double infrastructure deficit to deliver Europe's transition ambitions

INVESTMENT NEEDS ACROSS EUROPE'S COMPETITIVENESS AGENDA: DRAGHI'S €750–800BN ESTIMATE

If infrastructure is the common lever of the transitions, the natural question follows: is Europe's asset base equal to the task? The evidence assembled by the European institutions over the past years points to the conclusion that Europe invests too little in its infrastructure relative to what its own objectives require.

Mario Draghi's 2024 report on the future of European competitiveness estimates additional investment needs of €750–800bn per year, approaching 5% of EU GDP, across innovation, decarbonization, defense and other strategic priorities. This provides a macroeconomic context for the infrastructure needs discussed here, rather than an infrastructure-only financing gap. The ECB separately estimated cumulative strategic investment needs of €5.4tn over 2025–2031; the two aggregates should not be treated as identical measures[22].

These aggregate estimates must be distinguished from sector-specific infrastructure investment.[23] Assessing the infrastructure gap requires comparable definitions, territories and periods, and separate identification of maintenance, modernization and new capacity.[24]

Behind these headline envelopes lies a structural break: after two decades of stagnation, demand for networked services is growing again. European electricity consumption, flat since 2008, is projected to rise by around 20% over the next decade as transport, heating and industry electrify – with demand from electric mobility alone growing at double-digit annual rates[25]. The IEA draws the global consequence: annual grid investment must nearly double to over USD600bn by 2030[26].

Infrastructure demand is also cumulative, because several transitions place overlapping requirements on the same networks. Decarbonization requires grids, interconnectors and storage; digitalization adds data centers, whose global electricity consumption is set to double to around 945 TWh by 2030[27]; and demographic change increases demand for water services. A global estimate cited by the World Bank in 2024 put water-related infrastructure investment needs at USD6.7tn by 2030[28]. In addition, NATO's 2025 Hague commitment gives defense and security a stronger infrastructure dimension: by 2035, Allies are to account for up to 1.5% of GDP annually through broader defense and security-related investment, including critical infrastructure protection, network resilience and civil preparedness[29].

22 - Draghi M., *The Future of European Competitiveness*, 2024; European Central Bank, "Mind the gap: Europe's strategic investment needs and how to support them", 27 June 2024.

23 - Allianz Trade; EIB data, 2024.

24 - EIB, *Investment Report*, 2024.

25 - McKinsey, *Electricity Demand in Europe: Growing or Going?*, 2024; McKinsey, *Four Themes Shaping the Future of the Stormy European Power Market*, 2023; Eurelectric, *Power Barometer 2025: In Shape for the Future*, 2025.

26 - IEA, *Electricity Grids and Secure Energy Transitions*, 2023.

27 - IEA, *Energy and AI*, 2025.

28 - World Bank, "Remarks by Axel van Trotsenburg at the Financing Water Security event", 23 October 2024.

29 - NATO, "The Hague Summit Declaration", 25 June 2025

FIGURE 3

The European infrastructure bill: headline envelopes behind the Union's objectives

Sources: European Commission (Grids Package 2025, TEN-T 2024, HSR Plan 2025, Digital Decade 2025, Military Mobility 2025); Draghi report 2024; ECB 2024

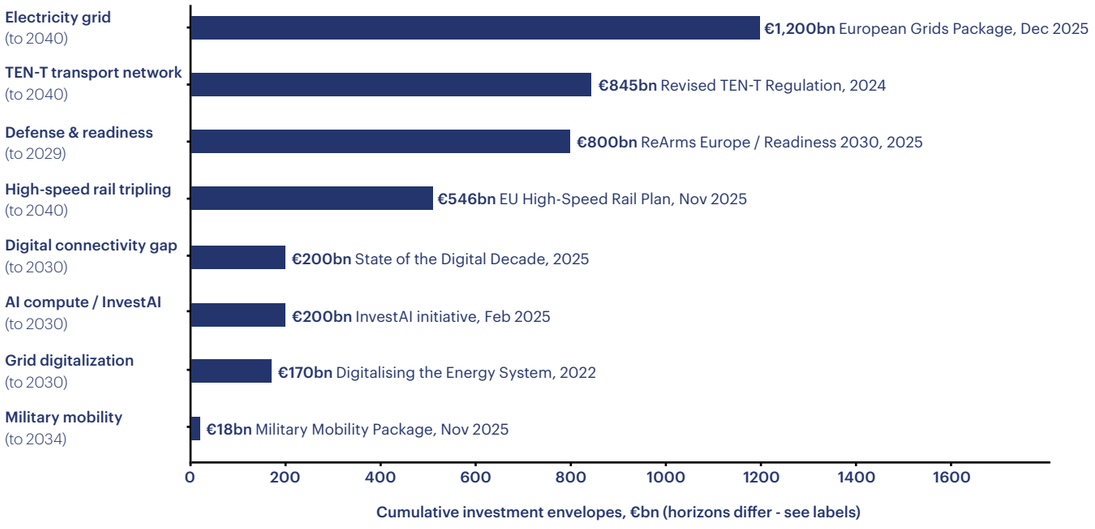
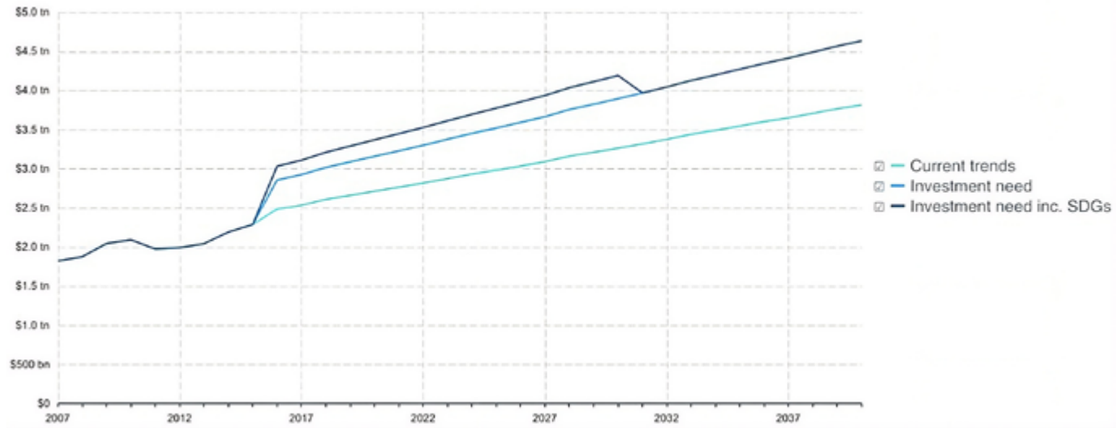


FIGURE 4

Global infrastructure investment: historical estimates and projections to 2040

Source: Global Infrastructure Hub and Oxford Economics, Global Infrastructure Outlook, 2017, with the 2018 country-coverage update.
Note: Annual investment in US dollars at 2015 prices and exchange rates. The additional SDG scenario includes the investment needed to achieve universal access to electricity, water and sanitation by 2030. These are historical projections, not a new forecast produced in 2026.



AN OBSOLETE ASSET BASE: AGING ASSETS, CONGESTION AND EXPOSED NETWORKS

A second deficit concerns the quality of the existing stock. The continent's networks are aging: 40% of EU distribution grids are more than 40 years old, and Eurelectric estimates that annual distribution-grid investment needs to roughly double, funding expansion alongside renewal, resilience and digitalization.[30] The same wear is visible above ground: Germany counts some 4,000 motorway bridges in need of renovation or replacement – the partial collapse of Dresden's Carola Bridge in September 2024 provided a warning – and French Senate reports place 30,000 to 35,000 road bridges in poor condition.[31]

Decay of this kind is not just a renovation backlog; it carries a running cost, because the transitions are being pushed through networks that were never designed for them. Germany spent around €2.8bn on grid congestion management in 2024 – a roughly fifteen-fold increase over a decade – while curtailing 9.4 TWh of renewable electricity[32].

To age and congestion, geopolitics has added a third dimension of quality: security. Some ten Baltic subsea cables have been damaged since 2022 – 7 between November 2024 and January 2025 alone – prompting NATO's Baltic Sentry operation and stronger EU attention to cable security. The EU's 2025 action plan also identifies close to €1bn allocated to digital infrastructure, including submarine cables, under the 2021–2027 financial framework, a broader scope than surveillance and repair alone. [33]

EXPERT POSITION 3

Roland Lescure – Sovereignty, competitiveness, and resilience: top priorities for tomorrow's infrastructure

"Europe's strategic autonomy must be built on robust infrastructure. Recent disruptions to energy and transport systems have demonstrated that economic prosperity, industrial capacity, and national security depend more than ever on the resilience of critical infrastructure.
As the backbone of our economies, infrastructure is both a source of strength and a point of vulnerability. Building the infrastructure of the next 50 years is the industrial project of the century. The expansion of clean electricity, modern industry, digital capacity, and advanced manufacturing must be pursued as a single transformation. Sovereignty, resilience, and competitiveness are the three priorities for building tomorrow's infrastructure. First, sovereignty begins with the ability to innovate, attract investment, develop AI infrastructure, and secure abundant low-carbon energy. The goal is not just to decarbonize, but to do so through European technologies, jobs, and diversified supply chains. This is a triple emergency: environmental protection, sovereignty, and industrial development. Second, resilience demands moving from ambition to action. Critical infrastructure must be adapted to climate risks, energy systems diversified, and electricity networks modernized. The cost of investing in resilience now is high, but the cost of inaction will be even greater. Third, to achieve competitiveness, Europe needs to mobilize investment at scale. As public finances face growing constraints, the challenge is not just defining strategic priorities but finding how to finance investment needs. Stronger cooperation among public authorities, industrial actors, and long-term investors, combined with simpler, more effective financial frameworks, will be essential to channel European capital toward our strategic objectives."



Roland Lescure
French Minister of Economy and Finance

30 - European Commission, *Grids Package*, 2025; Eurelectric, *Grids for Speed*, 2024.

31 - German bridge stock assessments, 2024-2025; Sénat, *rapport d'information sur l'état des ponts*, 2022.

32 - Bundesnetzagentur, SMARD electricity market data, 2024–2025.

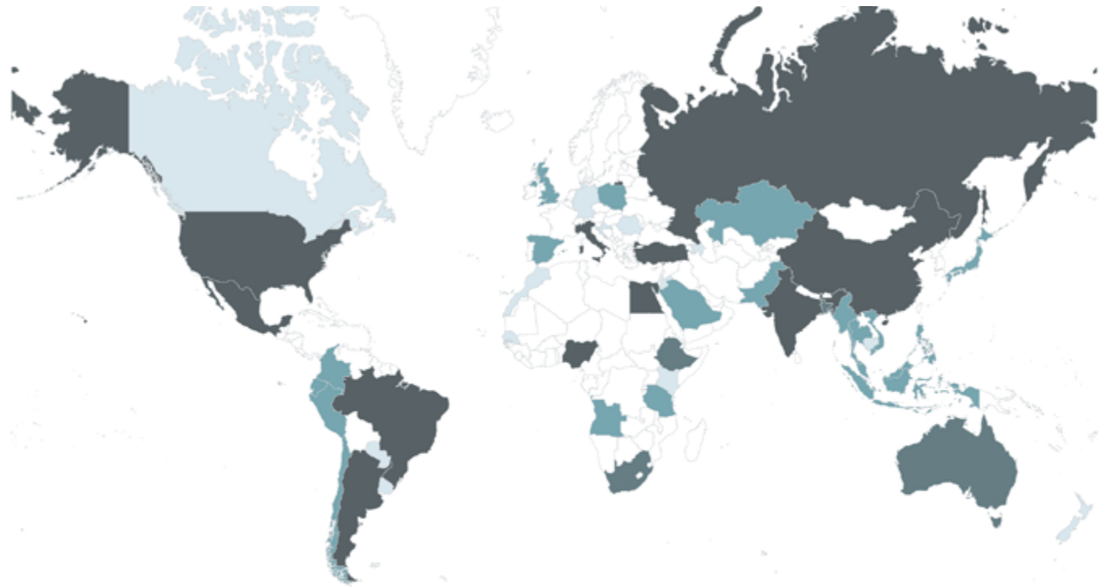
33 - European Commission, *EU Action Plan on Cable Security*, 2025.

FIGURE 5

Projected cumulative infrastructure investment gaps by country, 2016–2040

Source: Global Infrastructure Hub and Oxford Economics, Global Infrastructure Outlook, 2017, with the 2018 country-coverage update.

US dollars at 2015 prices and exchange rates. The map shows the countries covered by the Global Infrastructure Outlook; uncolored countries have no estimate in the displayed dataset. These historical projections provide global context rather than a current estimate of Europe's financing gap.



HIGHEST RETURNS – IF WELL CHOSEN

Underinvestment and an aging asset base are mutually reinforcing, further weakening Europe's infrastructure foundations. New capacity delivers little when the existing system cannot absorb it, and maintenance deferred becomes tomorrow's replacement bill. Two decades of under-investment have thus left Europe on the steep part of the returns curve – where each well-directed euro works hardest – provided investment follows the composition of the deficit rather than its headline: aging assets, missing interconnections and congested nodes indicate precisely where the marginal euro earns most.

The pattern is consistent with the quality-infrastructure literature: in mature network economies, the returns to maintenance, modernization and interconnection generally exceed the returns to new construction, making project selection rather than volume the growth lever.[34] Energy and digital infrastructure deliver the strongest economic returns, especially in advanced economies. According to BCG analysis, energy generation shows for instance the highest elasticity – 0.09 – meaning a sustained 1% rise in generation capacity lifts long-run GDP growth by 0.09 percentage points, and a 5% rise by 0.45[35]. Against average OECD growth forecast at just 1.7% for 2026, that gain would be material.

34 - OECD and IMF, *Reference Note on Quality Infrastructure Investment*, 2020.

35 - BCG, *Infrastructure Investment in an Uncertain World*, 2026.

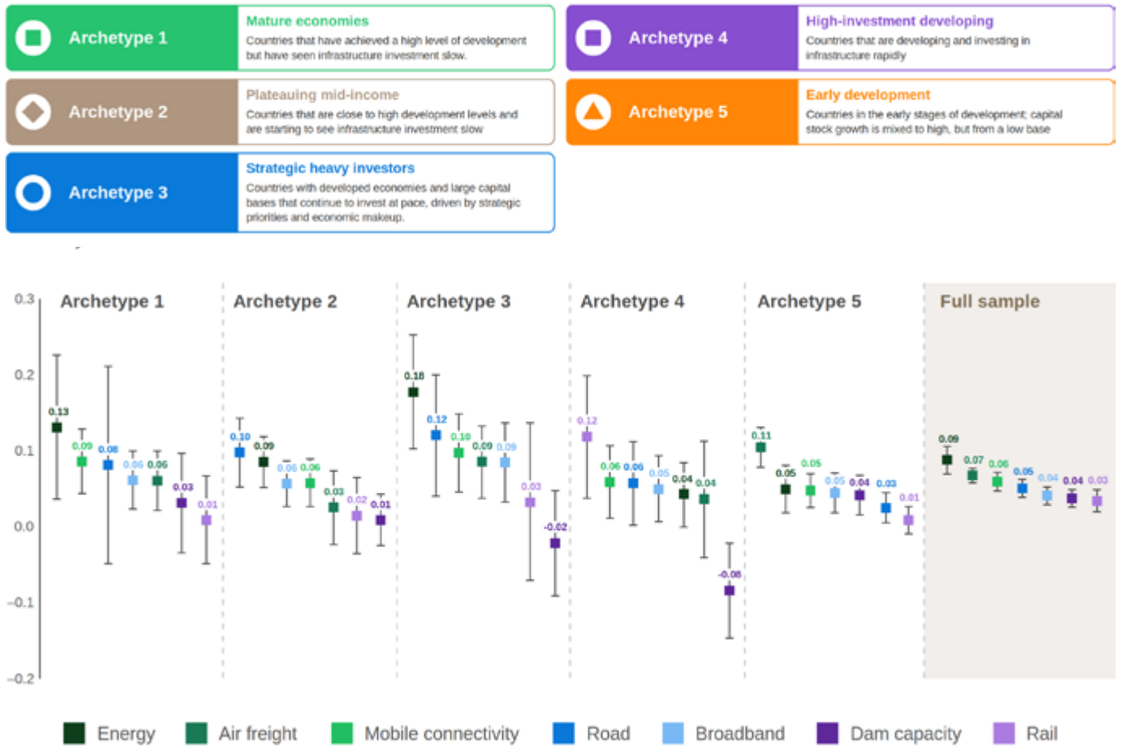
FIGURE 6

Estimated infrastructure–growth relationships by sector and country archetype

Source: BCG, Infrastructure Investment in an Uncertain World, 27 January 2026; underlying data from IMF, Penn World Table, UN and World Bank.

Estimated relationships between infrastructure stock and long-run economic growth, by sector, for five country archetypes and the full sample. The analysis covers 92 countries over 1990–2019. Markers show estimated coefficients; vertical bars show confidence intervals. The archetypes classify countries by development level and infrastructure-investment trajectory.

Note: A 0.09 elasticity means that a 1% sustained increase in infrastructure stock would raise long-run GDP growth by 0.09 pp; a 1% increase refers to an increase in the infrastructure stock (for example, if a country had 100km of road, a 1% increase in road infrastructure stock would bring the total road stock for that country to 101km); the confidence intervals are a function of how certain the model is in interpreting the relationship between our key variables: infrastructure stock and GDP.



The environmental transition: the sternest test of EU competitiveness

Pricing the unpriceable: the challenging economics of the environmental transition

THE MOST DEMANDING AND TIME-BOUND TRANSITION

Of the five transitions, the environmental one is the most demanding, for three reasons that set it apart in kind rather than in degree.

- First, it is the only transition bound by physical rather than political deadlines. The remaining carbon budget for a 50% chance of limiting warming to 1.5°C was estimated at some 170 Gt CO_2 from January 2026 – roughly four years if emissions remained unchanged[36]. Europe's own milestones are now legally binding: a reduction in net greenhouse gas emissions of at least 55% by 2030 and 90% by 2040 relative to 1990, followed by climate neutrality by 2050[37];

- Second, it is unmatched in physical scale: it requires replacing, within a single generation, an energy base assembled over two centuries. Electricity must rise from roughly 20% to around 50% of final energy consumption by 2050, renewable generation must grow five- to six-fold, and grid investment alone is estimated at €584bn by 2030 – and close to €1.9tn by 2050[38]. No other transition requires the simultaneous transformation of power, transport, heating and industrial systems;

- Third, **delay carries a distinct cumulative cost.** A lost decade of digitalization can, at least in part, be recovered through faster subsequent deployment. A lost decade of decarbonization cannot be caught up in the same way: the additional emissions released in the meantime consume part of the remaining carbon budget, narrow the range of feasible pathways and increase the pace of adjustment required thereafter. Some resulting environmental damage may also be irreversible on human timescales.

The final singularity carries the operational consequence that structures this entire report. Previous energy transitions were additions – coal alongside wood, oil alongside coal – each adopted because it was cheaper or superior. This one must achieve what markets have never done spontaneously: the orderly retirement of functioning, profitable assets on a defined schedule.

The environmental transition, moreover, extends well beyond energy and carbon. The 2025 Planetary Health Check assessed seven of the nine planetary boundaries defining a safe operating space for humanity as transgressed[39], and the degradation of living systems has become a macroeconomic variable in its own right: more than half of global GDP depends moderately or highly on nature and its services[40], and the ECB estimates that almost 75% of euro-area corporate bank loans are extended to firms highly dependent on at least one ecosystem service[41]. The ecological and energy transitions thus proceed together: one rebuilds the continent's energy base, the other redefines the resource base on which that reconstruction – and the other transitions – depend.

36 - Friedlingstein P. et al., *Global Carbon Budget 2025*, 2025.

37 - Regulation (EU) 2021/1119 (European Climate Law), as amended in March 2026.

38 - European Commission, *Implementing the REPowerEU Plan*, 2022; European Court of Auditors, *Making the EU Electricity Grid Fit for Net-Zero Emissions*, 2025.

39 - Planetary Health Check 2025; Stockholm Resilience Centre, Ocean acidification, assessment of the boundary's transgression in 2025.

40 - WEF, *Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy*, 2020.

41 - ECB, *Living in a World of Disappearing Nature: Physical Risk and the Implications for Financial Stability*, 2023.

EXPERT POSITION 4

Anna Creti – Energy and low-carbon transitions: reshaping traditional economics of infrastructure investment

"The energy and low-carbon transitions are fundamentally reshaping the economics of infrastructure investment. For decades, the prevailing approach to attracting private capital has been one of derisking: reducing uncertainty and providing investors with predictable, long-term returns. Yet the nature of these transitions challenges this paradigm. Infrastructure investments are increasingly exposed to multiple, interdependent sources of uncertainty, including future demand, technological trajectories, regulatory evolution, and market dynamics. Together, these factors are transforming the conditions under which investment decisions are made.

From an economic perspective, this marks a return of ambiguity: a situation in which uncertainty is so pervasive and multidimensional that it cannot be meaningfully reduced to probabilistic risk. Under such conditions, identifying an optimal investment path becomes inherently more difficult, as future outcomes depend on structural changes that are themselves uncertain.

At the same time, infrastructure operators are adapting their business models to this new environment. Across energy, transport and utilities, companies are diversifying both across sectors and within their traditional activities by developing new transition-related business lines. Many now combine regulated businesses, which provide stable and predictable revenues, with competitive activities that are more exposed to market dynamics. Others are repurposing existing assets to serve emerging uses associated with the transition. Rather than relying on a single source of value creation, these companies are building more diversified portfolios that balance different risk profiles while preserving their capacity to finance long-lived infrastructure."



Anna Creti
Professor of Economics at Université Paris Dauphine-PSL

THE COSTS OF STANDING STILL

Research developed over several decades, and brought to wider policy attention by the 2006 Stern Review, documents the economic risks of climate change[42]. Estimates differ substantially with the damage functions, adaptation assumptions and discount rates used. Physical risk assessments nevertheless show the benefits of limiting warming: Warren et al. (2022) estimate that holding warming to 1.5°C rather than 2°C reduces the global risk indicators they study by 10–44%, depending on the sector[43].

Uncertainty concerns the scale and distribution of damage, while lower warming reduces many physical risks. An Allianz Trade stress scenario published in May 2026, replaying each country's five hottest years from 2014–2024 over 2026–2030, estimates cumulative GDP losses of 5–7% in the most exposed economies, including USD240bn for France[44]. Separately, the World Bank's 2019 Lifelines report estimates that infrastructure disruptions cost households and firms in low- and middle-income countries at least USD390bn annually, including disruptions caused by natural hazards, poor maintenance and mismanagement[45].

42 - Stern N., *The Economics of Climate Change: The Stern Review*, 2006.

43 - Warren R. et al., "Quantifying Risks Avoided by Limiting Global Warming to 1.5 or 2°C above Pre-industrial Levels", *Climatic Change*, 172, 2022.44 -

44 - Allianz Trade, *Too Hot to Grow: The Economic Costs of Extreme Heat*, 28 May 2026.

45 - Hallegatte S., Rentschler J. and Rozenberg J., *Lifelines: The Resilient Infrastructure Opportunity*, World Bank, 2019.

EXPERT POSITION 5

Patrice Geoffron – The cost of inaction: a systemic perspective

"The cost of inaction must be assessed not only at the level of an individual asset, but also at the level of the system on which it depends. Delaying the reinforcement of an electricity grid, for example, can hold back investment in power generation, industry or mobility. The resulting economic loss may far exceed the cost of the deferred project. Similarly, failing to adapt infrastructure exposes its users to service disruptions whose consequences extend beyond physical damage.

This systemic perspective brings into view costs that project-by-project assessments tend to underestimate. It also highlights a defining feature of the climate transition: lost time cannot be fully recovered. Additional emissions deplete the remaining carbon budget and constrain future choices. Yet the report rightly stresses that the cost of inaction must be weighed against the cost of poorly designed action. Investing too early in an asset that networks or users cannot accommodate can tie up capital for decades.

We need to move beyond the false choice between waiting and accelerating indiscriminately. It calls for identifying bottlenecks, coordinating investments and preserving room to adapt. This is how we can determine when investment in resilience is a sound economic decision, rather than merely a defensive expense."



Patrice Geoffron
Professor of Economics at Université Paris Dauphine-PSL

FOCUS 1

Bilal and Känzig (2026): the undervaluation of climate change impacts

Estimates of the cost of inaction rely on models whose limitations are well known and seriously debated. By assuming a damage function and a discount rate that cannot be determined directly from observed data, integrated assessment models can generate very different results from equally coherent architectures[46]. Recent empirical work has produced substantially higher damage estimates, without resolving the wider debate over their magnitude.

Bilal and Känzig (2026)[47] use global temperature variation to estimate climate damage. Their results imply that a permanent 1°C increase in global temperature reduces world GDP per capita by more than 20% in the long run. Their model also implies that world GDP per capita in 2019 would have been more than 20% higher without the warming experienced since 1960. These are estimated counterfactual effects, subject to uncertainty over identification and extrapolation.

The authors attribute much of the difference from earlier estimates to global temperature's stronger relationship with damaging weather extremes. International trade spillovers alone do not explain the gap between global and local temperature estimates. The analysis therefore broadens the assessment of physical climate damage and their macroeconomic consequences.

For infrastructure, these estimates support testing valuations against a wider range of physical and macroeconomic damage. They do not determine the pace of regulatory tightening. Adaptation can create substantial economic value through avoided losses, but its investability depends on how that value is captured in revenues, cost savings or contractual payments.

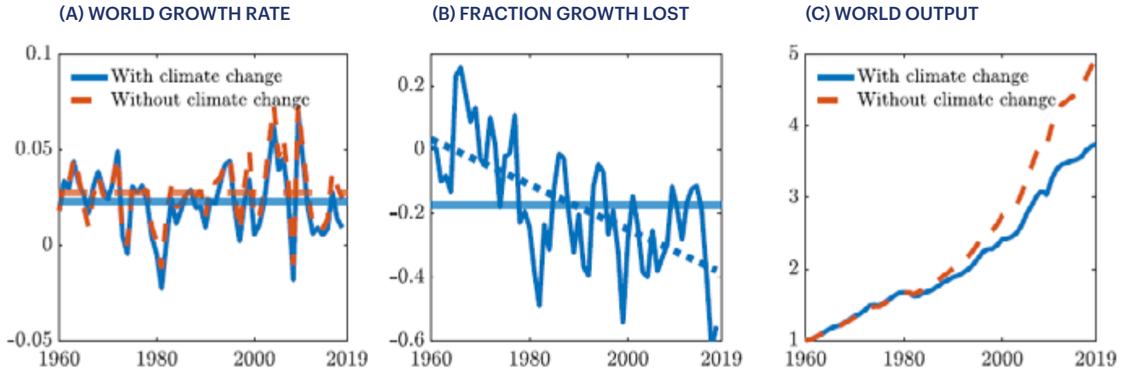
46 - Pindyck R. S., "The Use and Misuse of Models for Climate Policy", *Review of Environmental Economics and Policy*, 11(1), 2017, pp. 100–114.

47 - Bilal A. and Känzig D. R., 'The Macroeconomic Impact of Climate Change: Global vs. Local Temperature', The Quarterly Journal of Economics, 141(2), 2026, pp. 889–944.

FIGURE 7

Growth accounting with climate change

Source: Bilal & Känzig, 2026.



A PURPOSE BEYOND THE REACH OF PRICING

The most disruptive singularity of the environmental transition is its finality. Digitalization is pulled by productivity gains and private returns; demographic adaptation by household needs; geopolitical repositioning by the oldest incentive of all, security. While each generates its own demand, the environmental transition, by contrast, pursues an objective – planetary stability – that no market transaction spontaneously rewards: the Stern Review famously described climate change as "the greatest market failure the world has ever seen"[48].

Its consequences therefore extend to the entire structure of relative prices – energy costs have become a prime determinant of industrial location, and Europe's position is unfavorable, with electricity prices two to three times and gas prices four to five times those of the US[49].

CARBON PRICING: THE ONE OBJECT THAT A PRICE CAN HOLD

Within the broader environmental transition, greenhouse gas emissions have a widely used common accounting unit, the tonne of CO_2 equivalent, which supports explicit pricing and trading mechanisms. The associated damage can be estimated, although their magnitude remains uncertain. Integrated assessment models (IAMs), foremost among them the DICE model developed by William Nordhaus in the 1990s, incorporate the climate equation into the economic calculus through the social cost of carbon and the abatement cost (the cost per tonne of CO_2 avoided) – variables used to calibrate the intervention to be carried out on the market. Direct carbon pricing has thus widely expanded, and now covers nearly 30% of global emissions across 87 instruments and raised over USD107bn for public budgets in 2025[52].

For instance, in Europe, the Carbon Border Adjustment Mechanism (CBAM) entered its definitive regime on 1 January 2026, covering cement, iron and steel, aluminum, fertilizers, electricity and hydrogen. Its logic is competitive as much as environmental: as free ETS allowances

FOCUS 2

The Suez Canal between two markets and two ecosystems

By removing the detour around the Cape of Good Hope in 1869, the Suez Canal brought Europe closer to Asia and became one of the arteries of world trade. In the same act it created a continuity between two marine ecosystems that had been separated for several million years.

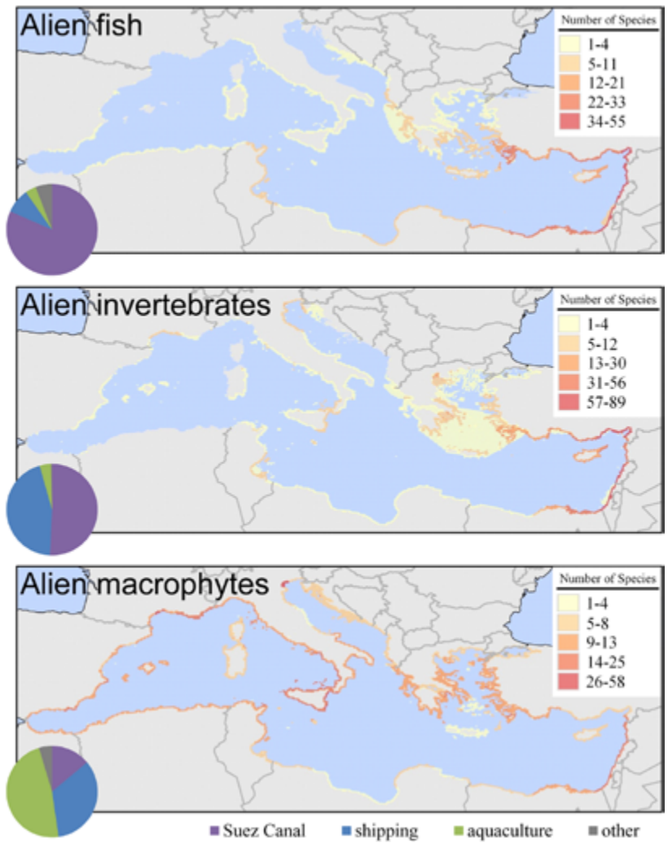
This continuity widened at the pace of the system's own transformations. The hypersaline Bitter Lakes initially acted as a partial barrier to species migration; as their salinity equalized with that of the Red Sea and the canal's successive enlargements widened the passage, that barrier weakened, while reduced Nile inflow following the Aswan Dam contributed to making parts of the eastern Mediterranean more favorable to Red Sea species[50]. Several hundred species from the Red Sea have since established themselves there. On the Israeli continental shelf, Albano et al. recorded only 12% of the historical richness of native molluscs on shallow soft substrates and 5% on hard substrates[51].

Economic analysis can immediately value the shorter distances and travel times this continuity provides, but it has no equivalent unit for aggregating the changes in fisheries, the shift in species composition, the exposure of coastal assets and the formation of a novel ecosystem that arose from the very same continuity.

FIGURE 8

Number of marine alien species introduced in the Mediterranean through the Suez Canal

Source: Katsanevakis et al., 2014.



are phased out, CBAM equalizes the carbon cost between European producers and importers, protecting the business case for industrial decarbonization investments made in Europe. Its success will be judged on three tests: administrative workability for importers and SMEs; compatibility with a rules-based trading system as partners respond; and extension over time to downstream products, without which carbon costs simply migrate one step along the value chain. The transition to the definitive regime points to consolidation rather than retreat. The definitive regime entered into force on schedule on 1 January 2026; the October 2025 'Omnibus' amendments softened its administration rather than its ambition – exempting some 90% of importers through a 50-tonne threshold while keeping roughly 99% of embedded emissions covered, and deferring the first certificate settlements to 2027; the phase-out of free ETS allowances in CBAM sectors began as planned; and in December 2025 the Commission proposed extending the mechanism to selected downstream products by 2028[53].

Coverage, however, measures the reach of the instrument, not its force. Across emissions covered by implemented carbon taxes and emissions trading systems, the global average carbon price stood at around USD21 per tonne of CO_2 equivalent in 2026[54]. Its ability to redirect investment depends on the price level, expected persistence and interaction with other policies. Political acceptability constrains this design. The amendment to the European Climate Law adopted in March 2026 made the 2040 target binding while postponing the full operation of ETS2, covering buildings, road transport and additional sectors, from 2027 to 2028[55]. The system also incorporates a market stability reserve and a Social Climate Fund. Its €45 threshold, expressed in 2020 prices, triggers additional allowance releases under specified conditions; it is not a guaranteed price ceiling[56]. A stronger long-term target can therefore coexist with a slower extension of carbon pricing. For infrastructure investors, both dimensions matter: the direction of policy and the timing and strength of the signal that reaches project revenues and costs.

EXPERT POSITION 6

Susanne Nies – When coherent rules collide: CBAM, market coupling and the sequencing of regulatory frameworks

"The energy transition depends on how different regulatory frameworks interact. Climate policy, electricity market integration, and energy security are often developed independently, yet their success depends on whether they can work together in practice. The challenge is not only to design effective instruments, but to ensure that they reinforce rather than obstruct one another.

The Carbon Border Adjustment Mechanism (CBAM) highlights this challenge in electricity markets. Unlike most goods, electricity is traded through integrated cross-border markets, with flows determined by algorithms matching supply and demand across countries. Ideally, electricity should flow from lower-priced to higher-priced markets. CBAM imposes a carbon cost on electricity entering the European Union, adding a price component only on one side of the border. This can distort the price signals essential for market coupling and reduce the economic incentives for cross-border trade.

Ukraine demonstrates the importance of these regulatory interactions. Since synchronizing with the continental European grid, the country has shown extraordinary resilience under wartime conditions and is advancing towards full integration with the European electricity market. However, regulatory timelines are misaligned. CBAM applies to electricity imports from January 2026, but market coupling is not expected before 2028. Meanwhile, the exemption foreseen in the regulation requires market coupling as a condition. The result is a circular problem: a mechanism intended to support decarbonization may complicate the market integration pathway needed for Ukraine to qualify for exemption.

The question is therefore not whether carbon pricing or market integration should take priority, but how they can be sequenced appropriately. Both remain necessary. A temporary transition period allowing market coupling and a domestic emissions trading system to be established before CBAM is fully applied would help align these objectives. Ukraine's experience highlights a broader lesson: individually coherent regulatory frameworks can create unintended barriers when they interact. Ensuring that climate policy, electricity market design, and integration objectives evolve together is essential if they are to reinforce rather than constrain one another."



Susanne Nies
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THE BLIND SPOTS OF THE PRICE SYSTEM

Yet much of the natural capital on which economic activity depends remains outside the price system. Ecological functions, including biodiversity, soil fertility and pollination, can deteriorate without generating a market signal commensurate with their scarcity or degradation. The difficulty goes beyond missing prices: the values at stake are only partially substitutable and cannot always be reduced to a single monetary equivalent, creating a problem of incommensurability[57] and requiring plural valuation instruments[58].

Three conditions resist pricing and explain this barrier:

Uncertainty. Pricing an externality involves estimating the additional damage caused by an additional unit of pressure, yet environmental damage often depends on long causal chains, on local ecological conditions and on interactions with other pressures. Under such uncertainty, the choice between a price instrument and a quantity instrument depends on the relative slopes of marginal damages and marginal abatement costs. Where damages may rise sharply around an uncertain threshold, a quantity constraint can offer greater protection than a price built on an unstable estimate of damage[59];

Non-linearity and irreversibility. Environmental damage need not be proportional to pressure: it may rise abruptly near an uncertain ecological threshold, so that marginal analysis becomes unreliable precisely when the location of that threshold is unknown and crossing it produces irreversible consequences60. This is where option value enters. Preserving an environmental asset keeps open the possibility of acting later with better information, whereas degrading it may eliminate that option for good, which justifies paying a premium to keep the option alive;

Non-fungibility. Unlike carbon, biodiversity has no universal unit that would let gains and losses be compared across sites: the value of a habitat depends on its composition, its connectivity and its role within the wider ecosystem, so that two hectares in the same administrative category may perform different ecological functions and cannot automatically compensate for one another[61]. This is why biodiversity offset schemes built on simple equivalence have so often failed to prevent net loss, and why the issue moves from pricing alone toward plural valuation, where several indicators inform a public decision rather than a single exchange rate settling it.

Although monetization is one form of internalization well-suited to carbon, for the objects that carry no common unit the question is no longer how to price these values better, but which instrument takes over where the price cannot reach. A price suffices for an ordinary externality, but here it meets a risk whose distribution defies its calculus and values that admit no common unit, so that the central instrument of economic analysis cannot carry the transition alone. The market failures at play are multiple and call for a mutually reinforcing set of instruments rather than a single price, which shifts the question from how the objective is measured to how it is actually reached.

Extreme climate risk exposes a further limitation of conventional appraisal. Potentially irreversible outcomes, uncertain thresholds and cascading effects make historical frequencies an unreliable guide to future losses[62]. This does not make any particular catastrophe certain; it makes a single expected-loss estimate an insufficient basis for decisions with severe and irreversible consequences63. The Bank for International Settlements' "green swan" framework therefore supports forward-looking scenario analysis, stress testing and resilience measures alongside conventional valuation, while acknowledging that models cannot capture the full range of possible disruptions[64].

EXPERT POSITION 7

Fabrice Lepoutre – Energy transition: creating broader economic and strategic value

"The energy transition is not only about reducing emissions; it is also about creating broader economic and strategic value. Infrastructure must simultaneously advance three objectives: decarbonization, energy sovereignty, and long-term competitiveness. Developing local energy resources – such as biomass, geothermal energy, waste-to-energy, and other domestic low-carbon sources – not only lowers carbon emissions but also reduces exposure to geopolitical tensions, volatile energy markets, and external supply disruptions. In this sense, the transition is as much an economic and strategic transformation as it is an environmental one."



Fabrice Lepoutre
President of Coriance

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A defining test for European infrastructure competitiveness and sovereignty

CLEAN ENERGY: A CRUCIAL INDUSTRIAL BATTLEGROUND

The environmental transition is creating a large industrial market that infrastructure both enables and depends on. The IEA estimates that the global market for selected clean-energy technologies reached nearly USD1.2tn in 2025 and could reach around USD2tn under current policies or almost USD3tn under stated policies by 2035. This includes vehicles and equipment as well as technologies used in infrastructure. In the stated-policies scenario, the value of net trade in these technologies more than doubles, from USD290bn in 2025 to USD620bn in 2035[65].

For Europe, reducing fossil-fuel consumption can lower exposure to imported energy, while domestic manufacturing can retain more of the industrial value created by the transition. These benefits are related but distinct: imported clean technologies can also reduce fuel dependence, and domestic production creates lasting value only if it remains competitive. Infrastructure shapes both outcomes through energy availability, network access, logistics and delivery costs. Industrial policy must therefore assess where European production strengthens strategic capability, and where diversified trade offers a more efficient route to deployment.

A RACE THAT STARTED WITHOUT EUROPE

The industrial geography of this market is already heavily tilted. China is home to more than 80% of global solar-PV manufacturing capacity; its battery manufacturing capacity – around 2,500 GWh in 2024, more than double global demand that year – is heading toward 6,300 GWh by 2030; and 60–80% of wind-component capacity is located there, depending on the segment[66]. This dominance is not incidental to China's growth model: clean-energy sectors accounted for more than a third of Chinese GDP growth in 2025[67]. Scale, vertical integration from refined minerals to finished goods, and a decade of deliberate industrial policy have produced cost positions that European entrants cannot match on price alone.

The US initially responded with the Inflation Reduction Act, using production and investment tax credits to attract clean-technology capital. Legislation enacted in July 2025 subsequently curtailed support for wind and solar, exposing the reversibility of that approach[68]. Europe's response, through the Green Deal Industrial Plan and the Clean Industrial Deal, combines public support with regulatory demand creation, carbon pricing and single-market scale. China's manufacturing strength, the changing US fiscal framework and Europe's use of market access and standards create different competitive conditions for investment. Each strategy has a weakness: overcapacity for China, fiscal reversibility for the US and, for Europe, the risk that demand-side instruments create markets that others supply. Europe's CBAM and the growing weight of resilience criteria in procurement are attempts to close precisely that gap.

The dependence question sharpens the point. Decarbonization changes the nature of strategic exposure: continuous fuel imports give way to requirements for equipment, critical materials, maintenance and replacement. The concentrated supply chains described earlier create vulnerabilities[69], but these are not identical to dependence on a fuel that must be imported continuously to keep a system running. The sovereignty outcome depends on supplier concentration, substitution options, inventories, technical control and the consequences of interrupted supply. Diversification and selective domestic capability should therefore target the dependencies whose disruption would compromise essential services or future deployment.

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68 - Public Law 119-21, 4 July 2025, sections 70512–70513; Internal Revenue Service, Notice 2025-42, August 2025.

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EXPERT POSITION 8

Gabriele Todesca – Strategic autonomy and the energy transition: understanding and managing dependencies with "humility"

"The energy transition is inseparable from Europe's broader pursuit of strategic sovereignty. Yet the objective cannot simply be to replace dependence on imported fossil fuels with new dependencies on the technologies and supply chains underpinning the low-carbon economy. The challenge is therefore not to eliminate dependencies altogether, but to understand their nature, assess their strategic implications, and determine where Europe should strengthen its capabilities.

Not all dependencies carry the same strategic weight. In some areas, Europe retains a strong industrial and technological base, with the capabilities required to design, manufacture, and operate critical infrastructure. In others, competitiveness has eroded but can still be rebuilt through targeted industrial policies, innovation, and investment. A third category is more challenging: sectors in which Europe depends heavily on third countries for essential technologies and components, including solar photovoltaic modules, batteries, permanent magnets, and parts of the wind energy value chain. Treating all dependencies alike would obscure these important distinctions. A more differentiated approach is needed to identify where vulnerabilities are most acute and where action can realistically restore greater strategic control.

Strategic autonomy should therefore not be understood as self-sufficiency. Rather, it is the ability to maintain control over critical capabilities while ensuring that key infrastructure remains resilient to geopolitical, technological, and economic disruptions. In some cases, this will require rebuilding domestic industrial capacity; in others, resilience will come from diversifying suppliers, strengthening partnerships with trusted allies, or securing access to strategic inputs.

Achieving this objective also requires a degree of strategic humility. Other regions – most notably China – have developed industrial capabilities and scaled deployment at a pace that Europe has not matched in several transition technologies. Just as many countries have historically drawn on European expertise in infrastructure and industrial development, Europe should be prepared to learn from the strategies and policy instruments that have proved effective elsewhere, adapting them to its own institutional and economic context."



Gabriele Todesca
Head of Infrastructure Investments at the European Investment Fund

FROM COMPETITIVENESS AGENDA TO INFRASTRUCTURE DELIVERY

As the EU's competitiveness agenda takes shape – from the Competitiveness Compass and the Clean Industrial Deal to the emerging Made in Europe agenda, and still expanding through 2025 and 2026 with the Affordable Energy Action Plan, the Grids Package and successive Omnibus simplification packages – one question is moving to the forefront: how can Europe mobilize and accelerate the investment needed in the infrastructure that underpins both the green transition and long-term competitiveness?

Europe's record shows that economic growth and falling territorial emissions can coexist. Between 1990 and 2024, EU net domestic greenhouse gas emissions fell by 40% while GDP increased by more than 70%. This aggregate decoupling does not establish that every climate policy improves competitiveness, nor does it isolate the effects of policy from structural change, trade or technology. It shifts the assessment toward the costs, distributional effects and industrial consequences of specific transition pathways[70].

The competitiveness test is therefore twofold. First, at the level of costs: the energy-price disadvantage described above[71] weighs particularly heavily on energy-intensive industries and on the economics of industrial electrification. Second, at the level of markets: decarbonization is creating the largest new industrial market of the coming decades, and the question is not whether it will be supplied, but by whom. Framed this way, the environmental transition is not a constraint on European competitiveness; it is the terrain on which competitiveness will be decided.

At this stage, the conclusions of Draghi's Future of European Competitiveness report regarding infrastructure converge on one systemic failure: Europe's infrastructure networks are too fragmented, too costly and too slowly built to sustain a low-carbon competitive economy. Capital is available, yet it is deployed across 27 national markets rather than at continental scale, and it is held back by permitting, coordination and financing bottlenecks. Taken together, these reveal a fundamental weakness in Europe's current growth model: the lack of a coherent infrastructure logic for managing systemic risk.

70 - European Environment Agency, *Key trends and drivers in greenhouse gas emissions in the European Union*, data for 1990–2024.

71 - Draghi M., *The Future of European Competitiveness*, 2024.

72 - European Commission, *Proposal for a Multiannual Financial Framework 2028-2034*, 2025.

FOCUS 3

The EU Commission competitiveness agenda

To ensure that European businesses can thrive in the global marketplace and to deliver sustainable prosperity, the Commission has placed competitiveness at the heart of its economic agenda. The Competitiveness Compass, presented in January 2025, translates the Draghi diagnosis into a roadmap organized around innovation, decarbonization and security.

Within it, two instruments carry the infrastructure agenda:

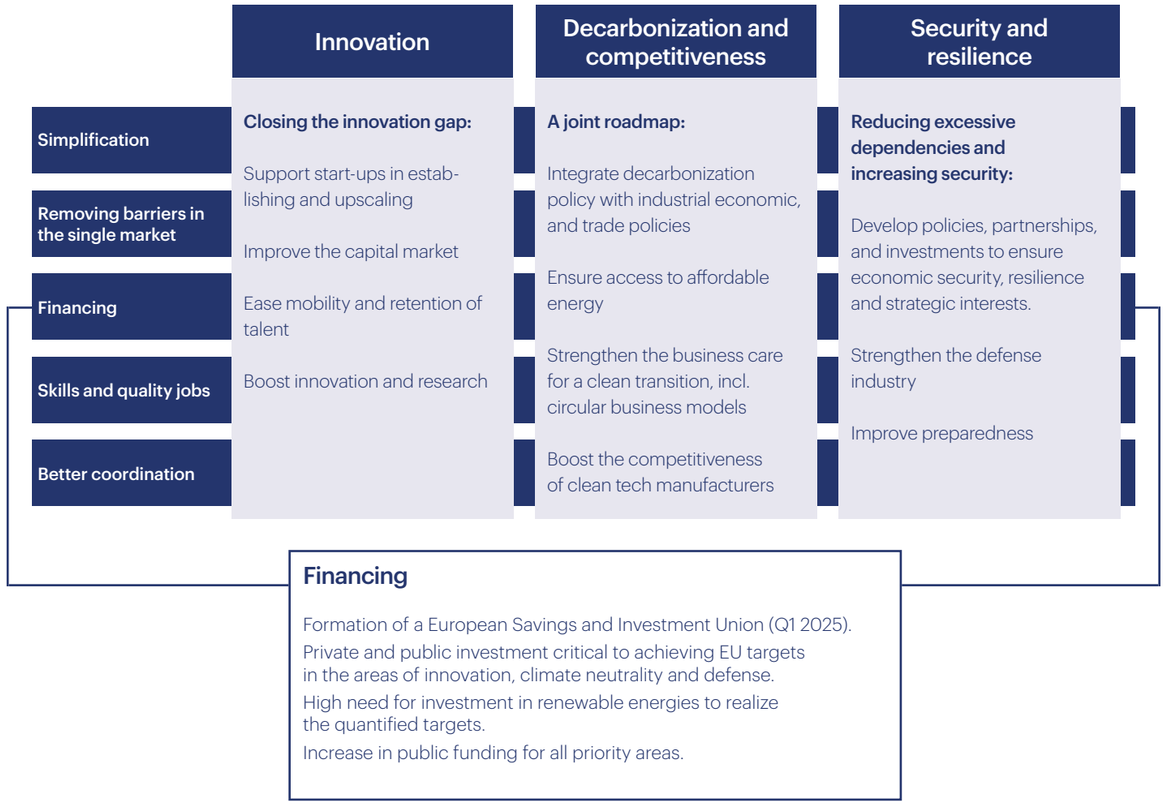
- The Clean Industrial Deal is a central building block on this path, as it aims to restore Europe's attractiveness as a location for energy-intensive industry by anchoring it in green technologies and circular business models. It mobilizes over €100bn for clean manufacturing, links industrial support to electricity-price reduction through the Affordable Energy Action Plan, and treats grids and interconnectors as preconditions for industrialization;
- The forthcoming Circular Economy Act extends the same logic to materials, channeling investment into recycling capacity and creating demand for secondary raw materials – a supply-security instrument as much as an environmental one, given that the EU imports the vast majority of the critical raw materials it consumes.

Both instruments pursue decarbonization and competitiveness as a single objective rather than a trade-off. The proposed European Competitiveness Fund in the 2028–2034 budget – part of a near €2tn framework, with some €590bn earmarked for competitiveness, research and innovation – is designed to concentrate EU public investment on the same convergence[72].

FIGURE 9

EU Competitiveness Compass

Source: EU Commission, 2025.



WHAT TO CARRY FORWARD

Five transitions converge on the same infrastructure base, making the capacity to build, reinforce and coordinate networks a growing constraint on economic transformation. For Europe, this challenge is compounded by an investment deficit and an aging, congested asset base, while competitiveness and sovereignty increasingly depend on where and how new infrastructure is deployed. The environmental transition brings these pressures into their sharpest focus: it is bound by physical limits, requires the transformation and retirement of long-lived assets, and pursues objectives that prices alone cannot deliver. Public and regulatory action therefore becomes part of the transition's economic architecture rather than a correction at its margin. This makes the quality of action decisive: the central risk is no longer only insufficient action, but committing to the wrong technology, the wrong sequence or the wrong allocation of risk. Part 2 turns from the destination to the pathway – how infrastructure transitions can be sequenced and adjusted without weakening the objective they are designed to achieve.

SUSTAINABLE PATHWAYS FOR INFRASTRUCTURE TRANSITIONS: FROM SETTING-UP TARGETS TO ENABLING TRANSFORMATION

Key takeaways

→ **A transition is a process of system reconfiguration, not the achievement of a target.** It begins inside an operating socio-technical system whose assets, users, rules, institutions and financing arrangements have co-evolved over decades; change is therefore systemic, multi-actor and non-linear, and success requires organizing the decline of the incumbent without interrupting the service it provides. **Targets set the direction but cannot determine the pathway: technology, pace, sequence and evidence for retirement** cannot credibly be fixed decades in advance, so the destination remains fixed while the route adjusts to observed condition.

→ **Adaptability is therefore a condition of delivery, not a retreat from ambition.** Infrastructure should increasingly be designed and governed for **multiple plausible futures** rather than optimized against a single forecast. Optionality – spare capacity, modularity, reserved land, repurposability or deferred commitment – has economic value because it preserves the ability to respond when uncertainty is eliminated. The Thames Estuary 2100 plan demonstrates the principle: the protection objective remains fixed while investment timing and technical choices move with evidence.

→ **Urgency increases the importance of direction rather than reducing it.** Europe faces costs both from acting too slowly and from acting in the wrong way. The latter occurs through **the wrong technology, the wrong sequence and the wrong allocation of risk:** technological choices can create new lock-ins, premature deployment can strand capital, and unstable risk allocation can destroy investor confidence. Infrastructure's longevity makes these errors particularly costly because today's choices shape the feasible pathway for decades.

→ **Competitiveness and sovereignty constrain which transition pathways are actually viable.** Achieving the environmental objective is insufficient if the chosen route leaves users unable to bear its cost or substitutes one strategic dependency for another. Technology and infrastructure choices therefore need to be evaluated not only by their environmental performance, but also by their system cost, supply-chain concentration, continuity risk and implications for European strategic capability.

→ **The fundamental delivery constraint is transformation in service: the system must change while continuing to operate.** This produces five conditions: preserve the service floor until users have substitutes; complete the weakest interface before adding dependent capacity; replace hidden functions as well as visible output; redirect capital as the bottleneck moves; and keep transition costs within the capacity of the actors who bear them.

→ **These five conditions form a dynamic capital-allocation framework, not a checklist.** They interact continuously: preserving an incumbent protects continuity but prolongs overlap costs; completing an interface can move the bottleneck to demand or affordability; retiring an asset can release cost but remove an unrecognized system function. And the framework holds only as long as the transformation remains politically sustainable: costs whose distribution is not accepted by those who bear them become, sooner or later, a revoked trajectory.

73 - Mattern J., "Le « pari de la transition » dans la sociologie française. L'exemple de Georges Friedmann", 201

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75 - Audet R., "Transition as Discourse", 2015.

76 - Grübler A., Wilson C., 2011; Markard J. et al., 2012.

77 - Sovacool B., 2016.

78 - IPCC, *AR6 Synthesis Report*, Annex I: Glossary, 2023; Geels F. W., "Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study", *Research Policy*, 31(8–9), 2002, pp. 1257–1274.

Infrastructure in transition: a process, not just an outcome

Reframing the concept of transition: from targets to systemic change

Before this report can assess how a pathway is governed, it must establish what a transition actually is – because the answer might contradict the way transitions are usually managed. Every operating condition in this Part derives from three properties the research establishes.

SYSTEMIC, NON-LINEAR AND MULTI-STAKEHOLDER

The use of the concept of transition in the social sciences is not new: it already appears among the thinkers of industrial modernity, from Auguste Comte to Alexis de Tocqueville and Émile Durkheim[73]. The first uses of the concept to denote a complex interweaving of several societal transformations emerged in the twentieth century – notably through the notion of "demographic transition", popularized in the 1940s and 1950s by the American scholars Davis, Notestein and Kirk, who interpreted major economic transformations as the primary driver of demographic change[74].

Transition, however, was not yet connected to the idea of systemic change, which developed in parallel from the 1930s onwards in the work of the biologist Ludwig von Bertalanffy. The Meadows report (1972) marks the founding moment of their convergence: by identifying the need for a "transition to global equilibrium" in the face of the environmental imbalances generated by human activity[75], it revealed what had been true all along – every transition is systemic in nature.

Practically, every transition begins inside a system already in operation. Europe's gas system alone comprises around 130,000 kilometers of transmission pipelines and 1.8m kilometers of distribution lines, built and depreciated over lives of about 80 years. Networks shape equipment choices; those choices sustain demand and specialist capacity; rules and finance adapt to the same configuration.

This convergence between transition and system matters because it led to the foundation of a dedicated field – sustainability transition studies – whose conclusions are consistent. Transitions, "processes of continuous change by which the structural character of a society transforms", are neither uniform nor fully controllable;[76] they are disruptive and non-linear,[77] typically triggered in crisis. Their object is the reconfiguration of a socio-technical system – technologies, infrastructure, institutions, uses and beliefs traversed by interdependent change – for which the multi-level perspective provides the canonical map: the landscape of structural trends, the regime of dominant technologies and rules, and the niches where radical innovations incubate until a window opens.[78]

Figure 10 shows this original multilevel, multiphase perspective. The multi-level perspective places the regime in its dynamic context: regimes emerge out of past transitions and develop path-dependently, through optimization and incremental innovation. Path dependency is not an anomaly but a consequence of sunk investments, economies of scale and co-evolution. The same forces that make a regime efficient eventually make it unable to change beyond optimization – generating the tensions that precede structural change. And when the disturbance comes – external crisis, internal tensions, or the maturing of superior alternatives – reorganization is not gradual but shock-wise and erratic.

A transition therefore succeeds not when the new is built, but when the old can retire without interrupting the service. Building is the visible half of the work; organizing decline is the harder half, and the one no market undertakes spontaneously. A companion multiphase model describes the temporal shape of the resulting change: predevelopment, take-off, acceleration, stabilization – an S-curve.

EXPERT POSITION 9

Hazal Kaya – Sustainability transitions: multidimensional and dynamic

"Infrastructure systems, traditionally characterized by high sunk costs, strong social dependencies, and the complexity of replacing existing systems, have generally been limited to incremental changes, making transformative shifts a high-risk endeavor. In this context, sustainability transitions in infrastructure are radical changes that drive innovation and reconfiguration within infrastructure systems. These transitions encompass the adoption or influence of sustainable technological alternatives (e.g., renewable energy challenging centralized electricity grids and demanding flexible decentralized grid solutions, or electric vehicles necessitating charging infrastructure or changing the role of transport infrastructure from passive network to active energy nodes), implementation of alternative infrastructure designs (e.g., decentralized water reuse systems), or new processes (e.g., circular economy practices). Another key aspect is the multi-dimensional and dynamic nature of sustainability transitions."



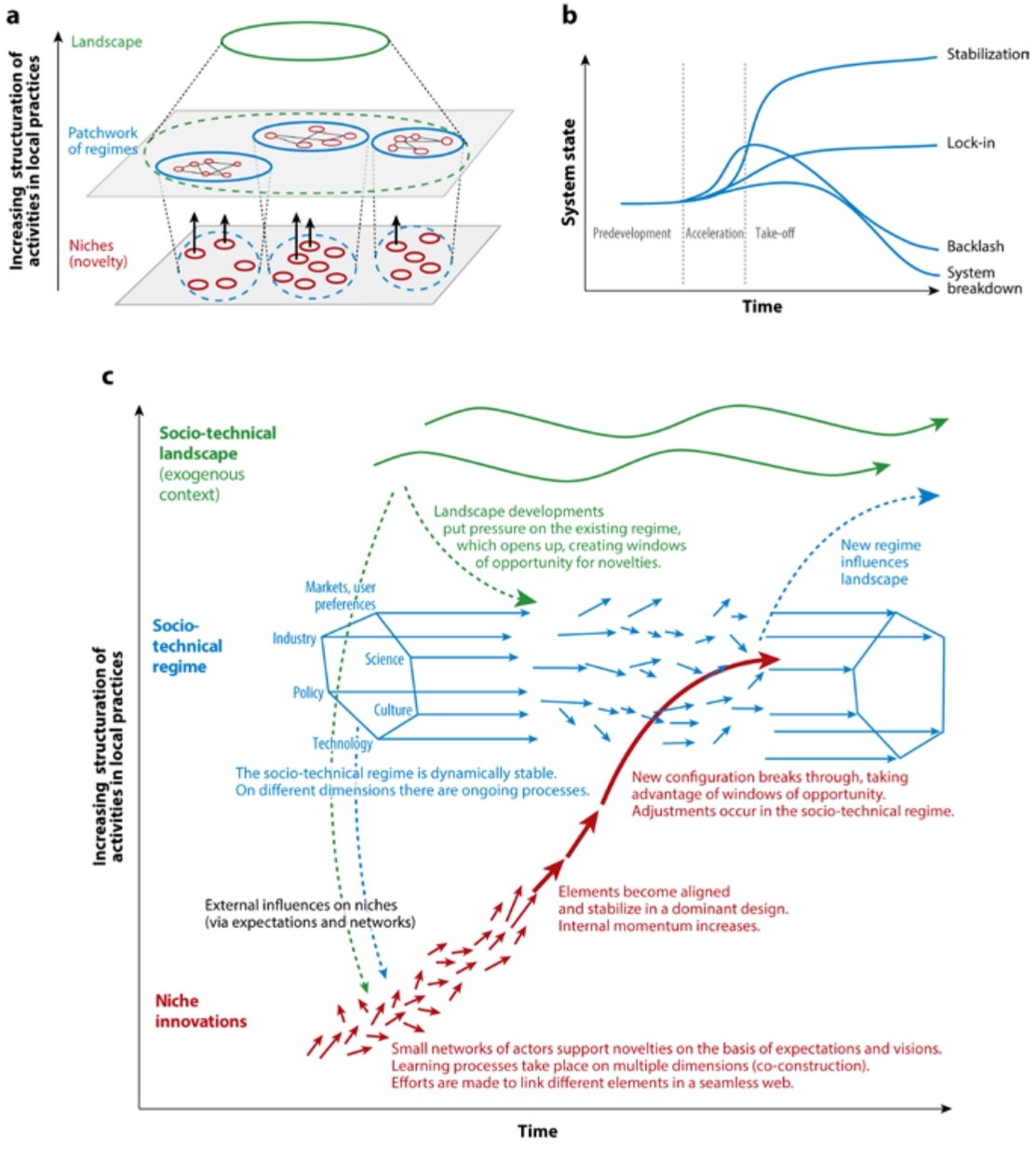
Hazal Kaya
PhD researcher at Delft University of Technology

FIGURE 10

Multilevel, multiphase perspective on transitions

Source: Loorbach, Frantzeskaki, and Avelino, 2017.

Note: the original multilevel, multiphase perspective on transitions with (a) the multilevel model depicting the coevolution between landscape, socio-technical regimes, and niches; (b) socio-technical regime change as a result of coevolving landscape pressures and emerging niches over time; and (c) the multiphase concept illustrating the nonlinearity of transitions and different types of pathways.



Loorbach D, et al. 2017.
Annu. Rev. Environ. Resour. 42:599–626

TOO OFTEN FOCUSED ON TARGET-SETTING

Everything in this body of research points in the same direction: a transition is defined by its process – systemic, non-linear, multi-actor, inseparable from the organized decline of the incumbent. Yet almost everything in the way transitions are actually governed points the other way: toward the endpoint. Consistent with this distinction, the IPCC glossary defines transition as the process of moving from one state to another over a given period, rather than the end state itself[79].

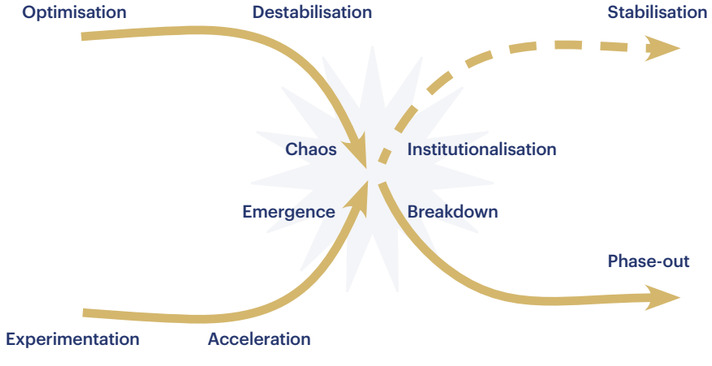
The result is a measurable imbalance: the world has grown dense in destinations and remains thin in pathways. As of September 2025, 137 of 198 national governments had adopted a net zero target, covering roughly three-quarters of global emissions: virtually the entire world economy now has a destination, and two-thirds of these targets are anchored in law or formal policy[80]. Pathways tell another story. In the EU, the most closely monitored jurisdiction, the independent European Climate Neutrality Observatory tracks some 150 indicators across thirteen building blocks of the transition; its July 2026 assessment finds that only a quarter of them progress at the required pace and that, for the first time since tracking began in 2023, none of the thirteen building blocks is on track – including governance itself[81]. The gap is not simply an absence of targets or legal duties. Some frameworks already impose binding interim milestones and implementation obligations, including the UK's five-year carbon budgets[82]. Yet these provisions do not, by themselves, specify how asset replacement, user conversion and incumbent retirement should be coordinated across a particular infrastructure system. The practical challenge is to translate legal commitments into an operational pathway: a sequence of investments, responsibilities and service conditions that can be monitored and adjusted.

FIGURE 11

A stylized pattern common to socio-technical transitions: building up the new system while managing the breakdown of the incumbent

Source: Hebinck et al., 2022.

Note: stylized representation; the pattern describes the general dynamics of socio-technical transitions, not a uniform path followed by every sector



FOCUS 4

The EU Commission competitiveness agenda

A review of major legal frameworks – spanning the largest emitters and the main legal traditions across the G7 and G20: the EU and its principal member states, the US, China, Japan, South Korea and South Africa – reveals a consistent pattern The EU has the most formalized architecture – transition activities defined in the Taxonomy Regulation, binding climate neutrality in the Climate Law, a Just Transition Fund – yet the "transition" itself remains defined by its end-state. France defines the energy transition through quantified objectives; Germany's Energiewende has no legal definition; the UK combines its net-zero duty with legally binding five-year carbon budgets and obligations to prepare implementation policies[83]; the US has no federal definition at all; China inscribes "ecological civilization" in its Constitution without normative content. The exceptions prove the rule: Japan's 2023 GX law promotes "a smooth transition to a decarbonized, growth-oriented economic structure" – making the linearity ambition explicit; South Korea's 2021 framework law defines just transition, energy conversion and carbon neutrality; South Africa's 2024 Climate Change Act defines the just transition in full. Where definitions exist, they define the destination, or fairness in reaching it – almost never the transformation process itself.

79 - PCC, *AR6 Synthesis Report*, Annex I Glossary, 2023.

80 - Net Zero Tracker, *Net Zero Stocktake 2025*.

81 - European Climate Neutrality Observatory (ECNO), *State of EU Progress to Climate Neutrality*, 2026 Flagship Report, July 2026.

82 - Climate Change Act 2008, sections 4 and 13; Department for Energy Security and Net Zero, *Carbon Budget and Growth Delivery Plan*, 2025.

83 - Climate Change Act 2008, sections 4 and 13.

GOVERNING BY PATHWAYS TO MANAGE UNCERTAINTIES

The danger of governing from the endpoint alone is not hypothetical. A target leaves open four things a transition cannot do without: the technology, meaning the configuration to build; the pace, meaning the rate at which the system can move and assets can be replaced; the sequence, meaning the order in which assets, interfaces and user conversion must arrive; and the evidence for retirement, meaning the proof on which the incumbent system can be wound down.

The energy system's own history makes its own case. Global renewable generation supplied more than one third of electricity in 2025, yet fossil-fuel CO_2 emissions still reached a record 38.1bn tonnes.[84] Coal increased timber use for mine supports, oil-based mobility required coal-intensive steel and manufacturing, and timber extraction remains above its level before the fossil era.[85] New sources have usually accumulated alongside incumbent ones rather than displaced them.

In this context, governing by pathways does not dilute ambition but keeps ambition credible when implementation conditions diverge from initial assumptions. Technology choices may need to evolve as costs, supply chains and adoption patterns change; sequencing may need to reflect what the market is ready to deliver; the pace of deployment may need to adjust to the increasing difficulty of the remaining task; and the retirement of incumbent systems may need to wait until their replacements can demonstrably provide the required service.

Recent European experience illustrates how these parameters can be revised in response to implementation constraints:

- **Technology.** Germany's heating reform shows a technology requirement moving under adoption and supply pressure: heat-pump sales fell 46% in 2024 to 193,000 units, against an objective of 500,000 a year, then rose 55% to 299,000 in 2025.[86] In July 2026, the Bundestag replaced a requirement for certain new systems to use at least 65% renewable energy with a fuel-blending ladder rising from 10% in 2029 to 60% in 2040[87].

- **Sequence.** What must exist before what: since a transition asset delivers nothing until the links it depends on are there, the order in which pieces arrive decides whether each euro produces service or waiting concrete – and when the planned order proves wrong, the order itself is what gets corrected. Great Britain did exactly this in 2025. Its grid-connection queue had swollen past 800 GW – more than three times what net zero requires – ordered on a first-come, first-served basis that let unready projects block ready ones. The reform approved in April 2025 re-sequenced the entire queue on two criteria, project readiness and alignment with the 2030 clean-power plan, with revised offers issued from autumn 2025 and pre-2030 connections served first. No date and no target moved: only the order did[88].

- **Pace.** How fast each step is taken, the order and the destination held constant – adjusted when the capacity of those who must follow (supply chains, adopters, balance sheets) proves thinner than assumed, and disciplined only if the adjustment is explicit, bound in time and honestly priced. The EU's car CO_2 standards imposed a step-change in 2025, with annual penalties for missing it; the industry could not take the step on schedule, electric sales ramping more slowly than planned while Chinese competitors squeezed margins. In June 2025 the EU moved the calendar, not the destination: Regulation 2025/1214 lets manufacturers average compliance over 2025-2027 instead of passing the test each year, the 2035 zero-emission target unchanged[89] – at a stated cost, an estimated 26 to 51 megatons of additional lifetime CO_2 [90] – which is what distinguishes a governed pace change from slippage.

- **Proof of retirement.** The UK's coal exit was announced in 2015, but the last plant, Ratcliffe-on-Soar, retired only on 30 September 2024 – after coal's share of generation had fallen from around 39% in 2012 to marginal levels, and with Capacity Market contracts securing the service floor throughout the interval.[91] The UK case illustrates how an announced retirement deadline can be supported by replacement capacity and mechanisms to maintain security of supply[92]. A deadline coordinates investment and exit decisions; operational readiness determines whether the required services can be maintained when it arrives.

These cases point to the same principle: **the destination can remain fixed while the parameters governing the pathway adjust to observed conditions.** Germany adapted the technology route as adoption and supply conditions evolved; Great Britain re-sequenced its grid-connection queue around project readiness; the EU adjusted the pace of compliance with car CO_2 standards; and Britain retired coal only once replacement capacity could reliably preserve the required service.

Such adjustments can make delivery more credible, but they do not automatically preserve ambition. Keeping the final target unchanged is insufficient if interim outcomes deteriorate or cumulative emissions rise. Each revision should therefore identify its effects on delivery, costs and emissions, and explain how any resulting gap will be addressed. The discipline lies in adapting the route while demonstrating continued compatibility with the objective.

84 - IEA, *Global Energy Review 2026*, 2026; Global Carbon Project, *Global Carbon Budget 2025*, 2025.

85 - Fressoz J.-B., *More and More and More: An All-Consuming History of Energy, Allen Lane*, 2024.86 -

86 - Bundesverband Wärmepumpe (BWP), *Wärmepumpenabsatz 2024 and Wärmepumpenabsatz 2025*, 2025–2026.

87 - Deutscher Bundestag, *Gesetz zur Änderung des Gebäudeenergiegesetzes*, Drucksachen 21/6278, 21/6565 and 21/7009, adopted 10 July 2026.

88 - Ofgem and NESO, *Connections Reform (TMO4+) Decision*, 2025.

89 - Regulation (EU) 2025/1214 amending Regulation (EU) 2019/631, 17 June 2025; European Commission, Industrial Action Plan for the European Automotive Sector, March 2025.

90 - ICCT, *An Amendment to the CO_2 Standards for New Passenger Cars and Vans in the European Union*, 2025.

91 - National Energy System Operator and UK Government, closure of the Ratcliffe-on-Soar power station, 30 September 2024, ending 142 years of coal-fired generation in Great Britain; coal supplied around 39% of British electricity in 2012 and under 2% from 2019, with Capacity Market contracts securing supply during the run-down.

92 - Department for Business, Energy & Industrial Strategy, "End to coal power brought forward to October 2024", press release, 30 June 2021

FOCUS 5

The Bazalgette paradigm – A historical lesson in designing for uncertainty (London, 1858): anticipation as a polar star

For a transition that must be largely completed within three decades, history counsels deliberate action. Interestingly, at moments of structural change, Europe has performed best when it invested in infrastructure early, at scale, and with a clear recognition that resilience is not something markets deliver on their own, but a property of the systems on which markets depend. The trans-European transport networks, integrated energy markets, and digital infrastructure were not built in response to crisis; they were built in anticipation of it. In each case, shared systems bred private confidence and sustained long-term growth, and this was already the case almost two centuries ago.

Confronted with the Great Stink and unable to anticipate London's future expansion, Chief Engineer Joseph Bazalgette deliberately rejected the optimization logic of his time. Rather than sizing London's new sewer system to projected demand, he doubled the diameter of its main interceptors, arguing that "we are only going to do this once." The decision reflected a recognition that infrastructure lifecycles far exceed the reliability of any forecast.

Bazalgette embedded optionality directly into the physical asset. What appeared as excess capacity became a source of resilience, allowing the network to accommodate more than four times the population it had originally been designed to serve without requiring fundamental reconstruction. By contrast, a perfectly optimized system would likely have reached its limits within a few decades, forcing costly replacement. The lesson extends well beyond Victorian engineering: in environments characterized by profound uncertainty, resilience often depends less on maximizing efficiency than on preserving the flexibility to absorb unexpected change.

EXPERT POSITION 10

Roland Kupers – Polycentric governance in the EU: aligning top-down direction with bottom-up innovation

“Europe's infrastructure challenges should not overshadow the strengths on which it can build. The continent already benefits from some of the world's most advanced infrastructure networks, robust institutions, and a long track record of delivering complex projects. The objective is therefore not to redesign infrastructure systems from first principles, but to build on these existing foundations, accelerate the deployment of proven solutions, and remain focused on the fundamentals that have underpinned Europe's success.

Drawing on Elinor Ostrom's concept of polycentric governance, the challenge is not to choose between centralized planning and decentralized initiative, but to orchestrate both. Effective transitions require strategic direction at the European and national levels while preserving the capacity of regions, cities, operators, and private actors to innovate and adapt to local conditions. Progress depends less on privileging one level of governance than on ensuring coherent action across them.

Europe often experiences this governance model as slow, fragmented, and sometimes frustrating. Yet this apparent complexity is also one of its greatest institutional assets. The ability to coordinate decisions across multiple actors and levels of governance has been instrumental in building infrastructure systems that are among the world's most reliable, resilient, and interoperable.

In this context, Europe must continue to strengthen the capabilities that have made its infrastructure successful, while significantly increasing the speed of implementation. At the same time, it must identify the relatively small number of catalytic interventions capable of generating system-wide effects, accelerating progress not only within individual sectors but across the transition as a whole.”

Both statements are true at once. Europe's networks remain among the best in the world, and Part 1 has shown how fast that advantage is eroded when investment lags. Kupers's argument follows from holding the two together: the starting point is strength, the task is renewal.



Roland Kupers
Complexity, Resilience, Energy Transition Expert

Governing for multiple plausible futures: consequences for the environmental transition

CHOOSING THE RIGHT DIRECTION: THE COST OF GETTING IT WRONG

The lesson for the environmental transition is not that targets are useless – they coordinate expectations, and this report does not propose to weaken them. The lesson is that the four parameters detailed above cannot be settled from the endpoint: they must be steered along the way, revised on evidence, within limits that protect the destination.

Europe’s test is therefore not whether to decarbonize, but whether it can convert decarbonization into a cost advantage, a market position and a sovereignty gain simultaneously: by building the networks that turn cheap clean generation into cheap industrial energy, by anchoring clean-technology demand in European capacity where dependence is strategic, by treating nature and materials as part of the competitive base, and by mobilizing its own savings to finance the effort. The window for this conversion is set by the physics of the transition and the pace of its competitors – not by the political calendar.

Yet **urgency is a poor guide to direction.** The cost of inaction is now documented well enough to anchor regulatory and investment decisions; the cost that remains within Europe’s control is a less visible one – that of poorly designed action, where stranded assets, locked-in trajectories and misallocated capital arise not from moving too slowly, but from choosing the wrong technology, the wrong sequence or the wrong allocation of risk. The distinction matters because Europe’s ambitions for a sustainable, competitive and sovereign economy depend on the capacity of its infrastructure to reshape demand, technology and operating conditions at once – and infrastructure, once built, forgives speed more readily than it forgives direction.

The cost of wrong action takes three recurring forms, each with a European precedent.

- The wrong technology locks resources into a dead end: Europe’s diesel episode is the cautionary case, as tax regimes that favored diesel to cut CO_2 per kilometer created a second, unpriced externality – the NOx and particulate pollution that culminated in “dieselgate”;

- The wrong sequence can leave capacity underused and raise system costs: Germany’s mismatch between renewable generation and transmission capacity illustrates the cost of expanding supply before the grid can deliver it where needed;

- The wrong allocation of risk destroys confidence or crowds out capital: Spain’s retroactive cuts to solar tariffs triggered years of arbitration and a lasting rise in its cost of capital.

Two scenes from the middle of the decade capture the problem better than any statistic:

On 8 September 2023, the UK published the results of its fifth allocation round, opened on 30 March 2023, with no offshore-wind project securing a contract: the price cap had drifted below viable cost as interest rates and supply chains repriced the industry beneath it (see above);

In 2025, after a decade of announcements and tens of billions in pledged support, the projects in the global hydrogen pipeline that had actually reached final investment decision amounted to just 9% of what had been announced

COMPETITIVENESS AND SOVEREIGNTY: TWO MAJOR FACTORS OF ADJUSTMENT

Nonetheless, adjustment does not operate in a vacuum. Competitiveness and sovereignty constrain the set of admissible routes – a pathway that meets the environmental objective can still fail if its cost weakens users, or if its material base replaces one external dependence with another.

The Critical Raw Materials Act makes this boundary measurable through four benchmarks for 2030: European extraction capacity equivalent to 10% of annual needs, processing capacity equivalent to 40%, recycling capacity equivalent to 25%, and no more than 65% of annual consumption of any strategic material, at a relevant processing stage, supplied by a single third country. The benchmarks are deliberately chained: more extraction does not secure delivery if processing remains concentrated; more processing does not reduce exposure if neither primary supply nor recycling can feed it.

Supply concentration can turn that constraint into an operating event. When China introduced export controls on seven heavy rare earths and related magnets in April 2025, shipments of rare-earth magnets fell by around 75% year on year in May and manufacturers cut utilization or paused production. China supplies 94% of sintered permanent magnets and was the leading refiner for 19 of the 20 minerals analyzed by the IEA in 2025, with an average market share of around 70%.[93] The project with the lowest unit cost can impose a higher system cost once interruption and replacement are included.

This exposure enters design before procurement. A technology route should identify the material stage that constrains it, the inventory or alternative specification able to bridge interruption and the capacity whose development reduces concentration. For an operator, continuity may justify a higher component cost; for an investor, it changes completion and utilization risk; for public authorities, it locates where industrial policy can alter delivery rather than subsidize demand for an input that remains unavailable.

TURNING PATHWAYS INTO INVESTMENT DECISIONS

Once strategic constraints have narrowed the feasible set, the remaining task is to make delivery choices explicit. For each candidate route, the capital plan records the technology selected, the pace at which supply and adoption can move, the interfaces that determine sequence and the evidence that would defer or redirect the next commitment:

Once technology, pace and sequence have been specified, the pathway still has to work as one system. Railway operators show what compatibility can require beyond the asset: British companies began adopting Greenwich-based railway time in 1847, most public clocks followed by 1855, US railroads introduced standardized zones in 1883 and federal law followed only in 1918.[94] Infrastructure can create the need, and the operating practice, for a rule before government enacts it; the planning task is not always to wait for a complete institutional design, but to identify which shared convention operators can establish and which legal change must follow.

The same logic governs project appraisal. An asset does not deliver a service on its own: a project can come in on time and on budget and still deliver nothing, because the interfaces it depends on are not there – onboard signaling without trackside equipment, a charging hub without its grid connection. Appraisal must therefore judge two things beyond commissioning: whether the interfaces that make the asset's output usable will exist when it does, and what options the asset creates or destroys – spare capacity, reserved land, modularity and lead time matter because an asset optimized for its first use can make later expansion or repurposing more expensive

Options, in turn, have a price – and it must be faced explicitly rather than discovered in retrospect. Victoria's Wonthaggi desalination plant, built for AUD 3.5bn after the Millennium Drought, was completed in December 2012, remained idle for more than four years, and first supplied water in March 2017; its availability cost was reported at about AUD 600m a year. That cost bought an activatable drought response, not merely unused capacity – the contract kept the plant maintained throughout the idle period, and its value lies in the lead time and losses avoided when scarcity returns.

Evidence is what keeps these comparisons honest over time. At each review, demand, capability, interfaces and cost either justify the next tranche of capital, or require the option to be preserved or redirected; a calendar review with no consequence merely records delay.

The architecture is now complete. The target provides direction, while competitiveness, sovereignty and irreversibility exclude inadmissible routes. Authorities, operators and investors can then distinguish what is ready, what remains conditional and which evidence would change its status.

Thames Estuary 2100 gathers the whole argument of this section (Focus 6) into a single working example: a destination held fixed, four parameters kept adjustable, boundaries respected, options priced, and capital committed on evidence. It demonstrates that a pathway can be governed without either freezing the route or reopening the purpose. The five operating conditions developed below, carry that discipline into delivery – with failure in any one able to reopen a choice made under another.

93 - IEA, *Global Critical Minerals Outlook 2025*, 2025; IEA, *Rare Earth Elements*, 2026.

94 - Royal Museums Greenwich, *"What is Greenwich Mean Time (GMT) – and why does it matter?"*, 2026; Smithsonian National Museum of American History, *Time and Navigation, "1883: Standard Time"*, 2026.

EXPERT POSITION 11

Ana Giros – Transitions require a paradigm shift in the infrastructure design: Modular, flexible and designed to adapt to future evolution

"Infrastructure investment should first be aligned with the long-term trends that are shaping our world and are unlikely to reverse: decarbonization, digitalization and industrial resilience. The challenge is that technologies, demand patterns and operating conditions continue to evolve rapidly. Waiting for certainty is not an option. A paradigm shift is required in the way infrastructure is conceived. It needs to be designed and deployed differently: more modular, more flexible and more capable of adapting over time.

Rather than building around a single technological pathway, infrastructure should be deployed in phases, allowing each stage to integrate new technologies and respond to changing needs. At Equans, this approach is increasingly applied in sectors such as data centers, where long-term infrastructure must accommodate fast-moving technological cycles. Modularity is more than a design choice; it is a form of resilience. It preserves optionality in an uncertain environment and helps infrastructure remain relevant as technologies evolve.

In addition, today's data availability enables better monitoring systems and asset visualization tools, making it possible to assess performance continuously and adjust investment choices as conditions evolve. The ability to observe, learn, and improve in real time is becoming a critical dimension of infrastructure performance.

In this context, infrastructure can no longer be viewed as a static asset delivered for a single purpose. It must be capable of evolving alongside the systems it serves, integrating new technologies, responding to changing demand and supporting future uses that cannot always be anticipated at the outset. The infrastructure of the future will not be defined by its permanence, but by its capacity to evolve."



Ana Giros
EVP Strategy, Development and CSR at Equans

EXPERT POSITION 12

Sébastien Fraisse – Building infrastructure that remains valuable under multiple futures: less predictable infrastructure planning

"For decades, infrastructure planning was built on a simple assumption: economic activity would continue to grow, demand for infrastructure would increase accordingly, and capacity could be expanded to match. In transport, this logic has traditionally been reflected in models linking traffic growth to GDP growth. Today, however, these relationships have become far less predictable. Climate change, demographic shifts, evolving mobility patterns, technological disruption, and growing geopolitical uncertainty are reshaping demand in ways that make linear forecasting increasingly unreliable.

In this new environment, long-term value creation depends less on accurately predicting future demand than on building the capacity to adapt to it.

Infrastructure assets must be designed to accommodate changing patterns of use, evolving technologies, and shifting territorial dynamics throughout their lifetime. Geographic diversification, portfolio diversification across infrastructure sectors, and concession models that allow assumptions to be revisited periodically all provide valuable sources of flexibility in an increasingly uncertain world.

The challenge is therefore no longer simply to build more infrastructure, but to build infrastructure that remains valuable under multiple futures. Rather than optimizing assets for a single demand scenario, cities, operators, and investors should prioritize optionality: designing assets that can be repurposed, upgraded, or adapted as economic, technological, and societal conditions evolve. Infrastructure planning must progressively move from forecasting the future to preparing for it.

Ultimately, adaptability is becoming a strategic asset in its own right. In an era where uncertainty is structural rather than temporary, the ability of infrastructure to evolve may prove more valuable than the ability to maximize capacity under a single set of assumptions."



Sébastien Fraisse
CEO of Indigo Group

FOCUS 6

Thames Estuary 2100, a fixed objective and an adjustable process

The Thames Estuary 2100 Plan holds flood protection fixed while keeping asset decisions open. London depends on 330 kilometers of defenses, nine barriers and hundreds of gates and pumps. The objective does not determine which works should be commissioned or when, so the plan connects monitoring to decision dates and preserves competing technical options.

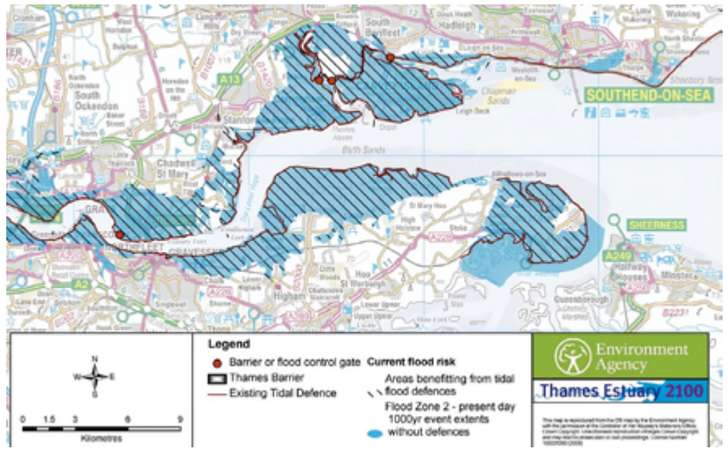
he 2023 review brought the deadline for raising defenses upstream of the Thames Barrier forward from 2065 to 2050 and the decision on the barrier's successor from 2050 to 2040. Asset condition, sea-level projections and urban development pulled the investment sequence forward by up to fifteen years without changing the protection objective.[95]

The 2040 decision date establishes the hierarchy: direction coordinates the process and evidence governs commitment. Capital is released when an observed threshold makes the next asset necessary; land, permissions and technical options are preserved beforehand so that waiting does not foreclose the response. Adjustment is part of delivery, not a reason to reopen the purpose whenever conditions change.

FIGURE 12

Thames 2100 Estuary project plan area

Source: Environment Agency, 2023

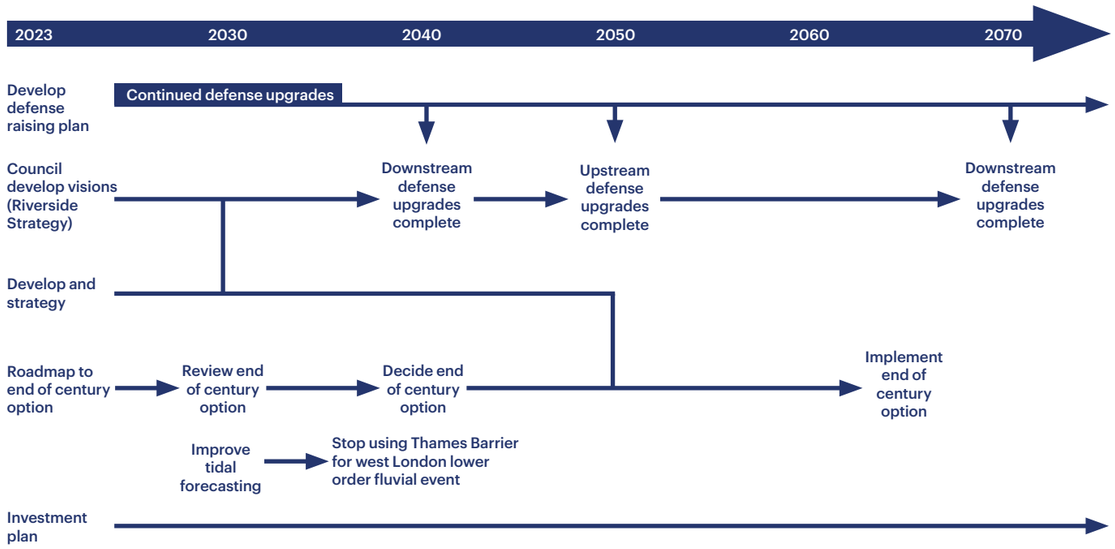


95 - Environment Agency, *Thames Estuary 2100 Plan*, 10-year review (major updates 2012–2023), 2023.

FIGURE 13

Thames Estuary 2100 adaptive pathways and decision points

Source: Environment Agency, 2023



The pathway in operation: five delivery conditions for a successful transition

Governing the pathway ultimately means moving from the transition objective to the services that must be maintained throughout the transformation, and to the assets that provide them. Capital planning therefore starts with an asset-and-service map: which components still carry an indispensable service, which can decline, which can be repurposed, and which replacements must be in place before retirement becomes possible.

This reveals the fundamental constraint of transition delivery: the system must transform while continuing to operate. From this single constraint, five delivery conditions follow in logical sequence:

Because the old and the new must run together for a time, the incumbent must keep serving until every user has a substitute – preserve the service floor;

- Because new capacity delivers nothing until every link in its chain exists, the binding investment is the weakest interface;

- Because the incumbent silently provided more than its visible output, every function must be replaced before retirement, including the hidden ones;

- Because each condition met displaces the constraint elsewhere, investment must be re-ranked as the bottleneck moves;

- And because the interim costs of all of the above fall unevenly, the actors exposed to them must remain able to complete the sequence.

CASE STUDY 3

Cyneo, building the missing market for construction reuse[96]

C–

Cyneo is a subsidiary of Bouygues Construction, launched in July 2023 to develop the circular economy in the construction sector by structuring a national network for the reuse of construction materials. It brings together suppliers, demolition operators, contractors, project owners and local authorities around an e-commerce platform, technical centers, and support services designed to guide construction projects in implementing reuse practices and to help industries create new circular offerings.

The initiative addresses a specific market failure. France's construction industry produces 46 million tons of waste per year, of which 80% could technically be reused, but only 1% is actually reused, largely because the supply, logistics, quality, guarantees and insurance frameworks for reused materials remain fragmented. Cyneo brings these missing links together in its community and technical centers, equipping each stakeholder with the necessary means to master the market, develop their activities, manage storage, reconditioning, transport and trade materials, and train their teams.

Since the first center opened in Vitry-sur-Seine near Paris in November 2023, the network has continued to expand its territorial presence to stay close to its community. Cyneo opened two new technical centers: one in Saint-Aignan-de-Grandlieu near Nantes in January 2025, and another in Saint-André-lez-Lille in February 2026. The latter introduced a hub-and-spoke model with satellite storage across the region to shorten logistics distances.

Today, the Cyneo community comprises more than 200 members all around France representing all construction trades, of which 100 are suppliers of circular materials. “La Boutique Cyneo” has also become France's leading e-commerce platform exclusively offering circular materials for construction professionals.

96 - Bouygues Construction and Cyneo, company, network and center information.



Condition one: preserve the service floor

SERVICE CONTINUITY MEASURED BY PERFORMANCE, NOT NAMEPLATE

Service continuity sets the floor that transformation cannot cross – and it is defined by performance, not by nameplate. Replacement must cover annual output, peak demand, reserve, flexibility and users without substitutes before incumbent capacity can close; installed capacity establishes none of these at the hour or location that constrains the service.

Transformation consequently creates a period in which two configurations run together: the incumbent supplies the functions that have not yet moved, while the emerging system builds capacity before every user or interface is ready. The program must fund that overlap and attach an exit condition to each incumbent service. Without the budget, continuity fails; without the exit condition, coexistence becomes indefinite.

FRANCE'S COPPER NETWORK MAKES THE TENSION VISIBLE:

Maintaining it costs around €500m a year even as traffic and access revenue move to fiber. The financial case for closure strengthens with each migrated user – but the operating case depends on telephone lines, payment terminals, lifts, alarms and emergency calls that broadband-coverage statistics do not capture.

In January 2026, commercial closure had reached about 25,000 municipalities, while 8,028 were deferred to January 2027. The last dependent use, not the national average, sets the retirement date.

The copper case distinguishes two stages: commercial closure stops new subscriptions, while technical closure ends existing services.[97] Deferring commercial closure where eligibility conditions are unmet is a preventive safeguard; it does not establish that premature retirement has already disrupted service. The underlying risks remain symmetrical: maintaining the incumbent indefinitely prolongs its cost, while technical closure before essential uses have migrated threatens service continuity.

Approval of the replacement asset is therefore distinct from approval of incumbent closure – and retirement follows service categories rather than a single coverage threshold. Each use requires a substitute, a migration owner, a funded conversion plan and evidence of operation before its incumbent function can close: one municipality can remain on copper because a critical service lacks a substitute even where fiber is present, while local closure can proceed before national completion where every dependent use has migrated.

THE INCUMBENT-RETIREMENT LEDGER AS THE CLOSURE TEST

An incumbent-retirement ledger makes the distinction operational:

For each service category and territory, it records the dependent users and their substitute, the migration cost and its accountable owner, the date of demonstrated operation, and the avoidable cost released by closure.

The ledger prevents two errors at once: financing the old network after its last indispensable use has moved, and removing it while a low-volume critical use remains. Continuity, however, only defines the floor. Whether the new system can actually take over depends on whether its capacity is usable – and capacity is usable only through complete interfaces.

97 - Arcep, "Que va changer la fermeture du réseau cuivre ?", 2026.

FOCUS 7

Groningen: closing Europe's largest gas field without breaking the floor

The Netherlands closed Europe's largest gas field – c. 2,300BCM produced since 1963 – in the middle of a continental gas crisis, and did it without a supply failure. Production from Groningen halted on 1 October 2023 and closure became definitive in April 2024, forced not by depletion but by induced seismicity that a 2023 parliamentary inquiry called an "unprecedented system failure" in the state's duty of care to residents.

The service floor was engineered before the retirement date, not after it. Because Dutch and neighboring appliances are calibrated to low-calorific Groningen gas, closure was possible only once the Zuidbroek nitrogen plant and expanded conversion capacity could transform imported high-calorific gas to Groningen quality at scale – the hidden interface that, more than any import contract, set the true closure date. The wells were then sealed, deliberately converting a political decision into a physical irreversibility.

The case completes the coal example from the other direction: Britain retired an incumbent when replacement was demonstrated; the Netherlands retired one when society's tolerance for its externality collapsed – and still had to satisfy the same condition. Whatever forces the retirement, the floor must be rebuilt first; the only choice is whether the interface is financed in anticipation or in emergency.



Condition two: complete the weakest interface

CAPACITY DEPENDENCIES ACROSS SYSTEM INTERFACES

An interface that no single actor can complete alone turns investment into a coordination problem: each party is right to wait for the others, and the service arrives only when the layers converge. Installed capacity becomes usable only when every interface in the service chain is available.

By the end of 2024, around 57% of the required radio layer on European Transport Corridors was equipped, against about 15% for trackside ETCS signaling and roughly one quarter of operating tractive vehicles for onboard equipment. A train can use ERTMS only where radio, trackside and onboard layers coincide; investment that expands the layer already ahead creates idle capacity, however large its nominal addition.[98]

The constraint takes three forms, and only one of them is made of steel:

Physical interfaces connect equipment and networks through compatible dimensions, voltage, pressure or loading gauge.

Digital interfaces align data, signaling and operating protocols.

Institutional interfaces determine whether physically compatible assets are allowed to operate across jurisdictions.

The institutional interface is usually the cheapest of the three to complete, yet long the most neglected. European rail illustrates it. In 2016, a vehicle technically able to run across the continent still had to be authorized against some 13,450 national technical rules; each rule was a legal reason to keep a compatible train idle at a border. Harmonization has cut them to 721 as of September 2025[99] – barriers removed that no construction budget could have addressed. The clean-up has a limit, though: off the main corridors, legacy national signaling remains in place, and trains must still carry several onboard systems – the ERTMS gap shown above. Condition two in miniature: one interface closes, and the constraint moves to the next weakest.

Standards decide when interfaces converge – and who pays for, and profits from, the convergence. EU regulation now requires a common connector for public EV charging, and charging pools of at least 400 kW every 60 km along the core trans-European road network by the end of 2025[100]. Such a standard looks technical; its effects are economic. It decides which users get access, which suppliers remain interchangeable over the asset's life, and who bears the cost of migrating from the old configuration to the new.

ONE UNIT OF SERVICE ACROSS THE CHAIN, HEADROOM AT THE WEAKEST LINK

Expressed in one common unit of service, the chain then reveals what planning needs: capacity at every link, the date at which each becomes technically and legally usable, committed compatible demand, and headroom at the weakest point.

A missing standard or authorization delays expenditure; missing physical capacity makes the interface itself investable; lagging demand keeps additional supply conditional. Capability, commissioning dates and contracted use must converge across the same chain.

98 - European Union Agency for Railways, *Interoperability Overview* 2025, 2025.

98 - European Union Agency for Railways, *Report on Safety and Interoperability in the EU*, 2026 edition.

100 - Regulation (EU) 2023/1804 on the deployment of alternative fuels infrastructure, 2023.

Condition three: replace every function, including the hidden ones

FUNCTIONS HIDDEN BEHIND NOMINAL CAPACITY

End-to-end capacity can still conceal functions that are lost when an incumbent asset retires. Electricity systems require reserve, fault response and voltage control in addition to energy; water, mobility and communications networks likewise carry reliability, emergency access or coordination functions absent from headline capacity.

Ireland exposes the gap: in 2024, the all-island electricity system operated with up to 75% instantaneous generation from wind, solar and converter-based imports – while keeping at least seven conventional units connected for inertia and fault response[101]. The operating logic must be replaced alongside the asset; a pathway that reproduces only visible output can remove the very function that made the incumbent service stable.

REPLACEMENT CAPABILITY BEFORE RETIREMENT

Hidden functions become actionable once they are specified, measured and procured as services. Great Britain's third stability tender awarded £1.3bn of contracts in 2022 for 17.1 GVA.s of inertia and about 12.7 GVA of short-circuit level, against a stated £14.9bn benefit between 2025 and 2035[102]. The tender did not add an energy target; it converted an operating requirement into a quantity that could be procured before the assets providing it retired.

Ireland followed the same route: system operators procured 10,963 MVA.s of low-carbon rotational inertia in 2024 – around 45% of the system floor for that service – from synchronous condensers due in 2027, and a second procurement approved in March 2026 targeted a further 14,000 MVA.s together with reactive power and short-circuit contribution.[103]

Evidence remains decisive after procurement. Ireland's trial to raise the instantaneous converter share from 75% to 80%, on a path toward 95% by 2030, remained on hold while large consumers demonstrated that they would stay connected through brief voltage dips during a system fault[104]: the remaining constraint sat with assets outside the system operator's ownership.

Decommissioning approval therefore follows a function-by-function acceptance test across every relevant owner – not a forecast that enough aggregate capacity exists. And once continuity, interfaces and functions are secured, a new question arises: where should the next unit of capital go?

101 - Single Electricity Market Committee, *Low Carbon Inertia Services (LCIS) Procurement Phase 2 Decision Paper*, SEM-26-011, 6 March 2026.

102 - National Grid ESO (now NESO), *Stability Pathfinder Phase 3 Results*, 23 November 2022.

103 - Single Electricity Market Committee, *LCIS Procurement Phase 1 Information Note*, 29 October 2024; Single Electricity Market Committee, *Low Carbon Inertia Services (LCIS) Procurement Phase 2 Decision Paper*, SEM-26-011, 6 March 2026.

104 - EirGrid, *Fault Ride Through Issue Update and Assessment of Alternative Solutions*, June 2026.



Condition four: redirect investment to the next bottleneck

BOTTLENECK DISPLACEMENT DURING TRANSFORMATION

Once continuity, interfaces and functions are specified, the next investment belongs at the constraint that limits delivered service – and that constraint changes precisely because the pathway succeeds.

In California, batteries absorbed around 14.7% of system load during high-solar late mornings in 2024 and supplied close to 84% of frequency regulation, while storage represented around 45% of capacity in the connection queue by mid-year. Generation had ceased to be the only constraint; moving available output across the day, and using it for system control, had become a larger source of marginal service. The queue did not prove that every battery was useful – but it showed why preserving the original project order would have directed capital at a link that was no longer the bottleneck.[105,106]

Eligibility rules must move with the bottleneck. Great Britain's stability procurements show the adjustment in real time: the second Stability Pathfinder contracted five grid-forming solutions; the third procured 29 contracts for physical inertia and short-circuit contribution; a long-term stability-market tender then replaced the Pathfinder format for delivery from 2029 onwards.[107] The requirement remained system stability, but the service definition, admissible technologies and contract horizon changed as capability became observable.

ADAPTIVE SYSTEMS AND ELIGIBILITY RULES

Operationally, sequencing starts with the distinction between enabling and dependent measures. Network upgrades, standards, data systems, permitting and operating rules enable capacity to function, while generation, vehicles or capture plants remain dependent where those conditions are missing (Focus 8).

FOCUS 8

Norway's electric-vehicle transition: thirty years of moving investment to the next bottleneck

Norway went from near-zero battery-electric sales to near-total electrification of new passenger-car registrations in roughly thirteen years: BEVs took 88.9% of new passenger-car registrations in 2024 and 95.9% in 2025 – a share no other country approaches, achieved across a record 179,550 registrations[108]. Its relevance to this condition is the redirection: each time one bottleneck cleared, investment moved to the next – purchase incentives first, then charging coverage, and now, with coverage built, grid capacity. The lesson from this transition is the order in which things were done – and four design choices carry it:

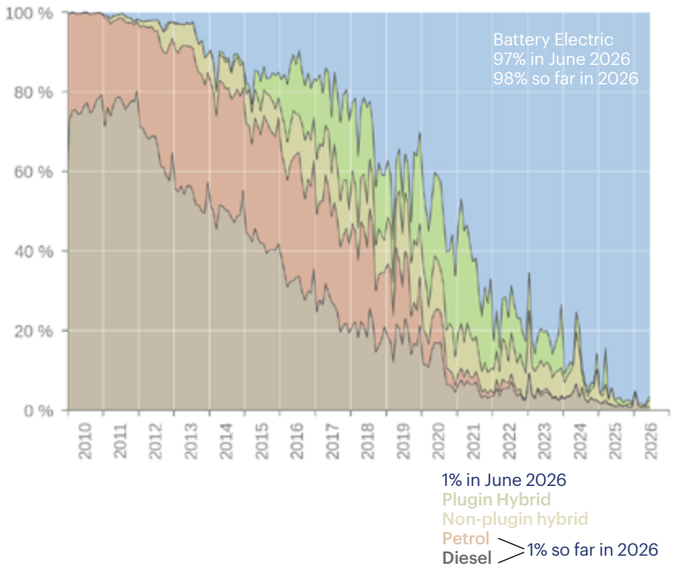
- **The default was engineered, not preached. Import-tax exemption from 1990, VAT exemption from 2001, toll relief and parking privileges – sustained over several decades, with instruments progressively adjusted as adoption increased – made the electric car the rational choice[109].**
- **Chargers preceded cars. Highway fast charging and dense urban coverage were built ahead of the fleet, killing range anxiety before it became a buying objection. Over 10,000 fast and ultra-fast chargers were deployed, with the focus now shifting from expansion to capacity strengthening[110]**
- **Friction was removed segment by segment – government, utilities, automakers and consumers each owned their piece of the journey; nobody waited for anybody.**
- **The comparison was rigged in the right unit. Norway made the market compete on total cost of ownership, not sticker price – the one contest the EV wins from day one.**

Transition support should be assessed against its purpose, duration and fiscal sustainability. Some support can be withdrawn as adoption and competitiveness improve; other mechanisms may remain justified where they pay for enduring system benefits that market revenues do not capture. Norway is also withdrawing the support on the sequenced model that built it: toll and parking privileges were scaled back from 2017, the VAT exemption was capped in 2023, and adoption still rose, to 95.9% of new registrations in 2025.

FIGURE 14

EV adoption in Norway (2006-2025)

Norsk elbilforening (Norwegian EV Association), Norwegian charging statistics – NOBIL database, 2025.



Condition five: sustain transformation under uneven cost incidence

UNEVEN EXPOSURE TO TRANSFORMATION COSTS

A technically coherent sequence can still stop if the actors exposed to its costs cannot sustain them. The share of the EU population unable to keep its home adequately warm rose from 6.9% in 2021 to 10.6% in 2023, then fell to 9.2% in 2024; 9% remained in arrears on rent, mortgage or utility bills.[111] Households below 60% of median income devote 37% of disposable income to housing, against 16% for the rest.[112]

Aggregate cost conceals both distribution and timing. Users may pay for new equipment before savings arrive, regions may lose employment before replacement activity scales and declining networks may retain fixed costs after higher-income users exit. Sequencing must therefore show when each group pays, when it gains access to the substitute and when benefits arrive.

NAMING THE BURDENS BEFORE COMMITMENT, VERIFYING THEY STAY BEARABLE

The discipline has two steps. The first comes before commitment: the burdens are named, and each is assigned a bearer. Germany's 2020 coal-exit package did exactly this – €4.35bn for lignite operators carrying stranded-asset losses, up to €5bn for older workers facing income disruption, and €40bn for coal regions adjusting through 2038[113]: three exposures identified, quantified and financed before the exit was locked in.

The second step comes once the policy runs: assumptions are checked against observed results, read for what they actually establish. Six months after London extended its outer low-emission zone, compliance exceeded 96% and roadside nitrogen dioxide in outer London was estimated to be around 21% lower than in a scenario without any ULEZ phase[114]. Those numbers establish that drivers adapted and that air quality improved; they do not establish that the adaptation was affordable for those who paid for it. Two further checks are therefore needed before the next step of a sequence is imposed: that affected users have an accessible substitute, and that the burdens concentrated on specific groups have remained within the limits announced at the outset. Early environmental results are not evidence that every group can sustain the rest of the journey.

FROM COST INCIDENCE TO POLITICAL LICENSE

Political acceptance is a delivery condition. The causal chain is short: costs concentrated on groups that do not accept them produce opposition; opposition finds electoral expression; and an election can revoke what planning committed. The arithmetic of infrastructure makes the exposure structural: an asset written over thirty years will live through seven or eight electoral cycles, in several countries and under governments not yet elected. A pathway is only as robust as its ability to survive alternation.

Two design levers determine this robustness. The first is distributional design – the discipline set out above: naming who pays, when the substitute arrives, and holding concentrated burdens below their stated limits, as Germany's coal-exit package did before committing. The second is an informed public sphere. Citizens accept trade-offs they can see and weigh: acceptance is formed upstream, by a decision clearly posed, transparent about its costs and open to contestation – the public sphere in Habermas's sense[115], where collective choices are explained, debated and legitimated, and where media carry the deliberation: they determine whether costs stay legible as trade-offs or harden into symbols. One practical consequence follows: opposition heard early, while design can still respond, strengthens a project; opposition discovered late leaves only confrontation.

Where this license is built, transitions survive shocks and outlive their initiators – the Vienna case below shows the mechanism at asset level. Where it is neglected, contested projects slow down, reversals multiply, and the fragility becomes measurable in risk premiums and financing costs; that economic translation is taken up in Part 3. Political sustainability is one of the criteria a pathway is designed against.

105 - California Independent System Operator, Department of Market Monitoring, update memorandum, 2024.

106 - California ISO, Department of Market Monitoring, *2024 Special Report on Battery Storage*, 2025; California ISO, Department of Market Monitoring, *2023 Special Report on Battery Storage*, 2024.

107 - NESO, *Long-term 2029 Tender*, 2025–2026.

108 - Norwegian Road Federation (OFV), *annual registration statistics*, 2024–2025 (88.9%; 95.9% of 179,550 registrations; 97.6% in December 2025).

109 - Norwegian EV Association, national policy record (import-tax exemption 1990, VAT exemption 2001, progressive withdrawal from 2017, VAT cap 2023, new VAT rules 1 January 2026).

110 - IEA Technology Collaboration Programme on Electric Vehicles (EV TCP), *Norway country overview*, 2026; Norsk elbilforening, NOBIL charging database (Enova), 2025.

111 - Eurostat, EU-SILC, "Inability to keep home adequately warm" and "Arrears on utility bills", 2025.

112 - Eurostat, *Housing cost overburden statistics*, EU-SILC, 2025.

113 - German Federal Government, *Kohleausstiegsgesetz* (Coal Phase-out Act) and *Strukturstärkungsgesetz Kohleregionen*, 2020.

114 - Greater London Authority and Transport for London, *London-wide ULEZ Six Month Report*, 2024; ULEZ One Year Report, 2025.

115 - Habermas J., *The Structural Transformation of the Public Sphere*, 1962

One system, five coupled conditions

The five conditions interact rather than form five successive approvals. Funding dual running protects continuity, but prolonging it can raise tariffs; accelerating retirement releases cost, but only if interfaces and hidden functions have moved; completing an interface can displace the bottleneck to user equipment, contracted demand or affordability. Each gain changes the evidence required at the next review.

A pathway is deliverable, in sum, only when the five conditions hold together – and they generate five linked capital decisions: fund dual running until the service floor is secured; complete the limiting interface; procure replacement functions before retirement; re-rank the pipeline around the current bottleneck; and keep interim burdens within the capacity of exposed actors. Failure of any one condition blocks or redirects the next commitment.

The five delivery conditions help identify risks of technological mismatch and poor sequencing before capital is committed. They do not, by themselves, establish that a technology is the best environmental or economic choice; that requires comparison with alternative pathways. Evidence should also match the decision being taken, from preparing an investment to commissioning it or retiring an incumbent asset. Where these tests are neglected, costs can accumulate through premature asset replacement, avoidable emissions and service losses, switching costs and capital unavailable to finance a revised route. Nominal progress is not enough: an investment must increase usable service without closing the system's ability to adjust. The third failure mode remains open. A pathway may be technically deliverable and still fail if it does not specify who finances the assets, absorbs uncertainty and bears the cost when assumptions break. This shifts the analysis from the pathway itself to the system of institutions, contracts and capital through which it must be delivered – the subject of Part 3.

FOCUS 9

Vienna: decarbonization that keeps its social license

Vienna owns or subsidizes housing for around 60% of its residents, and it is decarbonizing this stock – district-heating expansion, deep retrofits, geothermal energy, large-scale greening of façades, roofs and streets – while keeping rents among the lowest of any major Western European city[116].

The costs do not disappear, and their allocation depends on ownership and financing arrangements. In municipal housing, the city acts as owner; in subsidized cooperative housing, other housing providers also carry investment responsibilities[117]. Long-term ownership and public support can spread renovation costs over the asset's life, but do not automatically shield occupants from those costs. The relevant test is how financing, subsidies and energy savings translate into rents, charges and public expenditure over time.

As of 2024, some 80 retrofit projects were underway across Vienna's social-housing blocks, representing around €800m of investment; in a 1960s municipal block on Gregorygasse, added insulation, new windows and prefabricated timber extensions cut the building's energy needs by 87%, and retrofits of this depth can reduce housing-sector emissions by up to 51%[118]. Under the 'Raus aus dem Asphalt' program, some 320 unsealing and greening projects are cooling public space across the districts[119]. The model is not exportable as such – it presupposes a large public housing stock and the fiscal capacity to carry it. The transferable principle is to align renovation finance with the life of the asset while explicitly limiting the burden on residents. This can strengthen the affordability and political durability of decarbonization, provided that investment costs and energy savings are distributed in a way that sustains support.

116 - City of Vienna – Wiener Wohnen, 2025; Green European Journal, "Light, Air, Sun, Carbon Neutrality: Greening Vienna's Social Housing", 2024.

117 - City of Vienna, "The Vienna model", *Social Housing in Vienna*, undated.

118 - Green European Journal, "Light, Air, Sun, Carbon Neutrality: Greening Vienna's Social Housing", 2024.

119 - City of Vienna, Raus aus dem Asphalt – *Lebenswerte Klimamusterstadt*, programme review, 2025.

FOCUS 10

Plan France Très Haut Débit: a national roll-out that outlived its governments

Few programs have exercised every delivery condition at once. France's fiber roll-out is one of them. The direction was European – the EU's 2010 Digital Agenda set broadband targets for every member state[120] – and the destination was fixed in 2013 by the Plan France Très Haut Débit: full-territory coverage, some €20bn of public and private investment, a dedicated national mission to steer deployment and the sector regulator, Arcep, to police access[121].

The pathway, however, was designed condition by condition. Sequencing: the country was divided by density, so that each zone advanced at the pace its economics allowed – operators competing on their own networks in dense areas, private roll-out under coverage commitments in mid-density areas, and public-initiative networks (RIP), tendered by local authorities as long-term concessions, where no commercial case existed. Interfaces: rather than rebuilding, the new network completed the old one's physical layer – some 7,000 km of existing ducts and 200,000 poles reused in the Cap Fibre concession alone[122] – while Arcep's access regulation kept the institutional interface open to all retail operators. Adaptation: when each remaining connection proved longer and costlier than the last, the completion dates moved and the copper switch-off was tied to the progress of its replacement rather than to a calendar, as noted earlier in this Part – the destination held while the parameters adjusted. Cost incidence and license: subsidies flowed to the territories the market would have bypassed, and acceptance was built rather than assumed – in Nord and Pas-de-Calais, some 150 public meetings across 800 municipalities accompanied the roll-out, with local insertion and training programs attached to the works[123].

The dividend came from the capital market itself. A decade ago, banks treated digital networks as high-risk assets warranting only short-term lending; the stability of the concession framework reversed that perception, first lengthening bank structures, then drawing in institutional debt investors that now treat the asset class as resilient and essential. Regulatory credibility, in other words, converted directly into cheaper and longer capital – the mechanism Part 3 examines in general form.

The results are measurable: as of September 2025, France had 29.4m homes passed by FTTH/B, household penetration of 83.6% and take-up among homes passed of 89.4%[124], placing it among Europe's leading fiber markets[125]. Launched in 2013, the plan has crossed three presidential terms without losing its direction. A transition delivered not because its target was rigid, but because the system carrying it was stable.

120 - European Commission, *A Digital Agenda for Europe*, 2010.

121 - French Government, *Plan France Très Haut Débit*, 2013.

122 - Vauban Infrastructure Partners, 2021 *Report on Impact*, 2021.

123 - Vauban Infrastructure Partners, 2021 *Report on Impact*, 2021.

124 - FTTH Council Europe, *European FTTH/B Market Panorama 2026* (data as of September 2025), 2026.

125 - Scope Ratings, *Financing Fibre: France's Lead over Austria, Germany and Italy*, 2024.

WHAT TO CARRY FORWARD

This part has moved the transition from a target to a route. A destination, however firm, does not determine how it will be reached. Five delivery conditions help test the route: keeping essential services running, completing the interfaces that make assets usable, proving replacement functions before retiring the incumbent, directing investment towards emerging bottlenecks, and keeping interim costs bearable. Applied together, these conditions can expose delivery risks early and guide corrective action. They complement the comparison of technologies against environmental objectives and total system costs. Deliverability also depends on how the remaining risks are allocated and financed. The next part examines the institutions, contracts and capital arrangements needed to support that allocation.

MOBILIZING THE INFRASTRUCTURE FORCE: STRATEGIES TO OPTIMIZE VALUE-CREATION IN AN UNCERTAIN ENVIRONMENT

Key takeaways

→ **In the environmental transition, competitive advantage increasingly sits in the 'infrasystem', not the individual asset.** Low-carbon services depend on tightly connected chains: generation-grid-charging-vehicles; capture-transport-storage; heat source-network-buildings. These configurations often require several owners and authorities to align investments whose value depends on complementary assets arriving in time.

→ **Coordination creates economic value where markets alone cannot.** Shared capacity, coupled resource flows, industrial symbiosis, replication and common skills can raise utilization, reduce duplication and accelerate learning. The marginal euro of infrastructure investment is therefore worth more when it removes a constraint elsewhere in the system, than when it simply adds capacity to an already well-served segment. **The ability to orchestrate multiple actors becomes an economic capability in its own right.**

→ **Efficiency and sovereignty must nevertheless be optimized together.** Every synergy also creates a dependency – on another operator, infrastructure interface, critical resource or external supplier. Greater integration can therefore lower costs while increasing exposure to disruption. The objective is not maximum interdependence, but maximum system value net of dependency risk, with diversification, redundancy or domestic capability justified where the strategic cost of interruption exceeds the efficiency gain.

→ **Regulatory stability and credibility can turn policy uncertainty into a risk that capital can price.** Long-lived infrastructure does not require rules that never change; it requires rules whose change can be anticipated. When adjustment follows a known process and committed investments are treated predictably, investors face less regulatory uncertainty, reducing the risk premium attached to long-lived assets without requiring environmental ambition to be frozen.

→ **Resilience is becoming an economic asset and a condition of sovereignty.** Climate events, network failures, supply-chain concentration and technological or regulatory change ultimately affect the same variables: revenue, operating costs, capital expenditure, asset life and financing conditions. Resilience investments preserve value at asset level while maintaining continuity at system level. Redundancy, adaptability and strategic autonomy should therefore be valued against the losses they prevent, rather than treated simply as additional cost.

→ **The challenge is not to eliminate uncertainty, but to make it investable.** Risk should sit with the actor best able to control, mitigate or absorb it: operators for delivery risks, users or offtakers for contractible demand, and insurers or public authorities for genuinely systemic exposures. Poor allocation raises required returns without reducing underlying risk; good allocation increases debt capacity and lowers the cost of capital. Mobilizing infrastructure capital therefore depends as much on the quality of risk allocation as on the quantity of financing available.

Ecosystem strategies: a competitive edge in the environmental transition

Coordination within infrasystems[126] to unlock value-creation

THE EMERGENCE OF INFRASYSTEMS

The rapid expansion of renewable energy is creating a continuously growing investment universe, with important implications for both capital allocation and asset pricing. As the sector scales, it must attract sustained flows of private capital across the entire project lifecycle – from early-stage development through construction and into operation.

Fossil-energy systems have long depended on coordination across extraction, transport, storage and use. For tradable fuels such as oil, storage and transport can separate production from consumption and allow commodity markets to coordinate part of the chain. Many low-carbon configurations face tighter constraints: electricity supply and demand must remain balanced, heat transport is geographically limited, and hydrogen or captured CO_2 requires suitable connections to users or storage[127]. Asset performance therefore depends on complementary infrastructure, contracts and operating rules as well as on the efficiency of the asset itself.

A decarbonized service is consequently never a single asset: electrified mobility is generation plus grid plus charging plus a renewed vehicle fleet; industrial carbon abatement is capture plus transport plus permanent storage plus a payment mechanism; decarbonized heat is a source, a network and thousands of connected buildings. Each link typically has a different owner, a different investment horizon and a different regulator – making contracts, shared assets and common rules essential complements to price signals.

Two qualifications keep this argument honest.

- Historically, fossil systems also required massive coordination – pipelines, vertically integrated majors, regulated utilities; what is genuinely new is that today's interdependent systems must be built inside unbundled, liberalized sectors, where no single actor holds the whole chain by construction[128].

- Many transition technologies require substantial upfront capital. Solar and wind generation then have low short-run marginal production costs, while heat pumps and electrolyzers remain materially exposed to electricity input costs. Across these technologies, value depends on utilization, input prices and the surrounding configuration: connected demand, usable interfaces and operating rules determine whether the initial investment can earn a return.[129]

Those interdependences have their own implications. An actor can integrate the chain under single ownership, orchestrate it across independent owners, or join a configuration that others assemble. Which answer wins is an empirical question that transaction-cost economics frames precisely: integration dominates where coordination through negotiation is expensive and speed is decisive; orchestration dominates where no actor can hold the chain alone – for reasons of capital, competence or mandate – and where the synergies at stake exceed the costs of coordinating them[130].

The remainder of this section shows that the conditions of the environmental transition push a growing share of infrastructure into the second case, "infrasystems", without abolishing the first.

126 - Frantzeskaki N. and Loorbach D., "Toward governing infrasystem transitions: Reinforcing lock-in or facilitating change?", Technological Forecasting and Social Change, 77(8), 2010, pp. 1292–1301.

127 - IEA, *Electricity Grids and Secure Energy Transitions*, 2023.

128 - Coase R., "The Nature of the Firm", *Economica*, 4(16), 1937, pp. 386–405; Williamson O., *The Economic Institutions of Capitalism*, 1985.

129 - IEA, *The Future of Hydrogen*, 2019, analysis of electricity costs and electrolyzer operating hours.

130 - Williamson O., *The Economic Institutions of Capitalism*, 1985.

CONFIGURATIONS & COORDINATION OPTIMIZING VALUE-CREATION

Within infrasystems, dynamics move the source of advantage from the asset to the system around it, and require coordination strategies to optimize value-creation.

As a result, if coordination carries a premium, the practical question is where that premium sits. Four pools of value recur across sectors, each located between actors rather than inside any one of them – which is precisely why capturing them requires a multi-stakeholder arrangement.

Coupled flows. One actor's waste is another's input, and the value lies in the interface that connects them. Technically recoverable industrial excess heat in the EU is estimated at some 280 TWh a year[131], yet only a fraction is recovered – data centers supply about 1.5% of Stockholm's district heating, a share that is exceptional by European standards (Stockholm Exergi). Where the coupling is built, the economics are compelling: Hamburg's HafenCity district has drawn carbon-free process heat from the Aurubis copper smelter through a 3.7-kilometer connection since 2018 (Aurubis/enercity). What limits replication is not engineering but coordination: the interface is a small asset with two owners, and its revenue depends on a counterparty's industrial process that the network does not control.

Shared capacity. Charging stations, CO_2 pipelines and heat networks carry substantial fixed costs, so low utilization raises the cost per unit of service. Pooling compatible demand can spread these costs across more users and reduce duplicated investment, provided the shared asset has sufficient capacity and access is coordinated. Telecom towers established the model – one mast, several operators, the land, energy and capital divided between them. The transition now applies this at scale. Competing carmakers created Ionity because none of them, alone, had enough vehicles on the road to pay for a motorway charging network; together they did[136]. CO_2 pipelines and storage sites are built as open-access infrastructure – EU law mandates third-party access – because no single emitter could carry their cost; Norway's Northern Lights, the first commercial service of this kind, ships CO_2 from emitters across Europe to shared storage[137]. District heating exists because thousands of buildings, pooled, can pay for a geothermal or waste-heat source that no building could pay for alone.

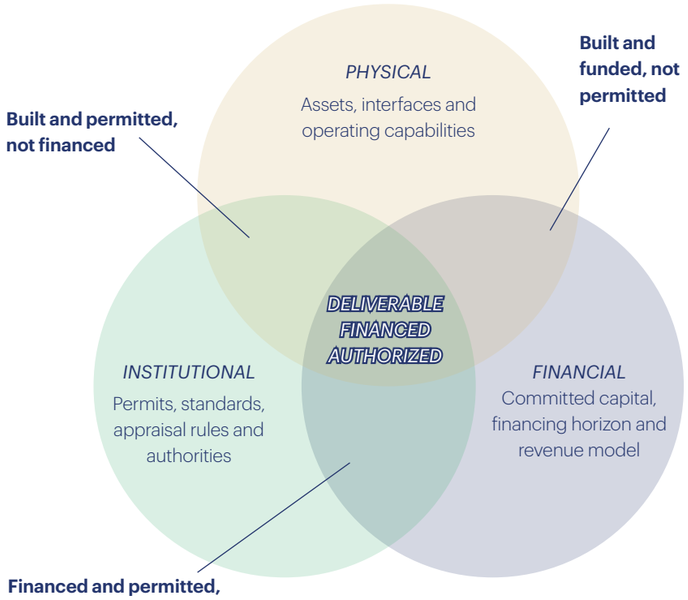
Replication and learning. Costs fall when delivery moves from bespoke projects to repeated products, and the learning accrues to the ecosystem, not to any single project. Solar module costs fell by around 90% between 2010 and 2020[139]; the UK's offshore-wind strike prices fell from £140–150/MWh in the early contracts to £37.35/MWh in the 2022 allocation round, in 2012 prices, a decline earned through serial delivery, standardized interfaces and a maturing supply chain[140]. Each project generates cost information and supplier capability that the next inherits – but only if procurement, standards and skills are organized to transmit it.

Shared factors: skills. The transition's scarcest inputs are collective. Three to four million European construction workers require new skills to deliver the Union's energy objectives (European Commission, Pact for Skills); an employer recruiting project by project redistributes the scarcity, while shared training platforms enlarge the base itself.

FIGURE 15

The three dimensions of an infrasystem, and the missing dimension when only two of them close

Source: Altermind analysis.



FOCUS 11

Sector coupling in Utrecht: using a car fleet to relieve grid congestion

Sector coupling links infrastructure systems that were planned separately – power, transport, heat – so that one can absorb what another cannot handle. The value does not sit in any single asset: it appears when several are made to work together, and someone has to organize that. Utrecht shows the mechanism live.

Around 35% of the city's rooftops carry solar panels[132]; on sunny days, midday generation overloads the local grid, which faces a peak shortfall of some 25 MW in the region – congestion acute enough that new connections queue[133]. Launched in June 2025, Utrecht Energized – Europe's first large-scale vehicle-to-grid car-sharing service – turns shared electric cars into the missing storage: through bidirectional charging, the fleet absorbs the solar peak and feeds it back when demand rises. Five actors, each with their own business case, make it work: Renault supplies the vehicles – 50 at launch, scaling to up to 500 – equipped with Mobilize's V2G technology; We Drive Solar owns and operates the bidirectional chargers; MyWheels runs the fleet as a commercial car-sharing service; grid operator Stedin manages the network interface; and the municipality anchors the collaboration, with a digital platform settling the flows[134]. The dividend is double. Residents get affordable shared electric cars without owning them; the grid gets distributed storage that, at full fleet, will provide around 10% of the flexibility the region needs to balance solar and wind at peak – deferring reinforcement the network cannot build fast enough[135].

The case illustrates the coordination value of sector coupling: the additional system capacity comes not from a new standalone infrastructure, but from making assets built for different purposes perform a second function together.

131 - "Quantification of Synergies between Energy Efficiency First Principle and Renewable Energy Systems", *Energies*, 2021.

132 - European Commission – EU Urban Mobility Observatory, "Two European Cities Advance Vehicle-to-Grid (V2G) Solutions", 2025.

133 - Last Mile Solutions and We Drive Solar, "Europe's First V2G Ecosystem in Utrecht", 2025.

134 - Renault Group, "Utrecht Becomes Europe's First City with a Vehicle-to-Grid (V2G) Car-Sharing Service", press release, 5 June 2025.

135 - Renault Group, "Utrecht Becomes Europe's First City with a Vehicle-to-Grid (V2G) Car-Sharing Service", press release, 5 June 2025.

136 - *Ionity GmbH, joint venture of BMW Group, Ford, Hyundai Motor Group, Mercedes-Benz and Volkswagen Group, corporate information*, 2025.

137 - Directive 2009/31/EC on the geological storage of carbon dioxide, Articles 21–22; Northern Lights JV (Equinor, Shell, TotalEnergies), corporate information, 2025.

139 - IRENA, *Renewable Power Generation Costs*, 2022.

140 - UK Department for Business, Energy & Industrial Strategy, Contracts for Difference (CfD) Allocation Round 4: Results, 2022.

FOCUS 12

Beyond silos, the shared resource base of transition infrastructure

Transition pathways do not remain independent once they are co-located. A review of 67 studies covering hydrogen, geothermal energy, bioenergy with carbon capture, direct air capture and lithium mining finds that each pathway is assessed on its own terms. Their deployments, meanwhile, increasingly land in the same places and draw on the same water, land and energy resources[138].

California illustrates the resulting blind spot. Hydrogen, bioenergy and direct air capture projects cluster in the Central Valley and coastal Southern California, while geothermal and lithium projects converge in the southeast of the state. Co-location can create synergies through shared infrastructure, financing and permitting, and can also accumulate demands that stay manageable at project level and become binding at regional level. Electrolytic hydrogen adds water demand where groundwater is already depleted, direct air capture competes for low-emission electricity and land, and geothermal development and lithium extraction draw on the same local resource base.

Co-location therefore extends the perimeter of the infrasystem. A transition infrastructure depends not only on its own assets, contracts and institutions, but also on the resources claimed by neighboring configurations. Where several transitions converge, the relevant unit of assessment is no longer the project or the sector, but the portfolio of infrastructures landing in the same territory.

138 - Zaki M. T. et al., "Beyond silos: a conceptual framework for assessing interdependencies in emerging energy transition pathways", 2026.

FOCUS 13

Terra Academia: a dedicated program to build the transition's skills base

The transitions' binding constraint is not only physical networks but the people to build and run them – and Europe's skills base is thinning just as demand accelerates.

Terra Academia, launched in March 2024 by Veolia and chaired by former education minister Jean-Michel Blanquer, offers a collective response to this constraint: a "school and accelerator of ecological transformation" that brings together companies, universities, public authorities and associations around a single objective – training 60,000 people in transition professions and introducing 100,000 young people to these careers by 2030.[141]

Three features make it relevant to this report's argument:

- **It treats skills as a shared asset. Rather than adding another diploma to the higher-education catalog, Terra Academia targets the operational trades in shortage – maintenance technicians, network operators, water and waste specialists – through nine-month work-study requalification programs, including a dedicated track for the gigafactories of the Hauts-de-France "battery valley". These are precisely the occupations on which grid build-out, industrial decarbonization and circular-economy capacity depend;**
- **It is territorial by design. Each campus – Arras first, then Deauville and Paris-Montmartre, with a network of some fifteen sites planned across French regions before international deployment – builds its curriculum on an ecological diagnosis of the surrounding inter-municipal area, matching training supply to the actual transition projects of each territory rather than to a national average;**
- **It is coalition-based. A founding company (Veolia) provides the industrial base and immediate employment – 1,500 unfilled positions at launch – while academic, public and associative partners supply certification and reach, a model closer to Germany's dual system than to France's traditional training institutions.**

Terra Academia leads diverse initiatives, such as TAVD (Terra Academia for the Sustainable City), a project selected under the France 2030 "Compétences et Métiers d'Avenir" call. Bringing together a consortium of twelve national and territorial partners, TAVD aims over five years to train 55,000 people in sustainable-city professions and to introduce a further 180,000 to these careers. The project is backed by the French State under the France 2030 plan and operated by the Banque des Territoires.

141 - Veolia, "Terra Academia, the first school dedicated to accelerating ecological transformation", March 2024.

EXPERT POSITION 13

Vincent Cuvillier: Why shared infrastructure matters to Europe's low-carbon transition

"Europe's energy transition will not be powered by renewable generation and electricity grids alone. It will also depend on the digital infrastructure connecting smart grids, electric mobility, distributed energy resources, industrial systems and artificial intelligence. Without secure, resilient and ubiquitous connectivity, many of the technologies expected to drive decarbonization will not operate at the scale required.

That makes the way connectivity networks are built an increasingly important policy and investment question. Demand is rising, but responding by duplicating towers and other passive infrastructure would consume more capital, land, energy and materials, while offering limited additional value to communities. The issue is therefore not simply how to build more, but how to expand capacity more intelligently.

The neutral-host model offers a practical answer. By enabling several operators to use the same passive infrastructure, it can speed up deployment, reduce duplication and environmental impact, and improve the efficiency of investment. For Europe, the stakes go beyond telecommunications: shared infrastructure can help reconcile stronger connectivity with industrial competitiveness and a more disciplined use of scarce resources. In that sense, it should be seen not as a technical arrangement, but as part of the enabling architecture of the continent's energy, digital and ecological transitions."



Vincent Cuvillier
Chief Strategy Officer at Cellnex

Every synergy in the four pools above is also a dependency: the heat network's revenue depends on a smelter it does not own; the shared store depends on emitters that must arrive; the co-located cluster competes for the same water and land it shares[142].

The objective is therefore not to maximize synergies but to keep only those worth their risk. In practice this means answering two questions before a coupling is signed. First: if the link fails – the partner's plant closes, the shared flow stops – who pays, and how does the service continue? The contract must name that party; a synergy whose failure has no owner is a risk no one has priced. Second: is the saving worth the exposure? Where an interruption would cost more than the coupling saves, the right answer is redundancy – two routes, two sources – even at higher running cost. Efficiency and resilience pull in opposite directions; where to stand between them is a design decision.

The system value of coordination can be estimated, although it is not automatically captured by the investor financing the enabling asset. Each euro invested in the electricity networks of the European ten-year plan is estimated to return more than two euros in system-cost savings[143]; the UK values 20 GW of long-duration storage at £24bn of system savings between 2030 and 2050[144]; and recent research finds that transition capital earns in proportion to the complementarity between what it funds and what surrounds it – the marginal euro is worth more where it closes a gap in the system than where it adds to a segment already served[145]. These gains are system benefits. Turning them into an investable return requires a tariff, contract or payment mechanism that assigns part of the value to the party carrying the enabling investment.

Completing the infrasystem supports both investment and operation. Before construction, a hydrogen project needs credible demand and access to the transport or storage its service requires. After commissioning, generation capacity needs a network able to carry its output. The hydrogen and grid-congestion examples discussed earlier therefore illustrate the same discipline: secure the complementary links that make capacity usable before committing capital that depends on them.

142 - Zaki M. T. et al., "Beyond silos: a conceptual framework for assessing interdependencies in emerging energy transition pathways", 2026.

143 - ENTSO-E, *Ten-Year Network Development Plan*, 2024.

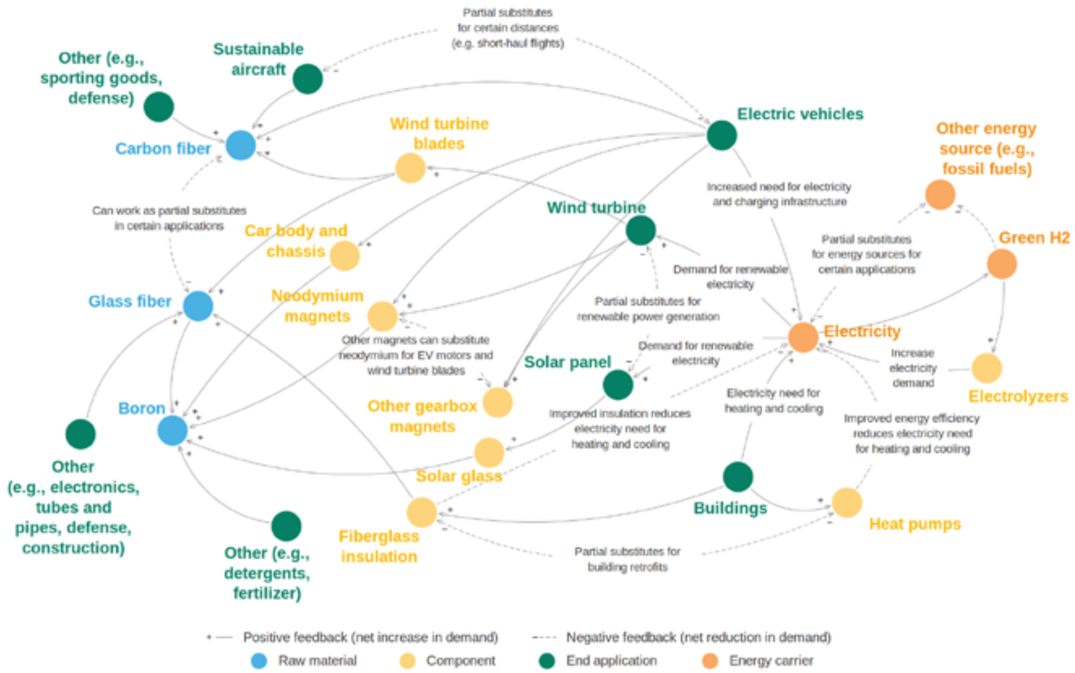
144 - UK Department for Energy Security and Net Zero, *Clean Power 2030 Action Plan*, 2024.

145 - Huang et al., 2026.

FIGURE 16

Dependency and substitution across a decarbonization value chain

Source: BCG, 2024.



EXPERT POSITION 14

Ana Giros – Delivering the transitions through system-wide coordination, not asset-by-asset deployment

"Delivering the transition at scale depends on the ability to coordinate interconnected systems. Electrifying mobility, decarbonizing industry, and increasing renewable energy generation all place new demands on infrastructure networks that must advance together. Across the energy transition, one of the main barriers remains the alignment of these different systems, stakeholders and timelines.

Meeting transition objectives requires a holistic approach that integrates production, distribution, demand, and long-term operation. Project deployment often stalls due to limited grid connections, permitting delays, or components that do not evolve at the same pace.

Coordination remains one of the most persistent bottlenecks to implementation.

Regulatory consistency is essential for effective coordination. Clear, enforceable regulations and predictable timelines offer a shared framework for investors, operators, and customers. Ambiguity causes hesitation, while clear rules enable confident design, deployment, and scaling of technical solutions. Infrastructure transitions need long-term direction that remains credible throughout project lifecycles.

Execution capacity is equally important. Europe faces a shortage of electricians, thermal engineers, technicians, and other specialists needed to deploy and operate infrastructure at scale. Supporting the transition requires investment in both assets and the skilled workforce needed to deliver, maintain, and improve these systems over time."



Ana Giros
EVP Strategy, Development and CSR at Equans

CASE STUDY 4

Coriance: Réseau Terra Confort, a territorial heat service assembled across assets and institutions

In the Greater Paris area, Coriance is delivering, through its subsidiary Réseau Terra Confort, a shared geothermal heating network for the neighboring communes of Châtenay-Malabry and Le Plessis-Robinson. Instead of running two separate municipal systems, the two towns pooled their legacy networks into a single one, designed to grow alongside their regeneration projects, including the LaVallée eco-district, the Cité-Jardin de la Butte-Rouge and the Loup-Pendu district.

The network reaches 88% renewable and local energy by combining three sources: deep geothermal energy from the Dogger aquifer, shallower geothermal energy from the Néocomien layer, and biomass. The geothermal plant draws water naturally heated to 68°C from the Dogger at 1,600 to 1,700 meters depth, transfers its heat through exchangers and reinjects the cooled water into the reservoir in a closed loop with no direct emissions. The plant was officially commissioned on 3 July 2026.

Once fully deployed, the network will distribute 133GWh of heat per year to the equivalent of 15,000 homes, avoiding 31,500 tonnes of CO_2 annually. For connected users, locally produced geothermal heat reduces exposure to gas and oil price volatility, and the network is designed to extend at the pace of the two towns' urban projects.



Systemic integration in practice: three deep dives on energy and transport

The cases that follow apply the three-dimensional infrasystem framework introduced above:

- The physical dimension covers assets, interfaces, user equipment and the capability to operate them;

- The financial dimension covers committed capital, its duration and the revenue line;

- The institutional dimension covers permits, standards, revenue rules and the authorities able to stop the chain.

A project can satisfy two dimensions and still fail on the third: buildable and fundable but not permitted; buildable and authorized but lacking a viable capital structure; or contracted and financed for a service the physical chain cannot deliver.

The three deep dives below apply this test to carbon capture and storage, multimodal terminals and battery storage. Across all three, investability emerges only when the actors controlling the assets, flows, revenues and rules are brought into a coherent configuration – although the mechanism that binds them differs in each case.

LOW-CARBON ENERGY ECOSYSTEMS

The UK's East Coast Cluster is being developed around shared CO_2 transport and storage infrastructure, with an initial Teesside phase serving Net Zero Teesside Power and providing capacity for future connected projects.[146] Physically, the Northern Endurance Partnership – a joint venture of BP, Equinor and TotalEnergies – is building common onshore and offshore infrastructure to a saline aquifer 145 kilometers off the Teesside coast, with an initial transport and storage capacity of 4m tons of CO_2 a year. Financially, the two linked projects reached close in December 2024 on facilities of around £8bn. Institutionally, a suite of government business models – a regulated revenue framework for transport and storage, and a dispatchable power agreement for the 742 MW gas-with-capture plant – made every link of the chain contractible before any of it existed.

The physical, financial and institutional layers were mutually dependent: capture required transport and storage, while financing depended on the payment frameworks supporting each service. The concentration of industrial emissions around Teesside and the Humber creates a potential market, but does not by itself establish contracted demand. Investability depends on the projects and revenue arrangements actually committed to the initial configuration, with expansion assessed as further users become ready.[147]

146 - Northern Endurance Partnership, announcement of financial close, 10 December 2024.

147 - Northern Endurance Partnership, "UK Government announces intention to select new Teesside users", 19 November 2025.



CASE STUDY 5

Vinci Airports: Supporting the H4 Marseille-Fos project, an ecosystem approach

Vinci Airports is the world's leading private airport operator, managing more than 70 airports in 14 countries across Europe, Asia-Pacific, North and South America, and Africa. Its environmental strategy targets net zero emissions on direct operations (scopes 1 and 2) by 2030 in the EU, London Gatwick and Edinburgh, and by 2050 globally.

As part of Vinci Airports' strategy to decarbonize air transport, on January 30 2025, the operator signed an agreement with Hy2gen France and H2V, a renewable-fuel specialist and a hydrogen developer respectively, to study and implement a supply chain of synthetic sustainable aviation fuel, e-SAF, which does not require modifications to the airport facilities or aircraft propulsion systems. This initiative aligns with the European ReFuelEU Aviation regulation, which imposes the progressive use of SAF and contributes to Europe's goal of achieving a 10% share of e-SAF in aviation fuels by 2040.

The plant, under development in the industrial port of Fos-sur-Mer, will use a methanol-to-jet process: a 390MW water electrolyzer will produce low-carbon hydrogen, which is combined with locally captured biogenic CO_2 to synthesize renewable methanol and then converted into drop-in e-SAF. Target output is 75,000 tons of e-SAF per year from 2032, cutting greenhouse-gas emissions by up to 84% compared to fossil kerosene, or roughly 240,000 tons of CO_2 equivalent avoided each year. It will be distributed to airports across southeast France, including Lyon-Saint Exupéry, Lyon Bron and Clermont-Ferrand Auvergne, via the existing pipeline network.

In addition to proposing the use of SAFs, VINCI Airports' main actions to decarbonize the value chain in collaboration with its stakeholders are:

Carbon modulation of landing fees: VINCI Airports was the first airport operator to implement a modulation of landing fees based on airlines' carbon emissions. Airlines using SAFs thus benefit from a bonus under this scheme.

Reduction of emissions from airport operations: VINCI Airports is implementing measures to reduce emissions from airport operations, such as the use of electricity from renewable sources, the electrification of vehicle fleets, APU-off solutions (limiting the use of auxiliary power units), etc.

Promoting sustainable modes of transport: VINCI Airports encourages the use of sustainable modes of transport to access airports, including public transport and electric vehicles. More than 700 charging stations for electric vehicles and machines have already been deployed across its worldwide network.

Passenger awareness: VINCI Airports raises passenger awareness on sustainable development challenges and encourages them to adopt responsible behavior, for example by offering a voluntary contribution for reforestation projects.

For the longer term, VINCI Airports has launched several major hydrogen initiatives, contributing in particular to the initiation of the Clean Hydrogen Infrastructure Fund operated by Hy24, the world's leading private asset manager dedicated to the deployment of the hydrogen economy, with the support of TotalEnergies and Air Liquide. This fund notably participated in a fundraising in Hy2Gen, a member of the consortium that will produce the e-SAF.

MULTIMODAL TRANSPORT

Rail-road-maritime terminals face the harshest version of the coordination problem, because their heavy fixed costs are amortized only at high throughput, while the volumes that create throughput are controlled by actors with divergent interests – shipping lines, rail undertakings, the infrastructure manager that allocates train paths, freight forwarders, road hauliers, the port authority.

Combined transport typically becomes competitive with road only beyond several hundred kilometers and at service frequencies no single shipper can justify: a terminal built ahead of committed flows is stranded concrete, and committed flows do not materialize without the terminal – a chicken-and-egg that only a coalition can break.

The Duisburg Gateway Terminal, Europe's largest trimodal hinterland terminal (barge, rail, road) and its first designed for climate-neutral, hydrogen-based operation, illustrates one way of reducing this coordination risk through ownership. Its shareholders bring together the port authority (duisport), an intermodal operator (Hupac), a global terminal operator (PSA International) and an inland-shipping group (HTS), embedding several of the actors able to generate and handle traffic directly in the terminal's governance.[148]

But DGT illustrates one coordination mechanism, not a general prescription for integration. Ownership can internalize only some dependencies; others remain outside the perimeter, including rail capacity allocation and traffic commitments. Investability therefore depends on identifying which dependencies are sufficiently difficult to specify, monitor or secure that bringing them inside the same governance structure creates more value than coordinating them contractually or institutionally across organizational boundaries.

ENERGY STORAGE

Grid-scale batteries illustrate how the economics sit in the configuration. A battery earns by arbitraging positions across services that other actors define – wholesale spreads, frequency regulation, congestion relief, stability – so that its revenue stack combines market-based revenues and contracted system services, with different levels of price, volume and counterparty risk. The leading projects are therefore co-designed with the system operator rather than merely connected to it:

Blackhillock in Scotland began operating in March 2025 with an initial capacity of 200 MW, as the first phase of a 300 MW project. Under NESO's stability program, its grid-forming battery technology was contracted to provide services including inertia and short-circuit contribution. The case shows how an explicitly procured system service can support investment in capabilities beyond energy arbitrage; it does not imply that all battery revenues are contracted or guaranteed[149].

The same relational logic governs siting and structure: in the £180m financing of a nine-asset, 612 MW British portfolio in March 2025, locating seven of the nine sites next to substations helped facilitate the network interface[150]; and for long-duration storage applications, the UK's cap-and-floor regime for long-duration storage supplies the institutional revenue floor that merchant markets cannot[151].

In each case the sequence is the same as at Teesside: the contract structure preceded the asset, and the coalition – developer, system operator, network owner, financiers – is the business model.

148 - DGT, 2024

149 - Zenobē, Blackhillock battery launch, 3 March 2025.

150 - Watson Farley & Williams, "WFW advises lenders on £180m BESS portfolio debt financing", 2025.

151 - Ofgem, *Long-Duration Electricity Storage Cap and Floor Scheme*, 2024.

EXPERT POSITION 15

Anna Creti – Storage: an active system component of energy systems

"The transformation of Europe's energy system is profoundly reshaping the role of storage. Alongside established gas storage and pumped-storage hydropower, batteries and hydrogen storage are expanding the available options, complemented by demand-side flexibility. As these solutions mature, storage is no longer a passive buffer but an active system component, enabling real-time balancing and facilitating interactions across energy vectors.

This shift brings with it a new set of economic and regulatory challenges. Storage no longer fits within the boundaries of a single sector; it operates at the intersection of electricity, gas, and hydrogen systems. Yet, governance frameworks have not fully adapted to this cross-system role. There remains no clear consensus on how storage assets should be owned, financed, or integrated into market structures.

Key questions around access rights, remuneration mechanisms, and system responsibilities are still unresolved. As storage becomes increasingly central to system stability and flexibility, its expanding functionality is likely to drive the emergence of new business models. Clarifying its role will therefore be critical to ensuring the coherence, efficiency, and investability of future energy systems."



Anna Creti
Professor of Economics at Université Paris Dauphine-PSL



Managing uncertainty to make infrastructure value investable

Regulatory stability, credibility, predictability & consistency: the winning formula

A SUPPORTIVE REGULATORY FRAMEWORK

An infrastructure configuration may create demonstrable value and still fail to attract investment if the rules governing that value cannot be relied upon. Decarbonization assets sharpen this dependency because their viability rests on public commitments – a tariff, a concession, a guaranteed offtake or a carbon-price regime – whose required duration, often 25 to 40 years, exceeds that of any government or political consensus. Economic theory describes the resulting exposure as time inconsistency: once capital is sunk and can no longer exit, a policy that was optimal to announce before investment may cease to be optimal to honor. The cost of capital therefore reflects not only the rule as written, but the rule investors expect another government to apply a decade later.

The response cannot consist in freezing the rule for 40 years. Demand, technology costs, political priorities and climate objectives will move during the life of the asset. What capital requires is predictability of revision: the assurance that a tariff, support scheme or concession will change through a procedure defined before the investment was committed. Stability, properly understood, is a decision that already contains the rule for its own change.

Failing this test in either direction carries costs. Retroactive change shifts an unresolved policy choice into litigation and future financing conditions. Spain's corrections to renewable remuneration gave rise to at least 51 treaty arbitrations; 43 had concluded and 8 remained pending at the end of 2024, with around €2bn awarded.[152] Germany's nuclear exit, adopted without an initial compensation mechanism, concluded a decade later in a constitutional ruling and a €2.4bn settlement. In both cases, the cost was not avoided; it was rerouted through the courts. Stop-work orders issued in 2025–2026 against fully permitted and majority-built American offshore-wind projects exposed investors to policy reversal after development and construction capital had already been committed.

An unchanged headline price can also coexist with material changes in exposure. France's ARENH mechanism combined a regulated price for historical nuclear electricity with rules governing the volumes EDF had to supply. In 2022, the exceptional increase in those volumes, alongside lower nuclear output and high wholesale prices, affected EDF's financial position[153]. The episode cannot be explained by the fixed tariff alone. Credibility requires the revision process to address both remuneration and the obligations attached to it, so that exceptional interventions have an explicit allocation of costs and risks.

A third failure mode requires neither a broken commitment nor a retroactive change. Two instruments pursuing the same objective can alter the same economic equation in opposite directions. The 2023 Greening Freight Transport Package illustrates the risk. Its revision of the Weights and Dimensions Directive sought, among other measures, to facilitate the cross-border use of longer European Modular Systems where Member States permit them, while its revision of the Combined Transport Directive sought to make intermodal freight more competitive[154]. Both were presented as contributions to freight decarbonization. Yet reducing the cost of long-haul road transport can weaken the relative economics of the rail alternative that the second instrument is intended to support. A K+P/Fraunhofer study illustrates the magnitude of that interaction: under a 44-tonne, 25.25-meter configuration, combined transport volumes fell by more than 13% on the most exposed corridor modeled[155]. The policy tension is visible elsewhere in the framework: in March 2026, the Commission adopted new State-aid rules allowing support of up to 90% of eligible avoided external costs to encourage traffic towards rail, inland waterways and sustainable multimodal transport[156]. For infrastructure investors, the lesson is not that either instrument is wrong in isolation. It is that the traffic case of a terminal depends on their combined effect. Regulatory credibility therefore requires coherence not only through time, but across policies acting on the same system.

Political durability is the other side of regulatory credibility. Part 2 showed why distributional design and public acceptance determine whether a pathway can survive electoral alternation; for capital, that political question becomes a financial variable before any reversal occurs. Investors commit against the expected durability of a rule, not only its legal status today. That exposure is measurable: in a choice experiment involving 1,575 investment decisions by European solar developers, one significant unexpected policy change over the previous five years required an additional 4.10 ct/kWh to maintain the same investment attractiveness; three required 10.28 ct/kWh[157]. Revealed investment follows the same pattern: across 26 European countries, retroactive changes to renewable-support schemes were associated with subsequent investment rates around 45% lower for solar PV and 16% lower for onshore wind[158]. Political fragility therefore carries a financing cost before it becomes a policy change, and a deployment cost once it does. Regulatory credibility depends not only on how rules are written and revised, but on whether they can remain politically durable enough for capital to rely on them.

152 - UNCTAD, *Recent Trends in Investor-State Arbitration Cases*, 2025.

153 - EDF, "Update on the claims relating to the allocation of additional 20TWh of electricity for 2022", press release, 27 October 2022; EDF, *2022 Annual Results*, 2023.

154 - European Commission, Greening Freight Transport Package, 2023; proposal amending Directive 96/53/EC on weights and dimensions and proposal amending Council Directive 92/106/EEC on combined transport, 2023.

155 - K+P Transport Consultants and Fraunhofer ISI, study for UIRR on the effects of longer and heavier vehicle combinations on combined transport.

156 - Article 93 TFEU; European Commission, *Community guidelines on State aid for railway undertakings (2008/C 184/07), and Commission summary of measures cleared on that basis*; Land and Multimodal Transport Guidelines adopted in March 2026.

157 - Lüthi S. and Wüstenhagen R., "The price of policy risk – Empirical insights from choice experiments with European photovoltaic project developers", Energy Economics, 34(4), 2012, pp. 1001–1011.

158 - Sendstad L. H., Hagspiel V., Mikkelsen W. J., Ravndal R. and Tveitstøl M., "The impact of subsidy retraction on European renewable energy investments", *Energy Policy*, 160, 2022, 112675.

EXPERT POSITION 16

Fabrice Lepoutre – The need for long-term investment certainty and efficient incentives

"The principal constraint is often not technological capability, but the stability of the policy and regulatory environment. Infrastructure investments are made over decades and therefore depend on long-term visibility. Frequent changes to support schemes, the abrupt withdrawal of incentives, or inconsistent policy signals increase uncertainty, raise financing costs, and delay investment decisions. Even mature technologies struggle to scale when investors lack confidence in the long-term rules governing their deployment.

Unlocking the full potential of decarbonization pathways, climate adaptation measures, and local energy systems therefore requires more than capital and innovation. It requires a stable and predictable regulatory framework that provides long-term investment certainty and aligns the incentives of governments, regulators, infrastructure operators, and investors. The pace of the energy transition will ultimately depend not only on technological progress, but also on the quality, consistency, and credibility of the institutional framework that supports it."



Fabrice Lepoutre
President of Coriance

EXPERT POSITION 17

Vincent Cuvillier – Coordination, credibility & regulatory predictability: prerequisites for successful sustainable infrastructure delivery

"Infrastructure delivery is often framed primarily as a question of speed. In telecommunications, however, experience shows that success depends above all on coordination. Building and operating digital infrastructure requires local authorities, landlords, energy providers, equipment vendors and customers to work towards a common objective. The greatest challenge rarely lies in any single component; it lies in aligning all stakeholders and enabling them to move forward together.

Telecommunications infrastructure also demonstrates that major transitions unfold over longer horizons than public debate often suggests. Europe's fiber networks were conceived and developed over decades before becoming the backbone of today's digital economy. Infrastructure operators must therefore plan 10, 20 or even 30 years ahead. Investments of this scale and duration depend on predictable regulatory frameworks, stable rules and access to long-term capital. Without that certainty, effective coordination becomes significantly more difficult and investment decisions risk being delayed.

As infrastructure systems expand in scale and complexity, data becomes increasingly essential to effective coordination. Managing large portfolios across assets, regions and countries requires comparable information, consistent benchmarks and evidence-based decision-making. Ultimately, successful delivery also depends on credibility: the ability to translate long-term commitments into tangible progress in investment, resilience and sustainability. In a rapidly changing environment, credibility is built not by setting ambitious goals alone, but by delivering measurable results consistently."



Vincent Cuvillier
Chief Strategy Officer at Cellnex

THE PREREQUISITES OF CREDIBLE ADJUSTMENT

Six prerequisites turn a general promise of stability into a rule that capital can price. The first two define the calendar.

A review date and periodicity tell investors when a tariff may move: Germany's hydrogen ramp-up account is reviewed from 2028 and every three years thereafter against a balance objective for 2055.[160]

An assessment window determines which variations are absorbed within each review. The cap-and-floor regime for interconnectors compares revenue against a ceiling and a floor over five-year periods rather than annually, allowing a strong year to offset a weak one without removing the incentive to perform.[161]

A formula can link indexed inputs, demand bands and verifiable changes in law to a pre-agreed calculation, so that an ordinary movement in cost or volume adjusts remuneration without reopening the complete bargain.

The treatment of committed assets addresses the more discontinuous case in which policy retires capacity early. Germany's first hard-coal closure auction in December 2020 selected eleven bids totaling 4,788 MW at a volume-weighted average of €66,259 per MW. The auction revealed the residual claim rather than leaving its recognition to a later dispute.

A verifying authority and an evidence rule determine who establishes that a trigger has occurred and against which data, separating an adjustment from a negotiation.

A route outside the calendar defines how exceptional conditions trigger a review, who can initiate it and how committed investments are treated. Denmark's November 2025 offshore-wind tenders illustrate the need to adapt after an earlier design attracted no bids: the new framework introduced support and greater flexibility following market dialogue and political agreements.[162] The case demonstrates redesign in response to evidence, rather than the automatic application of a revision rule fixed at the outset.

Europe starts from a position of relative strength, but direction is not yet consistency. The Clean Industrial Deal and the "One Europe, One Market" Roadmap seek to replace a patchwork of 27 permitting regimes, grid codes and procurement rulebooks with a more legible investment environment. The Draghi report reaches the same diagnosis from the financing side: the €750–800bn in additional annual investment it calls for covers a broad competitiveness agenda, including energy, infrastructure, innovation and defense, while regulatory simplification and predictability recur as conditions for mobilizing private capital at that scale. Announcing a common direction reduces uncertainty only when institutions, calendars and adjustment procedures support it.

Where these elements are written, adjustment becomes a priced parameter. Otherwise, where a foreseeable event has no procedure, the pricing happens elsewhere and later: changes to European renewable-support schemes after 2010 produced an arbitration record rather than a revision process.[163]

The six parameters share a common target: keeping institutional complexity legible to investors. Incompatible public logics, unsettled prioritization and overlapping jurisdictions can each create delay or uncertainty. When all three coincide, the framework in Figure 18 identifies "VOLATILE COMPLEXITY": the investor may be unable to determine which rule prevails, who applies it or how a conflict will be resolved. The other combinations remain relevant; an unchanged objective does not by itself ensure a workable decision process.

160 - Bundesnetzagentur, *Hydrogen Core Network Ramp-Up Tariff Decision*, 2024.

161 - Ofgem, *End of Period Assessment for the Nemo Link Electricity Interconnector to Belgium*, 2024.

162 - Danish Energy Agency, "The Danish Energy Agency opens tenders for three new Danish offshore wind farms", press release, 20 November 2025.

163 - UNCTAD, *Recent Trends in Investor-State Arbitration Cases*, 2025.

FOCUS 14

The EU carbon market

The EU carbon market illustrates a rule that contains its own revision. During the decade in which the EU ETS price collapsed under a structural surplus of allowances, each corrective intervention required a new political negotiation. The Market Stability Reserve, adopted in 2015 and operational from 2019, replaced part of that discretion with a formula: when the surplus of allowances in circulation crosses published thresholds, supply adjusts by a stated percentage.

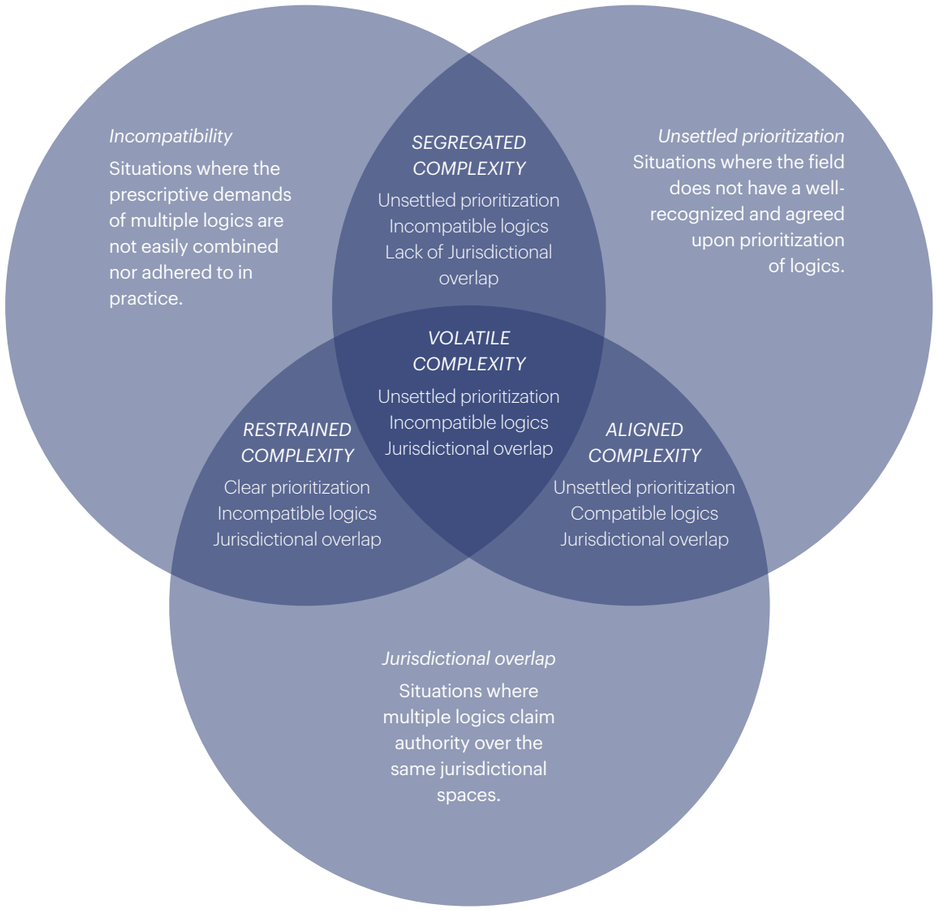
The reform did not remove uncertainty about the carbon price. It reduced uncertainty about the process through which the regime responds to shocks. Investors in abatement may still disagree about the future price level, but they no longer need to assume that every downturn will reopen the complete legislative settlement.

Credibility therefore does not eliminate regulatory risk. It binds the events, procedures and consequences through which public action can alter the investment case. Once that institutional uncertainty is contained, the remaining task is different: identify how physical events, technological change, demand and system dependencies affect the asset, then determine which exposures can be reduced before capital is asked to bear them.

FIGURE 17

Institutional complexity: four regimes produced by incompatibility, unsettled prioritization and jurisdictional overlap

Source: Hacker & Binz, 2021.



WHERE DOES EUROPE STAND VS THE REST OF THE WORLD?

Measured against the prerequisites above, Europe combines an unusual strength with a persistent weakness: regulatory adjustment is often procedurally predictable, but decisions can take too long to reach. In many network sectors, tariffs, allowed returns and support mechanisms are revised through published methodologies, defined review periods, independent regulators and legal recourse. Capital therefore does not need to assume that the rule will remain unchanged; it can form expectations about how and when it may change. The weakness appears when that predictability is spread across multiple authorities, legal regimes and levels of government whose decisions must converge before an investment can proceed. Europe's problem is therefore not procedure itself, but procedures that are insufficiently aligned with the investment window of the assets they govern.

The US provides a useful counterpoint because the policy support can be both larger and more exposed to political change. The Inflation Reduction Act created long-term clean-electricity production and investment credits; legislation enacted on 4 July 2025 subsequently accelerated their termination for wind and solar projects, with facilities placed in service after 2027 losing eligibility where construction begins after the statutory transition period. Three days later, an executive order instructed the Treasury to apply the new restrictions strictly, followed in August by guidance narrowing the routes through which projects could demonstrate that construction had begun[164]. The issue is not the direction of either policy. It is that a central parameter of the investment case was rewritten through a change in political majority rather than through an adjustment mechanism specified when capital was first invited in. Investors must therefore assess not only the generosity of a policy, but the durability of the political settlement behind it.

The UK shows that procedural credibility need not imply immobility. Ofgem's December 2025 RIIO-3 determination set the regulatory framework for the five years beginning in April 2026 and allowed a real cost of capital of roughly 4.3–4.7% across the network companies covered, compared with approximately 2.7–2.9% under the preceding RIIO-2 determination[165]. The economic parameter moved substantially as market conditions changed; what remained stable was the process through which it moved – a scheduled review, a published methodology and an identified decision-maker. Procedure did not prevent adjustment; it made adjustment legible to capital.

The comparative implication for Europe is therefore not to trade procedural credibility for speed. It is to preserve the former while reducing the accumulation of decisions that must be reconciled before the latter can produce an investable outcome. A known adjustment process allows capital to price change rather than treat it as an open-ended political exposure. But that advantage has an economic limit: credibility creates value only if the decision arrives while capital can still act on it.

164 - Public Law 119-21, enacted 4 July 2025, sections 70512–70513 amending sections 45Y and 48E of the Internal Revenue Code; Executive Order 14315, 7 July 2025; Internal Revenue Service, Notice 2025-42, August 2025.

165 - Ofgem, RIIO-2 *Final Determinations – Finance Annex, revised 2021*; Ofgem, *RIIO-3 Final Determinations – Finance Annex*, 2025.

EXPERT POSITION 18

Nicolas Notebaert – Rebuilding trust and speed to mobilize private capital in Europe

"The European infrastructure industry faces a paradox. In many parts of the world, developing infrastructure projects is often easier than in Europe itself. Countries such as India and Brazil are deploying projects at pace, actively attracting private investment, and increasingly looking to European operators for expertise. Far from rejecting Europe's approach, many of these partners are embracing similar ambitions around decarbonization, resilience, and climate adaptation.

Europe has the capital, industrial capabilities, and engineering expertise required to succeed. The challenge lies in execution. It stems in part from a multilayered governance system in which European and national procedures overlap, creating complexity and slowing decision-making. This institutional friction undermines investor confidence, delays project delivery, and ultimately makes it more difficult to mobilize private capital at the scale and speed required.

The objective is not to lower Europe's climate ambitions, but to create the conditions that allow projects to be delivered more rapidly. Rebuilding trust between governments, public institutions, and private investors will be essential. Europe already possesses the financial resources, technological capabilities, and industrial expertise needed to invest in infrastructure, energy, and decarbonization. What it now needs is a governance framework that provides the confidence, predictability, and speed required to turn these strengths into delivered projects."



Nicolas Notebaert
President of VINCI Concessions

EXPERT POSITION 19

Didem Nisanci – A widening transatlantic divergence on the transition

"The growing divergence between European and American approaches to the transition is creating an increasingly complex environment for infrastructure investors and companies operating across both markets. What was once a broadly shared direction of travel is giving way to two distinct strategic models, reflecting different assessments of economic priorities, energy security, and long-term competitiveness.

In Europe, the transition has become a central pillar of industrial strategy, closely intertwined with decarbonization, energy security, and economic resilience. In the US, policy has increasingly shifted towards energy abundance and strategic competitiveness, placing greater emphasis on domestic resource development, hydrocarbons, and energy affordability alongside investment in advanced technologies.

For long-term infrastructure investors, this divergence increases strategic uncertainty. Infrastructure assets are financed over decades and depend on policy consistency well beyond electoral cycles. Yet the policy environment is becoming increasingly asymmetric. European regulatory frameworks are often more demanding and slower to implement, but they generally provide greater long-term predictability. The US, by contrast, has demonstrated a greater capacity to adjust policy rapidly through executive action and deregulation, offering speed but potentially less stability over time.

These contrasting approaches shape not only the pace of project delivery but also the economics of investment, the allocation of capital, and the ability of companies to operate seamlessly across jurisdictions. Investors must therefore navigate not only technological and financial risks, but also an increasingly fragmented geopolitical and regulatory landscape.

The challenge is no longer simply to identify attractive investment opportunities. It is to understand how diverging policy frameworks, regulatory models, and strategic priorities are reshaping the long-term conditions under which infrastructure is financed, developed, and operated. As the European and American models continue to evolve along different trajectories, the ability to anticipate and manage policy divergence will become an increasingly important source of competitive advantage."



Didem Nisanci
Senior Fellow for Climate and Geoeconomics at the Global Climate Policy Project at Harvard and MIT

Anticipating and managing physical and transition risks

FROM LIFECYCLE UNCERTAINTY TO FINANCIAL EXPOSURE

Infrastructure risk changes bearer and form over the 25 to 40 years for which the investment case is built. Development capital carries permitting, design, land and interface risk; construction capital carries execution, cost and liquidity risk before any revenue exists; operating capital remains exposed to demand, technology, climate and regulation after completion. These exposures also extend beyond the project company. The grid-connection bottlenecks examined in Part 1 illustrate an exposure outside the generating asset: access to a network owned and scheduled by another actor. The lifecycle assessment must therefore separate the events that can be anticipated, the exposures the infrasystem can reduce, the design choices that must remain adaptable and the risks another party will ultimately have to carry.

EXPERT POSITION 20

Susanne Nies – Risk management in environmental policy

"Europe is entering an unprecedented cycle of infrastructure investment, but delivering it at the required pace will demand a fundamentally different approach to risk. One of Europe's enduring strengths has been its culture of prudence. Yet the scale and urgency of today's transitions expose the limits of a model that seeks to eliminate uncertainty before acting. Progress at speed inevitably entails experimentation, adjustment, and occasional setbacks. The greater risk may no longer be making mistakes, but delaying action while waiting for perfect certainty.

Infrastructure is also becoming increasingly visible in public debate. Once largely taken for granted, energy systems, transport networks, digital infrastructure, and critical supply chains have become matters of public concern, shaped by recent energy crises, geopolitical tensions, and climate-related disruptions. This growing awareness should be viewed as an opportunity rather than a constraint. Greater transparency and public engagement can help strengthen trust, build societal support, and reinforce the legitimacy of the investments and transformations required over the coming decades.

At the same time, resilience should not be understood solely as the ability to anticipate future threats. Many of the most significant disruptions of recent years – including pandemics, geopolitical conflicts, and extreme climate events – could not have been fully predicted. The experience of Ukraine illustrates that resilience depends as much on flexibility and adaptive capacity as on preparedness. The objective is therefore not only to identify and mitigate risks, but to design infrastructure systems capable of absorbing shocks, adapting to changing conditions, and continuing to operate under uncertainty. In practice, this points towards more distributed, modular, and hybrid infrastructure models that combine robustness with adaptability."



Susanne Nies
Energy Researcher and Electricity Expert at Helmholtz-Zentrum Berlin

PHYSICAL AND TRANSITION RISKS IN ASSET VALUATION

Climate risk reaches infrastructure through two channels, but both become material through the same financial variables. Physical risks include acute events such as floods, fires and storms and chronic changes such as heat, water stress or sea-level rise. Natural catastrophes caused around €900bn of damage across the EU between 1981 and 2023; more than one fifth occurred in the final three years and only around one quarter of the total was insured. Transition risks include carbon pricing, performance standards, changes in demand, technological substitution and early retirement. One channel damages or interrupts the asset; the other changes the market and policy conditions under which it earns.[166]

The distinction becomes operational only when each event is translated into capital expenditure, operating and insurance costs, revenue, economic life, residual value and financing terms.[167] A heatwave, for example, affects thermal-power assets through cooling and water constraints, but railways through track conditions, maintenance and interrupted service. The framework illustrated below applies this translation through asset-level scenario analysis.

EXPERT POSITION 21

Nicolas Notebaert – Making climate adaptation a first-order factor in infrastructure valuation

"Climate adaptation can no longer be treated as a secondary objective to mitigation. Infrastructure operators are already confronting the growing consequences of climate change, with more frequent floods, wildfires, heatwaves, and extreme weather events disrupting transport, energy, water, and mobility networks. Building resilience must therefore become a proactive rather than a reactive endeavor. Every year adaptation is delayed increases both the financial cost of repairs and the broader economic and social costs of disruption.

At a time when many governments face significant fiscal constraints, private capital has a critical role to play in financing climate resilience. Long-term infrastructure investment and concession models provide the stable investment horizons needed to fund adaptation measures over several decades while reducing exposure to future disruptions. Infrastructure investment should therefore be seen not only as a driver of economic growth and decarbonization, but also as a strategic instrument for strengthening resilience and safeguarding the critical assets on which Europe's economy and society depend."



Nicolas Notebaert
President of VINCI Concessions

166 - ECB and EIOPA, *Towards a European System for Natural Catastrophe Risk Management*, December 2024.

167 - Stanford Sustainable Finance Initiative, *Pricing Climate Risks*, 2020.

FOCUS 15

Pricing physical and transition climate risks

The research examines how climate risks are incorporated into financial markets, focusing on the mechanisms through which both physical climate impacts and the transition to a low-carbon economy affect asset prices, expected returns and capital allocation. It concludes that better measurement and pricing of climate risks are essential to improve investment decisions, enhance financial stability and accelerate the efficient allocation of capital towards resilient, low-carbon assets.

Based on the framework developed by In et al. (2020), the authors combine climate scenarios with asset-level financial modeling to assess how climate risks affect the resilience of debt and equity investments. Cash flow and scenario analyses are then used to estimate the likelihood of financial default under alternative climate risk scenarios.

Some risk factors are common across the three case studies (such as increased temperatures, increased frequency of extreme weather events, renewable energy technology advancement, and cost decline), while others are asset-specific (such as the ITC phase-down for solar PV projects). According to the authors, crucial characteristics of climate and financial risks are the: (1) non-linearity of climate impacts, (2) complexity and interconnected nature of relations and risk in the financial network, and (3) uncertainty on climate policy introduction.

The authors conclude that "the individual stakeholders would change their behaviors more promptly if they can specify impacts to their assets that might be caused by climate change, how these affect asset and portfolio valuation and what they can do now to prepare for them. A granular level climate risk assessment of energy investments can help companies consider the risks and opportunities associated with various energy sources and make informed decisions".

FIGURE 18

Climate risk variables, grouped by risk categories

Source: In et al., 2020.

	Case 1: Natural Gas CCGT in PJM	Case 2: Coal Power in Indiana	Case 3: Solar PV in California
Physical risks			
Water-related	•	•	•
Air and temperature related	•	•	•
Extreme weather	•	•	•
Transition risks			
Competitive RE tech			
Flexible fuel supply contracts	•	•	
Curtailment		•	•
PPA price reduction			•
Regulatory risks			
Carbon pricing	•	•	
Mandatory CCS	•	•	•
ITC Phase Down			

CASE STUDY 6

Willis Towers Watson: Insurability, rethinking risk in long-lived infrastructure

M—

Making long-lived infrastructure sustainable and insurable involves looking beyond the asset itself and treating resilience as a dynamic, system-wide challenge. Infrastructure should be assessed not only against the hazards it faces, but also against its exposure, vulnerability, criticality and dependencies on utilities, digital systems, transport networks, supply chains and operators. As climate, technological, geopolitical and cyber risks become increasingly interconnected, the resilience of an asset depends as much on the robustness of its surrounding ecosystem as on its own engineering.

For long-lived assets, this requires a forward-looking, decision-grade view of risk, covering both acute events and chronic stresses and translating them into measurable financial and operational consequences – from expected losses and downtime to revenue interruption, debt-service stress and recovery time. This enables owners, lenders and insurers to identify where resilience investment creates the greatest value and to quantify the residual risks that can genuinely be transferred.

Insurance should therefore be the final layer of a broader risk-treatment strategy, not a substitute for resilience. Risks should first be avoided where possible, reduced through engineering and operational measures, mitigated through system redesign and redundancy, and allocated to the parties best able to control them. Predictable losses can then be retained or financed, while insurance, reinsurance or capital-market solutions absorb residual, fortuitous risks.

There are, however, structural limits to what insurance can achieve. Insurance can absorb volatility, but not inevitability, obsolescence or public-policy uncertainty. Nor can annual insurance contracts guarantee protection over infrastructure lives spanning several decades. The boundary becomes particularly visible where risks are highly correlated: a single climate event, cyber failure or infrastructure outage can simultaneously affect assets, utilities, transport links, suppliers and entire portfolios.

Risk should ultimately sit with the stakeholder best placed to control it – or, where it cannot be controlled, with the balance sheet and mandate capable of absorbing it. Public intervention can legitimately complement private markets for highly correlated or systemic risks through catastrophe pools, guarantees, reinsurance mechanisms or resilience-linked finance. But it should sit above, rather than replace, private responsibility, preserving incentives for operators and investors to reduce underlying risk.

Overall, a sustainable infrastructure asset is one whose essential service can survive, recover and adapt as conditions change. An insurable asset is one whose residual risk remains measurable, bounded, accidental and transparently managed. The long-term answer to rising infrastructure risk is therefore not more insurance alone, but continuous investment in mitigation, adaptation and resilience.

RESILIENCE AS MITIGATION AND PRESERVED VALUE

Mitigation begins with the exposure the operator or infrasystem can influence. Adaptation reduces physical damage; redundancy preserves service when one component fails; and modularity limits the capital committed before demand is observed. At system level, coordination can reduce delays at the interfaces between separately owned assets. These measures matter through observable financial effects – fewer interruptions, lower repair and insurance costs, longer asset life and more stable revenue – rather than through a resilience label.

Insurance makes the remaining exposure visible. The three-quarter protection gap in the EU's natural-catastrophe losses left most of the damage with owners, users and public authorities. The joint ECB–EIOPA proposal published in December 2024 sets out two complementary instruments: an EU public-private reinsurance scheme funded through risk-based premiums, and a public disaster-financing fund supporting reconstruction subject to prior risk-reduction measures. It illustrates how responsibilities could be distributed across private insurers and public authorities; the proposal itself does not constitute insurance cover available to an individual project.[168]

Adaptation is also becoming a revenue-generating market. GIC estimated the opportunity across public and private markets at around USD2 tn in 2025, rising to USD9 tn by 2050, with approximately 60% still untapped. LSEG identified more than 2,100 listed companies generating over USD1 tn from adaptation-related products and services, while MSCI found no corresponding valuation premium in the providers it analyzed.[169] Flood protection, grid hardening, water security, cooling, weather intelligence and resilient materials therefore create markets for adaptation solutions. An individual infrastructure investment still requires a viable payment mechanism or sufficient internal cost savings; the existence of an aggregate market does not make every protection measure bankable.

That final distinction defines the boundary between mitigation and allocation. Resilience first creates value as an avoided loss – a flood that did not interrupt service or a heatwave that did not derate capacity – and an avoided loss produces no invoice by itself. It becomes contractible when a regulator admits adaptation investment into the asset base, an insurer converts verified protection into a premium reduction, or procurement pays for performance under adverse conditions. Those instruments can reduce or transfer part of the exposure; the climate, demand, technology or interface risk that remains must still be assigned to an actor and reflected in the financing structure.

168 - ECB and EIOPA, *Towards a European System for Natural Catastrophe Risk Management*, December 2024.

169 - GIC, *Climate-Adaptation Investment Opportunity Estimates*, 2025; LSEG, *Listed-Company Adaptation Revenues*, 2025; MSCI, *Valuation Analysis of Adaptation-Solution Providers*, 2025.

EXPERT POSITION 22

Vincent Cuvillier – Resilience by design: adapting infrastructure to a changing climate

“Climate change is no longer a distant risk for infrastructure operators; it has become an operational reality. Extreme weather events are already testing critical infrastructure assets across Europe, making resilience essential in both design and investment decisions. When La DANA struck Valencia in 2024, it affected a region where Cellnex operates mission-critical networks that support emergency and security services. In these situations, the immediate priority is business continuity: restoring connectivity and maintaining essential services.

However, the key lesson lies beyond crisis response. Traditional design assumptions for infrastructure are being challenged. Telecom towers are built using models based on historical wind and weather data, yet recent events have repeatedly exceeded those projections. What operators are observing today suggests that physical climate risks are evolving faster than the standards used to anticipate them.

This makes resilience fundamentally a planning challenge. For operators managing infrastructure over decades and across large portfolios of assets, adaptation cannot be addressed through reactive measures alone. It must be integrated into long-term strategy. At Cellnex, this means relying on live data and sensors to continuously validate models and updating design standards to reflect future, not just historical, climate conditions. Resilience requires a forward-looking assessment of what infrastructure will need to withstand in the coming decades, rather than relying solely on past exposures.

Resilience is also a question of capital allocation. Extreme events often create pressure for immediate action, but successful adaptation requires prioritization and long-term planning. The goal is not to react to every shock, but to invest progressively in infrastructure that is resilient by design and can perform under changing climate conditions.”



Vincent Cuvillier
Chief Strategy Officer at Cellnex

EXPERT POSITION 23

Christoph Bruguier – Resilience: a core determinant of long-term infrastructure value

“As climate change increasingly shapes economic and operational outcomes, infrastructure investors must reassess the foundations of long-term value creation. Rising climate uncertainty affects not only the physical performance of assets, but also capital allocation decisions, financing conditions, insurance costs, and regulatory expectations. In this environment, value can no longer be assessed solely through growth prospects or cash-flow projections. It increasingly depends on the ability of infrastructure assets to remain reliable, adaptable, and financially robust across a much wider range of future scenarios.

This evolution is reshaping investment strategy. Capital allocation must strike a better balance between pursuing growth opportunities and strengthening resilience. Greater attention is being paid to the resilience of capital structures, refinancing risks, lifecycle maintenance, and the capacity of assets to withstand increasingly frequent disruptions. Geographic diversification, operational flexibility, and the ability to adapt assets to evolving climatic, technological, or regulatory conditions are becoming strategic sources of value rather than simple risk-mitigation tools.

More fundamentally, climate resilience is changing the way infrastructure quality is assessed. Assets can no longer be evaluated solely on their efficiency under expected conditions, but on their performance under adverse ones. Investors are increasingly asking not only how much value an asset can create, but how reliably it can continue to create value under uncertainty.

Resilience is therefore no longer a secondary consideration or a compliance-driven risk management exercise. It has become a core determinant of long-term infrastructure value. In a world characterized by greater climatic volatility, the most valuable infrastructure assets will be those capable of maintaining operational continuity, adapting to changing conditions, and continuing to deliver essential services despite an increasingly uncertain future.”



Christoph Bruguier
Chief Investment Officer at Vauban IP

EXPERT POSITION 24

Gabriele Todesca – From asset resilience to system resilience

“Resilience must be understood at two complementary levels. The first is system resilience: the capacity of Europe's infrastructure networks to sustain economic activity, preserve strategic autonomy, and support competitiveness in the face of shocks. Questions of energy security, critical dependencies, supply chain resilience, and strategic sovereignty are ultimately questions about the resilience of the infrastructure system as a whole.

The second is asset resilience: the ability of individual infrastructure assets to anticipate, withstand, adapt to, and recover from an expanding range of physical, cyber, climatic, and operational threats. As infrastructure becomes increasingly interconnected and digitalized, vulnerabilities affecting a single asset can rapidly propagate across entire systems, making asset resilience a prerequisite for system resilience.

For many years, resilience at the asset level was largely treated as a technical or operational concern. That perspective is rapidly evolving. New European legislation and regulatory frameworks increasingly require operators to strengthen the security and resilience of critical infrastructure, reflecting the recognition that resilience has become a strategic imperative rather than a secondary consideration.

Investors are undergoing a similar shift. Resilience is no longer viewed primarily as a compliance obligation or a box-ticking exercise. It is increasingly recognized as a core driver of long-term value creation, influencing operational continuity, financing conditions, insurance costs, regulatory exposure, and ultimately the long-term performance and valuation of infrastructure assets. In an era of growing uncertainty, resilience is becoming a defining characteristic of high-quality infrastructure.”



Gabriele Todesca
Head of Infrastructure Investments at the European Investment Fund

Risk allocation and the cost of capital: making residual exposure investable

ALLOCATION BY CONTROL AND CAPACITY

Risk assessment does not by itself make an infrastructure configuration investable. It identifies how an event changes revenue, operating costs, capital expenditure, financing conditions or asset life; allocation determines who manages the deviation and who bears the loss. Grid access, demand uptake and policy direction are three exposures that often sit partly outside the asset owner's control. Transferring any of them to an operator that cannot influence the surrounding infrasystem raises the required return without reducing the risk, while retaining all three publicly leaves the fiscal claim open and detaches responsibility from delivery decisions.

The relevant division is therefore by control and capacity, not by a target public-private split. Construction and operating-performance risks can sit with the parties that control delivery; demand and price risks may require users, an offtaker or a regulator to share the exposure; and systemic risks that no project company can diversify may require insurance, a guarantee or a defined public backstop. Guarantees, risk-sharing mechanisms and credit enhancements reduce financing cost only when they cover a stated exposure rather than compensate for a configuration whose service, payer or interface remains undefined.[170]

Each allocation must then specify a bearer, a limit and a rule for change. The bearer needs the decision rights or balance-sheet capacity required to reduce the probability, limit the impact or absorb the remaining loss. The contract needs the event, evidence, formula and verifying authority required to move that exposure without reopening the complete bargain. Responsibility can also change across three gates: development capital carries permitting, design and interface uncertainty; construction capital carries completion and cost risk; and operating capital enters once delivery, availability and revenue are observable.

ALLOCATION REFLECTED IN THE COST OF CAPITAL

The quality of an allocation can be measured in financing terms. In a project-financing model for offshore wind, a two-sided contract for difference reduced real post-tax weighted average cost of capital by 1.4 to 2.4 percentage points and increased debt capacity by 15 to 27 percentage points.[173] The contract did not remove construction, operating or technical risk; it capped wholesale-price volatility and assigned the corresponding payment obligation. On a 25-year asset, that change can determine whether the projected service clears an investment threshold.

Credit performance shows the same relationship after financing. Over 1995–2023, infrastructure debt supported by resilient revenue structures recorded a five-year cumulative default rate of 0.7%, against 5.4% without such resilience.[174] Unrated infrastructure project-finance loans in the Moody's sample originated between 1983 and 2021 also achieved an average ultimate recovery of 84%, compared with 66% to 71% for non-infrastructure project finance.[175] Revenue structure does not explain every difference between the portfolios, but it explains why a lender translates unresolved interface, demand or policy risk into less debt, a shorter tenor or a higher margin, while equity requires a higher return for the deviations left after contractual protection.

170 - Global Infrastructure Hub, *How Can Risk-Mitigation Instruments Accelerate Private Investment in Infrastructure?*, 2019.

173 - Dukan M. et al., *The Impact of Two-Sided Contracts for Difference on Debt Sizing for Offshore Wind Farms*, 2025.

174 - Global Infrastructure Hub and World Bank, *Infrastructure Monitor 2024*, 2024.

175 - Global Infrastructure Hub and World Bank, Infrastructure Monitor 2024, 2024, p. 90, Moody's data on unrated project-finance loans originated between 1983 and 2021

EXPERT POSITION 25

Mike Nowak – Risk does not need to be eliminated; it needs to be allocated, structured and priced.

"Infrastructure projects do not fail due to uncertainty itself, but rather when risks are misunderstood, misallocated, or unmanaged. The purpose of infrastructure finance is to structure uncertainty, not eliminate it. Capital can be deployed under a wide range of conditions provided risks are transparent, assigned to those best equipped to manage them, and properly reflected in project economics. A good financing turns a coordination problem into a contractual one.

The infrastructure sector has repeatedly demonstrated its ability to mobilize capital at scale when risk allocation is clear. Construction risk, technology risk, volume risk and refinancing risk can all be managed through contractual arrangements that create visibility for investors and operators. In this context, certainty is not the true prerequisite for investment; what matters is whether risks can be isolated, allocated and made investable.

From a banking perspective, institutional risks most often slow capital deployment. Retroactive policy changes, inconsistent regulations, and unproven revenue models are much harder to price than technical risks. Investors can manage uncertainty when its limits are clear, but struggle when rules for future cash flows change abruptly.

Policy is most important as a source of long-term credibility, not just ambition. Capital flows when regulatory frameworks inspire confidence in project performance over time. The most effective policies provide durable signals, such as clear phase-out dates, enforceable long-term commitments, or time-bound support that encourages deployment without creating permanent dependencies. Ultimately, investment is driven not by the absence of risk, but by confidence that the rules affecting future cash flows will remain predictable throughout an asset's life."



Mike Nowak
Global Head of Infrastructure Coverage at CACIB

CASE STUDY 7

CACIB: CATI, routing institutional savings into transition debt

In January 2025, Crédit Agricole Assurances, Crédit Agricole CIB and Crédit Agricole Transitions & Energies, alongside the Regional Banks, launched the Crédit Agricole Transition Infrastructure (CATI) debt fund. Predica subscribed the fund's €300m investment capacity. The structure connects the group's project-origination capabilities with institutional savings, while RGREEN INVEST manages the fund and selects investments.

RGREEN INVEST selects projects originated by Crédit Agricole CIB and the Regional Banks and can also originate and structure additional transactions directly. The fund is classified under Article 9 of the SFDR and focuses on financing transition infrastructure. These roles describe how projects and capital are brought together; they do not by themselves establish which entity retains each credit exposure or provides any guarantee.

The portfolio finances real-economy projects eligible under the European Taxonomy, from renewable generation, biogas, storage and EV charging to waste-heat recovery and energy efficiency, with scope to diversify into low-carbon digital infrastructure[171]. Through CATI, the loans the bank originates become an asset that insurers can invest in, giving institutional capital a route into the real-economy transition. "We have become as much an originator, distributor and structurer of risk for institutional investors as we are a balance-sheet lender. A vehicle like CATI channels insurance capital into transition debt, which is exactly the kind of structure the transition needs," Mike Nowak, Global Head of Infrastructure Coverage, Crédit Agricole CIB[172].

CATI illustrates a route from bank origination to institutional debt investment. Its relevance lies in matching financing needs with a dedicated pool of capital and specialist investment selection. How losses are ultimately shared depends on the terms of the fund and of each transaction, not on the division of origination, management and subscription roles alone.

171 - Crédit Agricole Assurances, Crédit Agricole Assurances launches a fund dedicated to financing the energy transition, 20 January 2025.

172 - Michael Nowak, guest, Trade-Offs, Risk Dynamics, episode 2, The Awakening of the Force, n.d.

ONE RISK STORY ACROSS CONTRACT, REGULATORY DECISION AND FINANCING PLAN

A lower cost of capital is obtained only when the three documents carrying the allocation tell the same risk story. For a delayed grid connection or slower uptake of a low-carbon service, the commercial contract, the regulatory or tariff decision and the financing plan must identify the same five elements: the event, the named bearer, the maximum liability, the permitted adjustment and the phase at which responsibility moves. If one document assigns the revenue shortfall to the operator, another recovers it from users and the third assumes a public guarantee, the risk has been described three times but financed only once.

This consistency test also defines what an instrument cannot achieve. A revenue guarantee cannot compensate for an unavailable connection, and a completion guarantee cannot create a payer base for a service that users do not adopt. Each instrument covers a deviation only from a configuration that remains technically usable and economically recoverable under the stress case. As development, construction and operation replace assumptions with evidence, contracts and guarantees can step down; refinancing then converts the observed reduction in risk into a lower lifetime capital cost instead of leaving the development premium embedded for 25 to 40 years.

The allocation must finally remain legible to three actors. The operator tests delivery cost and the demand it can influence; the investor tests whether revenue survives the downside case and whether retained risks fit the balance sheet; the public authority tests access, distributional effects and the residual public claim. The chain is complete when the regulatory framework defines how rules change, asset-level analysis translates physical and transition events into financial exposure, mitigation reduces what the infrasystem can influence and the contractual structure assigns what remains. Capital then supports the service configuration rather than protecting an isolated asset.

FOCUS 16

Constantine Energy Storage: financing a battery portfolio

Constantine Energy Storage secured £180m of debt financing in 2025 for a portfolio of nine battery projects in England and Wales, with 612 MW of power capacity. Seven sites are located next to substations, facilitating the network interface. The transaction demonstrates that a portfolio of battery assets can attract substantial debt financing, while the siting strategy addresses one identifiable delivery constraint[176].

Assessing the resulting risk allocation requires a separate test: how merchant revenues are stressed, how battery degradation is reflected in operating and capital expenditure, and which performance obligations remain enforceable over the financing period. The public transaction announcement does not specify that allocation in sufficient detail to identify every bearer or limit. Financial close demonstrates an agreed financing structure, not the elimination of the underlying risks.

176 - Watson Farley & Williams, "WFW advises lenders on £180m BESS portfolio debt financing", 2025.

WHAT TO CARRY FORWARD

In transition infrastructure, value increasingly depends on the configuration around the asset: the physical interfaces that make it usable, the revenue model that supports it and the institutional rules governing both, must work together across the actors that control them. Coordination can unlock value through shared capacity, coupled flows, replication and common capabilities, but every additional connection also creates a dependency that must be assessed against the value it creates. Once that configuration is in place, the remaining uncertainty must be made transparent to capital. Part 3 has identified three disciplines for doing so: regulatory frameworks that make policy adjustment predictable; physical and transition risks translated into financial exposure and mitigated where possible; and residual risks allocated to actors with the control or balance-sheet capacity to carry them. The objective is not to eliminate uncertainty, but to cap it – naming the event, the bearer, the maximum exposure, the permitted adjustment and the point at which responsibility moves. Combined with Part 2's delivery conditions, this determines whether a viable pathway can also become investable, and on what terms. One question remains: which transition solutions should capital commit to, and under which conditions can they be integrated and scaled without creating the next lock-in? Part 4 turns to that choice.


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FROM INNOVATION TO DEPLOYMENT: SELECTING, INTEGRATING AND SCALING TRANSITION SOLUTIONS

Key takeaways

→ **In infrastructure, novelty and innovation are not the same thing.** Transition value comes from solutions that can be integrated into operating systems and scaled – whether they rely on a new technology, a proven technology deployed differently, or a new business and operating model. **Innovation leadership therefore increasingly means deployment leadership.** The technologies needed for most near-term decarbonization already exist: more than 80% of the emission reductions required by 2030 in the IEA pathway come from technologies already available on the market. The strategic challenge is therefore less to wait for an ideal end-state technology than to identify solutions that can be activated under real infrastructure conditions and deployed rapidly at scale.

→ **Urgency makes technology selection more demanding, not less.** Europe must navigate a narrow corridor between two costly failures: moving too slowly and reinforcing path dependency, or committing too early to immature configurations and creating stranded assets. The relevant objective is therefore governed acceleration: prioritize solutions mature enough to deliver now, while preserving compatibility, adaptability and optionality as technologies and markets evolve.

→ **The most valuable solution is often the one that unlocks more from the infrastructure Europe already has.** Compatibility with existing networks, institutions and user practices can accelerate diffusion and reduce capital requirements, while solutions targeting bottlenecks can create greater system value than additional headline capacity. Biomethane-exploiting existing gas networks or grid-enhancing technologies releasing connection capacity illustrate that a solution should be valued by the system constraint it removes, not by its technological novelty.

→ **Europe's competitiveness will depend increasingly on its capacity to industrialize innovation.** Successful pilots do not create competitive advantage unless they can become repeatable products and processes. Scaling requires standardization upstream, modularity downstream, replicable business models and mature supplier ecosystems. The decisive capability therefore shifts from invention toward **integration, replication and deployment at speed and scale** – the point at which infrastructure becomes the bridge between technological innovation and industrial competitiveness.

→ **Optionality is a strategic asset for both competitiveness and sovereignty.** A technology can reduce emissions today while locking Europe into scarce inputs, external suppliers or architectures that become expensive to change tomorrow. Solutions choices should therefore be assessed against what they make possible later: interoperability, modularity, reversibility and resource diversification can justify apparently less efficient choices when they preserve future strategic options. The test is not simply whether an innovation is cleaner today, but whether it makes the system more transformable tomorrow.

→ **Europe needs a two-track innovation strategy:** deploy what is mature while preserving the breakthroughs that could redefine future advantage. Urgency argues for directing infrastructure investment toward scalable technologies today, but concentrating exclusively on mature solutions could leave Europe dependent on technologies developed elsewhere tomorrow. Mission-oriented funding, deeper capital markets and protected experimentation can sustain disruptive alternatives until they become deployable. **Strategic autonomy therefore requires simultaneously exploiting today's technological frontier and retaining the capacity to shape tomorrow's technological frontier.**

Selecting – under urgency and uncertainty – the solutions ready to deliver now

The preceding parts established that infrastructure transition is a systemic transformation, constrained by long-lived asset inertia, regulatory uncertainty and the distribution of risk between public authorities, operators, investors and users.

This section sets out the system-level conditions that determine whether a selected solution can actually be deployed and scaled. This Part first examines how solutions should be selected and sequenced under urgency and uncertainty, then tests whether they are mature enough across their technical, systemic, institutional, financial and contractual, and social and territorial dimensions to be integrated and scaled without creating new lock-ins.

Searching for 'plug-and-play' solutions

LOCK-INS, URGENCY AND THE OSTRICH SYNDROME

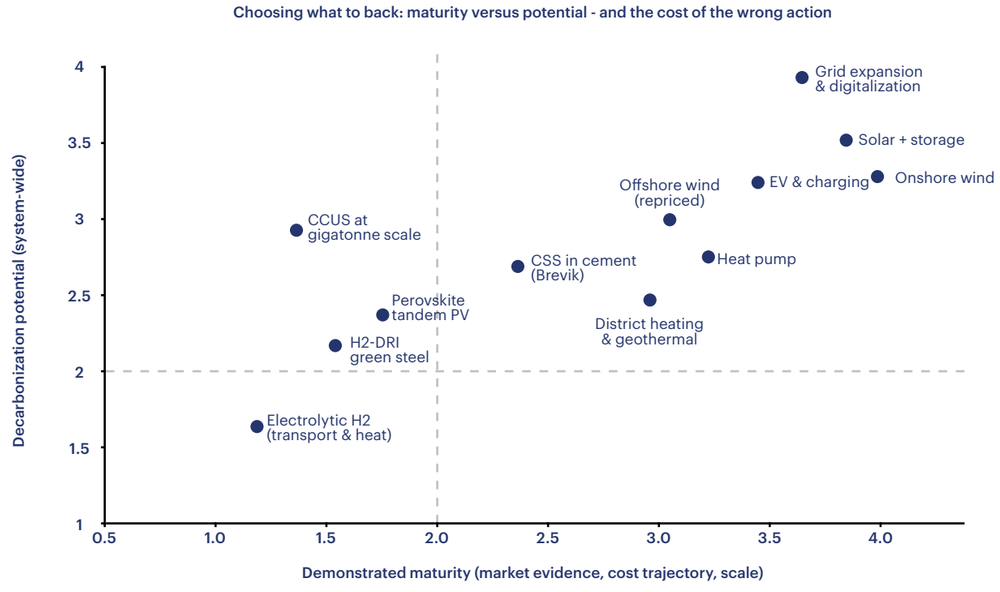
Infrastructure assets are subject to powerful lock-in dynamics, examined in Parts 2 and 3: technological lock-in through long asset lives and sunk costs; institutional lock-in through regulatory path dependency; and behavioral lock-in through entrenched user practices. As Pierson showed for political institutions, increasing-returns dynamics make reversal progressively harder over time. The challenge is to select solutions mature enough to break through these lock-ins – without creating new ones.[177]

177 - Pierson P., "Increasing Returns, Path Dependence, and the Study of Politics", *American Political Science Review*, 94(2), 2000, pp. 251–267.

FIGURE 19

Technical progress as no guarantee of an announced pipeline reaching investment

Source: International Energy Agency, Net Zero Roadmap, 2023.



CASE STUDY 8

EIF / CIP Advanced Bioenergy Fund II: financing deployment rather than novelty

In May 2026, the European Investment Fund committed €200m as a cornerstone investor in Copenhagen Infrastructure Partners' Advanced Bioenergy Fund II, a fund targeting €1.5bn for industrial-scale biogas and biomethane projects across Europe. Rather than financing an emerging technology, ABF II targets a proven production process, draws on an identified pipeline of projects and produces biomethane compatible with existing gas infrastructure.

The fund also builds on the capabilities developed through its predecessor, ABF I, whose portfolio includes Tønder Biogas in Denmark, one of Europe's largest biomethane plants. The case illustrates what deployment maturity can mean in practice: a proven technology, an existing infrastructure interface, a replicable development capability and capital available against an identifiable pipeline. Compatibility with the existing gas network reduces a major deployment barrier; it does not, by itself, eliminate longer-term lock-in risk.



Urgency is central to that selection, keeping in mind infrastructure investment cycles are long relative to the speed at which environmental constraints intensify. The challenge is not to identify ideal end-state technologies, but to determine which solutions can be activated now, under real infrastructure conditions. This gives strategic importance to solutions activable without delay:

Transition debates often display an "ostrich syndrome": a bias toward immature technologies that appear attractive in theoretical terms, paired with an underestimation of the opportunity cost of waiting. In infrastructure, where asset lives are long and implementation windows matter, such bias is costly. [178]

The most valuable solutions are those deployable within existing infrastructures and regulatory settings – and the constraint happens to coincide with the state of the art: in the IEA's net-zero trajectory, technologies already available on the market deliver more than 80% of the emission reductions required by 2030, and the share of 2050 reductions expected from technologies not yet fully commercialized has been revised downward, from around one half in the 2021 roadmap to around 35% in its 2023 update. [179]

In this context, urgency should reinforce attention to solutions already mature for deployment at scale, while preserving room for radical options to emerge later.

178 - Meyer R., Kunreuther H., *The Ostrich Paradox: Why We Underprepare for Disasters*, 2018.

179 - IEA, *Net Zero by 2050*, 2021; Net Zero Roadmap: 2023 Update, 2023.

180 - California Energy Commission and California Air Resources Board (CARB), *Joint Agency Reports on AB 8*, 2024.

181 - Bloomberg, "Few Stations and USD200 to Fill Up: Life on California's Hydrogen Highway", 2024.

182 - California Energy Commission, *New ZEV Sales*, 2024.

183 - TU Darmstadt and Hessen Mobil, ELISA Project, 2024.

184 - Trafikverket, *E20 Electric Road Project*, 2025.

185 - VINCI Autoroutes and Electreon, *Charge as You Drive*, 2025.

FOCUS 17

Timing is key: California's hydrogen highway versus Europe's electric road pilots

Hydrogen refueling in California. The "hydrogen highway" demonstrates the risk of deploying enabling infrastructure ahead of a demand base that fails to materialize. From 2013, California legislated up to USD20m per year to fund at least 100 hydrogen refueling stations ahead of confirmed vehicle demand. By 2024, only some 55 retail stations were open, many chronically offline, and Shell – a major station operator – permanently closed six of its seven light-duty stations and declined a USD41m state grant to build around fifty more, citing hydrogen demand growing "much more slowly than projected". Only 3,143 hydrogen cars were sold in California in 2023, against roughly 381,000 battery-electric vehicles. It is a clean case of enabling infrastructure deployed well ahead of a dependent measure that never materialized at scale.[180,181 182]

Electric Road Systems (ERS). Europe's ERS pilots illustrate a more cautious, incrementally tested approach to the same sequencing risk. Germany's ELISA project electrified around 10 km of catenary lanes on the A5 motorway near Frankfurt from 2019, extended to some 17 lane-kilometers by 2023-2024. Sweden piloted 1.6 km of inductive ERS on Gotland in 2020 and planned the E20 Hallsberg-Örebro corridor as the world's first permanent electrified road – before canceling the procurement as costs rose and removing the project from the national transport plan in 2025. France launched eRoadMontBlanc in October 2023 and the Bpifrance-supported "Charge as you Drive" project on the A10, whose 1.5 km of induction coils delivered the world's first dynamic-charging results on a live motorway in 2025.[183,184,185]

The contrast carries the lesson. The staged, small-scale European approach allowed exit at limited cost when the economics disappointed – Sweden's cancellation destroyed study budgets, not assets – whereas California's larger, less incrementally tested rollout left a network of stranded stations. Deploying enabling infrastructure is a bet on dependent demand; the smaller and more reversible the initial commitment, the cheaper the lesson if the bet fails.

FIGURE 20

Europe's proposed energy highways

Source: European Commission, 2025



CASE STUDY 9

Vinci Autoroutes: Electric Road System, ‘Charge as you drive’ pilot

V

VINCI Autoroutes is a subsidiary of VINCI Concessions and the leading motorway operator in Europe, managing more than 4,400 kilometers of motorway under concession in France. Road transport represents around 95% of mobility in France and close to one third of the country’s greenhouse-gas emissions.

Electrifying heavy road transport comes with the challenge of requiring heavy resource-intensive batteries that can provide the needed range, in addition to the recharging downtime that can penalize logistics operations.

The ‘Charge as you drive’ project, lead by VINCI Autoroutes in collaboration with Electreon, VINCI construction, Gustave Eiffel University and Hutchinson, seeks to address this challenge by allowing battery size to be reduced through rethinking road infrastructure.

Between January and October 2025, around 900 copper induction coils were installed roughly 10 centimeters below the pavement over a 1.5km stretch of the A10 motorway near Angervilliers, about 40km southwest of Paris. Powered by the grid, the coils generate an electromagnetic field that receiver coils fitted under vehicles can convert into electricity to power the engine and recharge the battery simultaneously. In late October 2025, the first real-world driving trials began with four prototype vehicles: a heavy-duty truck, a bus, a utility van and a passenger car. It is the first dynamic induction charging system deployed on an open motorway anywhere in the world.

Preliminary measurements by three laboratories at Gustave Eiffel University indicate that the system safely transfers peak power above 300kW and average power above 200kW under optimal steady-state conditions, comparable to today’s fast-charging stations. Mechanical durability trials at the LAMES laboratory simulated more than 25 years of heavy-truck traffic without premature degradation of the pavement sections containing the coils. A life-cycle analysis by consultancy Carbone 4 confirms significant potential to reduce CO_2 emissions and raw-material use linked to battery manufacturing.



MAKING THE HARD TRADEOFFS: A NARROWING CORRIDOR BETWEEN PATH DEPENDENCY AND STRANDED ASSETS

Yet urgency cannot justify indiscriminate acceleration. Moving too slowly risks locking infrastructure systems into carbon-intensive configurations for decades; moving too quickly behind technologies whose economic, systemic or governance conditions remain immature can create stranded assets, destroy value and ultimately weaken the capacity to finance subsequent stages of the transition. Infrastructure decision-makers therefore operate within an increasingly narrow corridor between two forms of failure:

Path dependency, where delayed action or continued investment in incumbent systems embeds carbon intensity through the inertia of long-lived assets.

Stranded assets, where premature commitment to insufficiently mature technologies or configurations locks in capital before the conditions for their sustainable deployment are in place.

The challenge, therefore, is not acceleration at any cost, but governed acceleration: moving decisively where technologies and systems are sufficiently mature, while preserving compatibility, adaptability and optionality where uncertainty remains high. This requires infrastructure choices to be assessed not only against their immediate contribution to decarbonization, but also against their ability to remain valuable across different technological, regulatory and market trajectories.

This is where Europe’s transition increasingly becomes a challenge of delivery. Converting today’s momentum behind decarbonized infrastructure into assets on the ground requires confronting trade-offs that policy discourse has often deferred: between affordability today and system costs tomorrow; between speed and due process; and between European harmonization and the legitimate diversity of national circumstances and choices. Different Member States will not necessarily reach the same solutions to the same infrastructure needs – nor should effective coordination require them to do so.

What matters is that these different pathways remain consistent with a common direction and sufficiently coordinated to function as part of an integrated European system. Without stronger alignment between policy objectives, regulatory frameworks, infrastructure planning and the incentives that ultimately mobilize private capital, deployment will remain slower, more fragmented and more incremental than either Europe’s climate objectives or its industrial ambitions can afford.

THREE CRITERIA FOR IMMEDIATE DEPLOYABILITY

Urgency and systemic thinking are not opposed. A measure can be activated without delay only if the institutions governing it are capable, the relevant actors have incentives to cooperate, financing channels exist, and the effects on users are manageable.

Three conditions are required:

First, compatibility with existing infrastructure. Solutions should work with current networks, operational practices, institutional responsibilities and financing structures, or require only limited adaptations deliverable within the relevant time horizon. As the ABF II case illustrates, compatibility can materially shorten the path from a mature technology to deployable infrastructure.

Second, targeting systemic bottlenecks. Solutions improving grid visibility, flexibility, storage integration and demand-side response can be more immediately valuable than adding generation capacity to systems that cannot absorb it. Dynamic Line Rating lets grid operators safely carry more current on existing transmission lines by measuring real-world conditions – wind, temperature – instead of relying on conservative static assumptions. The IEA estimates that a combination of grid-enhancing technologies, targeted network upgrades and non-firm connection agreements could unlock enough capacity to connect 1,200-1,600 GW of renewable projects already at an advanced stage but stuck in interconnection queues.[186]

Third, preserving future optionality. OECD work on transition finance shows that investments presented as transitional can prolong high-emitting regimes under a different narrative. Short-term solutions should be assessed by what they make possible or impossible later: a solution that reduces emissions marginally while hardening system architecture may be less valuable than a modest improvement that keeps multiple pathways open. Germany's 2024 power plant strategy – some €16bn envisaged for new gas-fired plants labeled "hydrogen-ready" – illustrates both the logic and its fragility: the optionality claim is only as good as its credibility, and the scheme was subsequently scaled back and its hydrogen-conversion requirements loosened.[187,188]

186 - IEA, Electricity 2026, "Grids", 2026.

187 - OECD, *Mechanisms to Prevent Carbon Lock-in through Transition Finance*, 2023.

188 - BMWK, *Kraftwerksstrategie*, 2024; Clean Energy Wire, "Germany's Power Plant Strategy", 2025.

EXPERT POSITION 26

Samuel Champion – Adapting as a strategic capability: from climate urgency to organizational advantage

"Climate change is accelerating demand for ecological solutions. For infrastructure operators, the impacts are already visible and are creating growing needs for resource efficiency, water management and adaptation. The question is no longer whether adaptation will be necessary, but how quickly solutions can be deployed.

Awareness of climate risks is growing among public authorities, businesses and citizens alike. This creates momentum for ecological transformation and for the deployment of solutions that help territories adapt to new environmental realities. Adaptation can no longer be treated as a secondary consideration or postponed to a later stage. Those who act early will help shape future standards, while others will ultimately have to follow them.

At the same time, adaptation requires organizations that can evolve continuously. Recent geopolitical crises and technological developments have shown that infrastructure operators must remain capable of adjusting to changing conditions. A clear long-term strategy remains essential, but so does the ability to adapt continuously as circumstances evolve. The capacity to adapt is becoming a strategic advantage in its own right."



Samuel Champion
Chief Financial Officer at Veolia

CASE STUDY 10

Veolia Italia: Trieste: scaling mature technologies through a performance-based infrastructure model

Environmental security is a strategic priority that concerns not only sustainability and technical and regulatory aspects, but also national sovereignty, industrial competitiveness, and public health and well-being. For Italy, a country that is not energy self-sufficient and is therefore particularly exposed to environmental and geopolitical crises, a systemic, long-term approach is needed. This approach should be based on the integration of energy efficiency with local renewable energy generation, as well as on the use of innovative solutions. In this process, cities and local territories play a central role, as it is at the local level that security and sustainability objectives are translated into concrete actions. It is from this perspective that the experience of Trieste fits in, where the Municipality entered a 15-year public-private partnership with a consortium led by Veolia in Italy, for modernization and energy efficiency. Rather than treating insulation, heating equipment, photovoltaics and LED lighting as separate projects, the Energy Performance Contract brings them into a single long-term performance perimeter.[189]

The contract changes the economics of deployment. Investment is organized across the portfolio, while the concessionaire's remuneration is partly exposed to the energy performance achieved: consumption reduction and renewable-production targets are measured under a formal Measurement & Verification protocol, and underperformance can reduce the energy component of the concession fee. The project, which integrates advanced efficiency with local production from renewable sources supported by AI, guarantees the Municipality a reduction in primary energy consumption of 3,829MWh, saving 1.5GWh of electricity and preventing the emission of 582 tons of CO_2. From the fourth year, the contractual structure also incorporates at least €500,000 of annual savings.[190]

Building-automation systems and continuous monitoring set in 177 buildings provide the data used to verify performance and therefore to allow for performance optimization through energy models and AI algorithms that manage the operation of production systems in real time. The case shows that scaling infrastructure innovation does not always require a technological breakthrough: it can depend on an architecture that turns proven technologies into measurable performance, assigns the corresponding risk and makes a fragmented asset base investable as one program.



System design beyond project-by-project logic

A change in the system's operating logic, not only in its components

Solutions cannot be selected in isolation. Many transition strategies approach infrastructure change through a project-by-project logic, even though the systems being transformed are interdependent. This creates a mismatch between the scale of decision-making and the scale at which transition outcomes emerge.

The transition is therefore about redesigning how infrastructure systems deliver services: new coordination between networks, different pricing and remuneration logics, revised operating models, and new user-infrastructure interactions. It is the operating logic of the system that changes, not only its component technologies.

In electricity systems, adding renewable generation is insufficient if networks, storage, market rules and demand response do not evolve in parallel – the migration of the binding constraint documented in Part 2. A system-design approach asks whether the whole electricity architecture is becoming more capable of integrating variable supply, managing congestion, maintaining affordability and ensuring resilience.

In mobility, the transition extends beyond vehicle electrification to multimodal system design, public space management, charging infrastructure integration, service pricing, digital interfaces and the territorial distribution of alternatives. User practices are part of that system compatibility. Non-plug-in hybrid-electric cars, which require no charging infrastructure and little change in established driving practices, accounted for 34.5% of new passenger-car registrations in the EU in 2025, the largest single powertrain segment. Their diffusion illustrates a broader point: solutions that can be absorbed into existing patterns of use can scale faster, making integrability a competitive attribute in its own right – although the lock-ins created by accommodating them must still be assessed[192].

ASSESSING SOLUTIONS AT SYSTEM LEVEL, NOT IN ISOLATION

A system perspective changes the unit of assessment. The question is not which technology performs best in isolation, but which combination of assets, operating models, rules, user practices and interfaces improves the performance and transformability of the system as a whole. Trade-offs therefore move beyond project-level compromises between cost, performance and speed: they concern pathway coherence – whether acceleration today reduces future optionality, whether lower short-term cost creates longer-term fragility, or whether an apparently efficient solution shifts costs or constraints elsewhere in the system.

189 - Veolia Italia, *Comune di Trieste case study*; Veolia Italia, *"Efficienza energetica, Siram Veolia e il Comune di Trieste insieme per raggiungere il NET Zero"*, 29 January 2024.

190 - Comune di Trieste, procurement documents for the PPP for municipal thermal and electricity services and Energy Performance Contract, C.O. 22151, including Measurement & Verification requirements, energy-performance deductions and the annual Quota Risparmi.

191 - Veolia Italia, *Comune di Trieste case study.*

192 - ACEA, *full-year registrations*, 2025; US EIA, 2026.

193 - Rand J. and Hoen B., "Thirty years of North American wind energy acceptance research: What have we learned?", *Energy Research & Social Science*, 29, 2017, pp. 135–148; RIFS Potsdam, 2026.

194 - Global Infrastructure Hub, *Inclusive Infrastructure and Social Equity*, 2019; InfraVision, *Infrastructure & Inclusion*, 2024.

195 - §6 EEG 2023; Länder participation laws.

EXPERT POSITION 27

Roland Kupers – Catalytic infrastructure: unlocking system-wide transformation

"The science of complex systems provides a valuable lens through which to understand infrastructure transitions. Rather than focusing exclusively on expanding or maintaining existing assets, policymakers should seek to identify catalytic infrastructure investments capable of generating non-linear effects and accelerating transformation across multiple sectors. Such opportunities are relatively rare, but their systemic impact can far exceed the direct value of the infrastructure itself.

The emergence of autonomous robo-taxis illustrates this dynamic. Beyond reducing transport emissions, autonomous mobility could fundamentally reshape the economics of the automotive sector by shortening vehicle replacement cycles, accelerating technological innovation, and significantly improving fleet utilization, road safety and energy efficiency. It could also dramatically reduce parking requirements, freeing up urban land for higher-value uses. Its effects would therefore extend well beyond mobility, influencing energy demand, urban planning, real estate, health and public space.

A second example is the development of a continental high-voltage direct current (HVDC) backbone. By enabling electricity to flow more efficiently over long distances, an integrated HVDC network could connect Europe's complementary renewable resources including solar generation, offshore wind, hydropower, and storage into a more resilient and flexible energy system. Linking geographically diverse production and storage assets would reduce variability, strengthen security of supply, and unlock efficiencies that isolated national grids cannot achieve.

The challenge, therefore, is not simply to build more infrastructure, but to identify those investments that act as systemic multipliers. Europe's greatest opportunities may lie in infrastructure interventions that unlock cascading benefits across several sectors simultaneously, increasing the speed, resilience, and cost-effectiveness of the transition as a whole."



Roland Kupers
Complexity, Resilience,
Energy Transition Expert

FOCUS 18

Social acceptability at asset level: securing the license to operate

Part 2 established political acceptance as a delivery condition of the transition, sustained by distributional design and an informed public sphere in which media shape how costs and trade-offs are understood and contested. At asset level, the same requirement becomes a license to operate: whether a specific infrastructure can be built, operated and expanded in a given territory.

Social acceptability conditions every phase of an infrastructure project's lifecycle, and low-carbon infrastructure enjoys no exemption – as the record of local opposition to wind development shows even in countries clamoring for renewable power. Securing a social license to operate therefore requires identifying the groups exposed to the asset, the costs and benefits they receive, and the procedures through which they can influence its design.

Project-level opposition can nevertheless aggregate beyond the asset itself: repeated local conflicts can slow wider infrastructure programs and feed the political dynamics examined in Part 2. At project level, however, the evidence points to a more specific mechanism: opposition is driven less by proximity alone than by perceived procedural unfairness and an uneven distribution of local costs and benefits.[193]

Inclusive infrastructure aims to ensure that low-carbon development does not cause social regression: availability, accessibility and financial sustainability are the factors infrastructure managers must balance against transition urgency. Germany's practice of channeling up to 0.2 cents per kilowatt-hour from new wind and solar plants to surrounding municipalities – with participation made mandatory in several Länder – shows that financial participation measurably improves acceptance.[194,195]

System design does not mean centralized planning. It means giving enough structure to the target architecture to orient investments and policy choices, while leaving room for learning, revision and differentiated territorial application. The target should be sufficiently specified to guide action, but not so over-determined that it eliminates adaptive capacity. Targets indicate direction; they do not determine the pathways, complementarities and institutional arrangements through which transition becomes feasible. A system-design approach shifts attention from the destination alone to the quality of the means – and especially to the cost of the wrong action.

MANAGING COEXISTENCE AND PHASING BETWEEN LEGACY AND EMERGING SYSTEMS

Part 2 established that infrastructure transition takes place through a period of coexistence rather than through instantaneous replacement. Here, the point is narrower: coexistence and phasing should be treated as tests of solution deployability. A solution that requires incumbent capacity to disappear before replacement services are ready is not deployable, regardless of its technical maturity.

A credible phasing strategy should still distinguish preparation, scale-up, system reconfiguration and managed decline or repurposing. In Part 4, these phases matter only insofar as they reveal whether networks, operating models, skills, financing, regulation and affected users can adapt in the required order.

FOCUS 19

Selecting the solutions absorbable by the system: the long-duration storage regime[196]

Great Britain had about 2.9 GW of long-duration electricity storage installed against a public requirement of 4 to 6 GW by 2030. To close that gap, the regulator applied to storage the cap and floor instrument already used for electricity interconnectors, and opened a first application window in April 2025.

The funnel shows what selecting a solution means in practice. Of 171 applications representing 52.6 GW of storage, 77 projects totaling 28.7 GW passed the initial eligibility assessment. On 26 June 2026, Ofgem announced the provisional selection of 16 projects totaling 7,645 MW and 136.9 GWh, with durations ranging from eight to twenty-two hours, and opened a consultation. Fewer than one applicant in ten reached this provisional selection stage; it was not a final award.

Two stages structured the assessment. The first tested seven eligibility criteria, including the ability to provide at least eight hours of continuous output at full power. The 94 rejected applications failed one or more eligibility criteria; they were not all excluded by the duration requirement alone. The eligible projects then entered a comparative assessment of system benefit, deliverability and cost.

The provisional shortlist spans several storage technologies. Pumped hydro projects include schemes of 1.4 GW, 600 MW and 400 MW, while eleven battery projects contribute around 3.6 GW. The shortlist illustrates a search for complementary system services across technologies; it does not establish that Ofgem has already procured a final portfolio of duration and responsiveness.

196 - Ofgem, *Long Duration Electricity Storage: Eligibility Assessment Outcome*, September 2025; Ofgem, "Ofgem boosts long duration storage to secure more homegrown energy for customers", 26 June 2026 (provisional selection and consultation).

Clearing the remaining blockage: shifting towards socio-technical integration

Within the framework of system design and sequencing, the question of solution selection returns – no longer as "which technologies exist or appear promising", but as which innovations are sufficiently mature to alter infrastructure regimes without creating new lock-ins. This section defines maturity in multidimensional terms – technical, systemic, institutional, financial and social – and links it to lock-in prevention and to the alignment of business models with transition objectives.

Defining innovation maturity in multidimensional terms

Whether an innovation is sufficiently mature to alter infrastructure regimes under real deployment conditions cannot be answered in purely technological terms. Infrastructure systems are shaped by interacting lock-ins – technological, institutional and behavioral – and transformation requires simultaneous adjustment across all three.

A technology that is technically ready but cannot be absorbed by existing institutions, financed through available instruments, or adopted by users without unacceptable friction is not, in the relevant sense, mature.

Public debate tends to focus on emblematic transition technologies and solutions – renewable generation, storage, low-carbon fuels, digital optimization, carbon capture, circular materials – as if technical availability were enough to make transition possible. In practice, many fail to scale not because their technical principle is unsound, but because the surrounding system is not ready to absorb them.

A multidimensional notion of maturity is required:

- **Technical maturity:** reliability, safety, replicability and performance under real operating conditions;
- **Systemic maturity:** the degree to which an innovation can fit into, complement or progressively reshape existing infrastructure systems without creating disproportionate fragility or bottlenecks;
- **Institutional maturity:** whether standards, permitting rules, governance arrangements and public authority capacities are sufficiently developed to support deployment;
- **Financial and contractual maturity:** whether reliable revenues and an acceptable allocation of risk make the project financeable. Bankability can rely on credible public support; competitiveness without support and the fiscal sustainability of that support are separate tests;
- **Social and territorial maturity:** whether users, workers, communities and local institutions can absorb the change without unacceptable distributional or legitimacy costs.

This multidimensional approach is consistent with established assessment frameworks such as the World Economic Forum's Energy Transition Index, which applies comparable criteria across technical, institutional and economic dimensions.[197]

197 - World Economic Forum, *Fostering Effective Energy Transition*, 2025.

EXPERT POSITION 28

Roseline Legrand – Systems thinking and the industrialization of innovation

"For infrastructure, value increasingly resides not in individual assets, but in the way interconnected systems operate together. As infrastructure networks become more digital, electrified, and interdependent, competitive advantage will stem less from optimizing individual components than from orchestrating the system as a whole. Success will increasingly depend on the ability to coordinate investments earlier, integrate infrastructure across sectors, and create long-term visibility along the entire value chain – from planning and financing to construction, operation, and maintenance.

This requires greater standardization upstream to reduce complexity, increased modularity downstream to accelerate deployment and maintenance, more industrialized delivery models, and stronger ecosystems of suppliers, contractors, and technology partners. Creating scalable infrastructure is not simply a question of engineering; it is also a question of industrial organization. Replication, rather than one-off optimization, must become a central design principle.

This is often where innovation reaches its limits. Pilot projects frequently succeed because they benefit from exceptional attention, dedicated resources, and bespoke solutions. Scaling, however, requires the opposite. Innovation must become ordinary: simple to specify, straightforward to procure, familiar to delivery teams, and economically viable across hundreds or thousands of projects. The transition from demonstration to deployment is therefore not only a technological challenge but an industrial one, requiring common standards, repeatable business models, and organizational capabilities that allow successful solutions to be reproduced consistently across regions and sectors.

Ultimately, the next frontier of infrastructure competitiveness will lie less in inventing new solutions than in building the capacity to replicate, integrate, and deploy them at speed and scale. In the coming decade, the winners are likely to be those who can transform innovation into repeatable industrial processes capable of delivering systemic change."



Roseline Legrand
Director of Concessions at Bouygues Construction

EXPERT POSITION 29

Anne-Christine Champion – Connected ecosystems for global competitiveness

"In high-tech industries, scale is now essential for competitiveness. Leadership in sectors such as artificial intelligence, robotics, semiconductors and space depends on bringing together capabilities, expertise, and industrial actors within integrated ecosystems. The appropriate scale is increasingly continental rather than national. For Europe, the challenge is both to foster innovation and to organize its capabilities at the scale required to compete globally. No individual European country can realistically master every capability across today's technology value chains.

In this context, strategic partnerships are becoming increasingly important. The proposed collaboration between Airbus, Thales, and Leonardo in the satellite sector shows how European companies can combine their strengths to achieve the scale needed for international competitiveness in sectors closely linked to sovereignty and security. Similar dynamics may develop in artificial intelligence, robotics, cybersecurity, and semiconductors.

To achieve competitiveness and strategic autonomy, capabilities need to be organized into competitive ecosystems. Europe has significant industrial, technological, and engineering strengths. The challenge is to connect these assets more effectively, deepen cooperation where scale is required, and strengthen Europe's position in global value chains through robust industrial ecosystems."



Anne-Christine Champion
Co-Head of Global Banking and Investor Solutions

EXPERT POSITION 30

Mike Nowak – Infrastructure scales when projects become repeatable, bankable and attractive to institutional capital.

"Transitioning from pilot projects to scalable deployment requires both bankability and repeatability. A bankable project can operate without subsidies. A scalable project can be replicated, financed repeatedly, and supported by proven demand. The key difference between pilots and scalable projects is often not just technology, but the ability to demonstrate a viable business model, reliable revenues, and long-term investment potential.

From a financing perspective, scale depends on standardization. Investors and lenders need confidence that the fiftieth project can be financed and operated much like the first. This is why repeatability, operating data, proven demand, and access to debt markets are so important.

Infrastructure scales when projects move from bespoke opportunities to established asset classes that institutional capital can support over decades.

Policy is also critical in moving from pilot to scale. Grants and subsidies can launch new technologies, but long-term investment requires credible signals that extend beyond support programs. Clear regulatory commitments, phased deadlines, and stable policy frameworks create predictable demand and assure investors that markets will continue to develop.

The cost of delaying this process is often underestimated. Postponement does not reduce infrastructure needs; it compresses investment into a shorter period and increases pressure on supply chains, labor markets, and financing. Often, those who bear the costs of delay are not those responsible for it.

Infrastructure transitions require scale, which is achieved only when projects become repeatable, bankable, and able to attract long-term capital."



Mike Nowak
Global Head of Infrastructure Coverage at CACIB

Linking maturity to the prevention of lock-ins

CLEANER TODAY IS NOT THE TEST; MORE TRANSFORMABLE TOMORROW IS

The value of the maturity framework becomes clearer when linked to lock-in. Infrastructure assets are long-lived, capital-intensive and deeply embedded in regulatory, financial and territorial systems: innovation choices made today shape economic options for decades. The transition question cannot be reduced to choosing "better" technologies in the abstract; it must also ask whether current choices expand or narrow future pathways.

A technology may reduce emissions relative to the incumbent regime while still locking the system into a narrow architecture – relying on business models that discourage later reconfiguration, creating dependence on constrained resources, or producing incentives difficult to unwind. Transition finance faces the same test: the OECD warns that financing emissions-intensity improvements or long-lived assets without credible phase-out or conversion plans can extend incumbent regimes rather than unwind them. The relevant question is not only whether a solution is cleaner today, but whether it leaves the system more capable of transformation tomorrow.[198,199]

Maturity and lock-in prevention must therefore be assessed together. A mature innovation is not merely one that works in present conditions; it is one whose deployment is compatible with the desired direction of long-term system change – either reducing current constraints while keeping multiple pathways open, or actively enabling later phases of transition. Under uncertainty, optionality itself becomes strategic value.

The contrast between optimization and optionality returns here at the level of technology choice: investments that appear highly efficient because they optimize a narrow function – throughput, cost per unit, short-term utilization – can make later adaptation more difficult, while investments that are less efficient short-term but improve interoperability, modularity, reversibility or network flexibility may offer greater long-term value.

Sectoral examples support the point:

- In electricity, network and storage investments that increase flexibility and connection capacity may have lower political visibility than generation projects, but they expand future decarbonization options;

- In circular infrastructure, service-based models and design-for-reuse principles may not maximize short-term asset turnover, but they create a system more capable of reducing resource dependence over time;

In transport, digital integration and service design can preserve multiple modal pathways, whereas asset-heavy choices tied to narrow behavioral assumptions may become brittle.

FUNDING THE MATURE WITHOUT STARVING THE BREAKTHROUGH

Past divergences in innovation financing illustrate the institutional gap. Research funding for perovskite solar cells – a higher-efficiency alternative to silicon photovoltaics – long trailed silicon's because perovskite lacked comparable near-term market prospects. Preventing underinvestment in disruptive alternatives while channeling urgent deployment toward mature solutions requires dedicated policy instruments: at European level, this points toward integrating capital markets to fund higher-risk innovation at scale, and entrusting a dedicated, DARPA-type agency with steering targeted innovation policy.[200]

Preventing lock-in also requires governance tools. Taxonomies, transition plans, sector roadmaps and public investment frameworks should embed criteria relating to flexibility, future compatibility, interoperability, phased decline of incumbent systems and stranded-asset exposure. Contracts should include review clauses, adaptation mechanisms and decision gates where uncertainty is high. Lock-in prevention is not only about selecting the right technology at the start; it is about keeping the pathway corrigible over time.

198 - OECD, *Mechanisms to Prevent Carbon Lock-in through Transition Finance*, 2023.

199 - Unruh G. C., "Understanding Carbon Lock-in", *Energy Policy*, 28(12), 2000, pp. 817–830.

200 - Seto K. C. et al., "Carbon Lock-In: Types, Causes, and Policy Implications", *Annual Review of Environment and Resources*, 41, 2016, pp. 425–452.

FOCUS 20

Mission-oriented innovation policy and the DARPA model

The challenge of balancing urgent deployment of mature technologies with continued support for breakthrough innovation has prompted renewed interest in mission-oriented innovation policy. The Draghi report argues that Europe's innovation gap relative to the US stems in part from fragmented capital markets and the absence of a dedicated agency capable of steering high-risk, long-horizon research toward strategic objectives – and recommends reforming the European Innovation Council into an ARPA-type agency.[201]

The DARPA (Defense Advanced Research Projects Agency) model combines program managers with significant autonomy, tolerance for failure, milestone-based funding and an explicit focus on technologies too risky for private capital but with potential for transformative impact. Economists working on directed technical change argue that adapting this model to climate and energy could help bridge the "valley of death" between laboratory innovation and commercial deployment – a gap that conventional market-based instruments and incremental R&D support struggle to close.[202]

For infrastructure, the implication is a two-track design. Market-based signals and regulatory frameworks steer urgent deployment toward already scalable technologies – the mature solutions this part emphasizes; dedicated mission-oriented instruments maintain optionality by funding disruptive alternatives, such as perovskite cells or next-generation storage, that lack near-term market prospects but could reshape future pathways. The challenge is institutional: ensuring both tracks operate in parallel, without the promise of breakthrough innovation becoming a pretext for delaying action on mature solutions.

ADAPTABILITY AND THE DISTRIBUTIVE TEST

In many transition contexts, environmental performance, resilience and user value are not rewarded by legacy business models. Infrastructure-as-a-service approaches may realign incentives by focusing on delivered outcomes, but raise questions of inclusion, access and governance; PPPs and related contractual forms can support transition if they integrate sustainability and stakeholder considerations, but reproduce old logics if climate, social and flexibility criteria remain peripheral.

Risk allocation is especially important – the cornerstone identified in Part 3. The wrong risk allocation can prevent mature solutions from scaling, while the right one can make transition pathways investable. Public authorities may need to absorb early-stage regulatory or demand risks, provide guarantees, create minimum-revenue mechanisms or support blended finance where solutions generate system value not yet monetized; as markets deepen and uncertainty declines, risk can be reallocated. Contracts also shape adaptability: where uncertainty is high, rigid long-term contracts may increase lock-in risk even when they support initial financing. Performance-based remuneration, periodic review clauses, phased commitments and incentives linked to system outcomes may provide a better balance between bankability and adaptability.

The distributive dimension completes the test. Business models that support transition but undermine affordability or access may erode legitimacy and demand. The "five A's" framework of inclusive infrastructure – access, affordability, adequacy, acceptability, accountability – shows how infrastructure value creation must be tested against user realities, not only investor returns; value-sharing and stakeholder engagement are increasingly central to project durability.[203]

Public policy should treat business-model innovation as a transition lever in its own right. Too often, attention concentrates on technology support while commercial and contractual innovation is treated as secondary. Yet in infrastructure, the shape of the contract can determine whether the technology scales, who bears risk, how incentives evolve and whether the system remains adaptable. Business-model innovation is one of the mechanisms through which technological change becomes systemic.

201 - Draghi M., *The Future of European Competitiveness*, 2024.

202 - Acemoglu D. et al., *Green Innovation and the Transition Toward a Clean Economy*, 2023; Aghion P. et al., *The Power of Creative Destruction*, 2021

203 - Global Infrastructure Hub, *Inclusive Infrastructure and Social Equity*, 2019; InfraVision, *Infrastructure & Inclusion*, 2024.

From technological choice to socio-technical integration

ALIGNMENT ACROSS LAYERS – AND THE COST OF A POOR FIT

Solution choice, in the end, is socio-technical integration rather than a purely technological decision. A solution succeeds only when several layers align: the technology must work, but it must also be connectable to networks, acceptable to operators, understandable to regulators, financeable through available instruments, and compatible with user behavior. A failure at any layer can limit system effects even when the technology itself performs well.

This is where infrastructure differs from many other fields of innovation policy. In sectors with low capital intensity or short product cycles, markets absorb experimentation and failure relatively quickly. In infrastructure, experimentation is slower, assets are harder to repurpose and errors are more costly: the price of a poor fit between technology and system is not only financial underperformance, but potentially prolonged lock-in or political backlash.

Sectoral evidence shows how alignment fails even where technical maturity is not the constraint. Decarbonized hydrogen lags for infrastructural, institutional and economic reasons – projects at final investment decision represent some 9% of the announced pipeline to 2030. Carbon capture faces comparable circularity between infrastructure, offtake and liability despite commercial projects dating back to the 1990s. Urban district heating outside Northern Europe has been held back by limited public confidence, regulatory gaps and lengthy permitting – institutions, not pipes. Conversely, well-integrated solutions reshape possibilities across connected sectors: a grid modernization program can enable new forms of generation, mobility and building electrification; a circular procurement model can change design practices, maintenance regimes and waste streams across entire value chains. The system effect comes from integration, not from the isolated superiority of any single technology.[204,205,206]

204 - IEA, *Global Hydrogen Review*, 2025.

205 - Global CCS Institute, *Global Status of CCS 2025*, 2025.

206 - Tong D. et al., 2020; Cour des comptes, 2021.

207 - Strambach S., 2010; Tongur S., *Engwall M.*, 2017.

208 - Johnstone P., *Schot J.*, 2023; Jacobsson S., *Lauber V.*, 2006.

209 - Foxon T. et al., 2013; Turnheim B., *Nykvist B.*, 2019.

210 - Jain M., *Rohracher H.*, 2022.

211 - Lucas-Healey K. et al., *analysis of early V2G experiments in Australia*, 2022.

EXPERT POSITION 31

Didem Nisanci – Competitiveness: from innovation to integration

"Competitiveness is no longer determined by innovation alone, but by the ability to combine innovation with industrial capacity and infrastructure. Increasingly, the countries that lead are not those that invent first, but those that can scale, manufacture, deploy, and integrate new technologies most effectively.

Artificial intelligence illustrates this shift. While the United States continues to lead in frontier software and foundation models, competitive advantage increasingly depends on the infrastructure that enables them: data centers, electricity networks, semiconductor manufacturing, and the capacity to deploy AI throughout the physical economy. China has pursued a different strategy, building an advantage through the simultaneous development of industrial capacity, manufacturing scale, energy infrastructure, and digital networks, allowing new technologies to be deployed rapidly and at scale.

The same evolution is reshaping the energy transition. Climate policy and energy security have become inseparable from industrial policy. Competitive advantage is increasingly determined by control over critical supply chains, manufacturing capabilities, infrastructure deployment, and the ability to shape the standards that will govern future technologies and energy systems.

In this context, access to technology and infrastructure has become a geopolitical issue. Technologies that were once widely available are increasingly subject to export controls, industrial strategies, and geopolitical bargaining.

The resulting fragmentation risks pushing Europe towards costly duplication rather than productive cooperation. Europe's challenge is therefore not simply to innovate, but to reinforce the industrial and infrastructure foundations that allow innovation to be commercialised, deployed, and scaled, while building resilience through a carefully managed strategy of selective interdependence."



Didem Nisanci
Senior Fellow for Climate and Geoeconomics at the Global Climate Policy Project at Harvard and MIT

WINDOWS OF OPPORTUNITY AND BRANCHING POINTS

The integrability challenge has a temporal dimension for innovation adoption specifically. Certain configurations open temporary windows of opportunity, generating institutional plasticity during which the prevailing socio-technical regime becomes more receptive to alternative innovations. Beyond ordinary renewal cycles, exogenous shocks can interrupt path dependency – as Chernobyl and Fukushima did for Germany's nuclear withdrawal – and such windows can open at city level too, as the Covid-19 disruption did for Manila's transport reform.[207,208]

Because transitions are difficult to fully control, anticipating plausible branching points – critical moments at which pressure forces decisions shaping the subsequent trajectory – helps build alignment strategies. Two types deserve attention: early signals of growing demand for alternatives, to which incumbents' strategies abruptly adapt; and capacity tensions arising from the interdependence between technological development and infrastructure needs, which typically surface as bottlenecks – the migration of the binding constraint documented in Part 2.[209]

PROTECTED SPACES: WHERE INNOVATIONS MATURE WITHIN THEIR SYSTEM

Protected spaces for experimentation allow innovations to mature within their surrounding socio-technical environment before wider diffusion. Decentralized urban infrastructure systems – for renewable generation, rainwater management or shared mobility – deployed within urban redevelopment programs can serve as such niches; the discipline lies in evaluating when a niche is ready to scale, as the sober assessments of the first vehicle-to-grid trials illustrate.[210,211]

GOVERNANCE FOR COORDINATION, NOT COMMAND

Governance, finally, must enable coordination rather than only command. Because innovation success depends on alignment across multiple layers, no single actor controls the whole process: operators, regulators, investors, users, local authorities, technology providers and communities all influence whether integration succeeds. Transition governance must create arenas in which complementarities can be identified, conflicts managed and course corrections made.

FOCUS 21

Manila's jeepneys: anatomy of a window – and of its limits

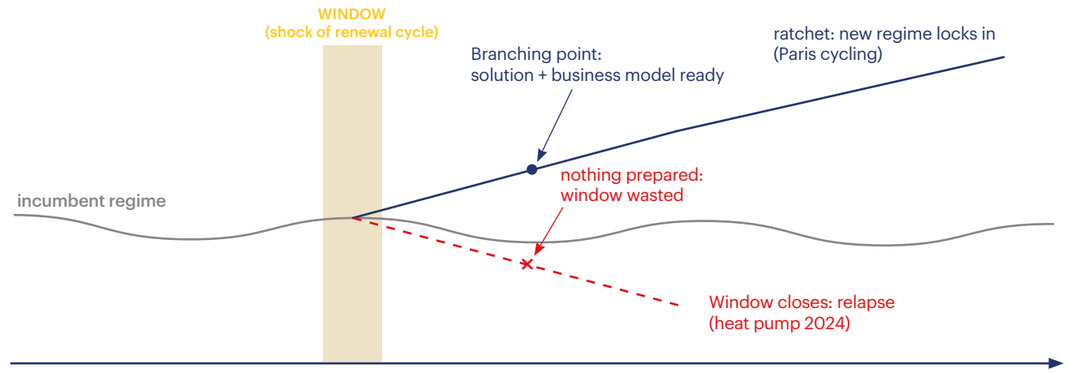
When the Covid-19 pandemic brought Metropolitan Manila's transport to a near-halt, the long-entrenched informal jeepney system – a textbook case of behavioral and institutional lock-in – was abruptly destabilized. The authorities used the window to accelerate a franchise-consolidation and fleet-modernization program and to invest massively in protected cycling infrastructure.

Half a decade on, the episode reads as a cautionary tale as much as a success. The cycling investment endured; the jeepney modernization stalled – route rationalization far behind schedule, repeated national strikes, deadlines extended again and again, with drivers facing vehicle costs more than ten times the price of a traditional unit. The window was real; what was missing was the just-transition financing that would have made passage through it affordable to those asked to change. A window of opportunity is a necessary condition – never a sufficient one.

FIGURE 21

Opening and closing windows: sequencing and the legacy of a crisis

Source: InfraVision analysis, based on Foxon et al., 2013; Turnheim and Nykvist, 2019.



FOCUS 22

Hackney Council: a regulatory sandbox in action

Hackney Council's residential solar program illustrates the regulatory work needed to share rooftop generation with tenants while preserving their electricity-supply rights. The obstacles addressed by Emergent Energy's model included metering, electricity settlement and residents' ability to choose another supplier within a private-wire arrangement; they did not amount to a general prohibition on landlords supplying solar electricity to tenants.

Emergent Energy developed a building-level private-wire model through which residents can use locally generated solar electricity while retaining the ability to switch supplier. Ofgem's regulatory sandbox supported testing of arrangements that required changes to industry rules. The Balancing and Settlement Code modification P455, implemented on 24 September 2024, established a standard route for relevant metering and settlement arrangements on license-exempt networks, marking one step from experimentation towards wider application.

In January 2025, Hackney Council announced a pilot covering 28 council blocks, with around 4,000 panels intended to serve some 800 households, backed by a £2m council investment to be repaid through electricity sales. Regulatory reform and housing delivery are distinct stages: P455 had already been implemented, while a separate sandbox trial concerning network charges had been extended in November 2024. The case therefore illustrates both an achieved step towards generalization and remaining implementation work, rather than a wholly bespoke exemption still awaiting its first standard regulatory pathway.[212]

212 - Hackney Council, "Council tenants to see lower bills as pioneering solar energy pilot begins", January 2025; Ofgem, *Regulatory Sandbox: Emergent Energy Systems Ltd*, 2022; Elexon, BSC modification P455 (implemented 24 September 2024); Ofgem, Emergent Energy sandbox decision letter, updated 11 November 2024.

INFRAVISION 2026 STUDENT COMPETITION

Designing infrastructure systems under uncertainty

"INFRASTRUCTURE AS A SYSTEM: RETHINK THE FUTURE"

For its 2026 competition, sponsored by Clifford Chance and BBVA, and themed Infrastructure as a System, InfraVision invited students to design projects able to adapt to changing demand, technology, regulation and resource availability. The three winning proposals connect technical choices with governance and investment sequencing. Together, they examine conditions central to this report: how infrastructure can remain useful, affordable and adaptable as its operating environment changes. All project costs, performance figures and outcomes presented here are the teams' estimates or targets, rather than demonstrated results.

THE JURY

Chaired by Sadie Morgan, founder of the Quality of Life Foundation and a champion of design excellence while serving on the UK's National Infrastructure Commission, and including leading experts in economics, policy, energy and environmental transition, and innovation, the jury evaluated the submissions for creativity, feasibility, and potential impact:



SADIE MORGAN

Chair of the jury
Co-founder of drMM



JEAN-MICHEL BLANQUER

Former French Minister of Education and President of Terra Academia



ERIK JONES

Director of the Robert Schuman Center for Advanced Studies at the European University Institute



PATRICE GEOFFRON

Professor at Université Paris Dauphine-PSL



DIDEM NISANCI

Senior fellow at the Global Climate Policy Project at Harvard University and MIT, and former Chief of Staff at the US Department of the Treasury

1ST PLACE

Before the Wall

Before the Wall locates the challenge of zero-emission logistics at the interfaces between freight networks and the city. The proposal reorganizes where large loads are broken down, how deliveries are consolidated and how scarce curb space and electrical capacity are allocated. It was developed through morphological analysis of five problem areas (curb space, power demand, movement, waste-free flow and narrow-channel throughput) and draws on documented precedents such as Mail Rail, Gnewt Cargo and Cargo Sous Terrain.

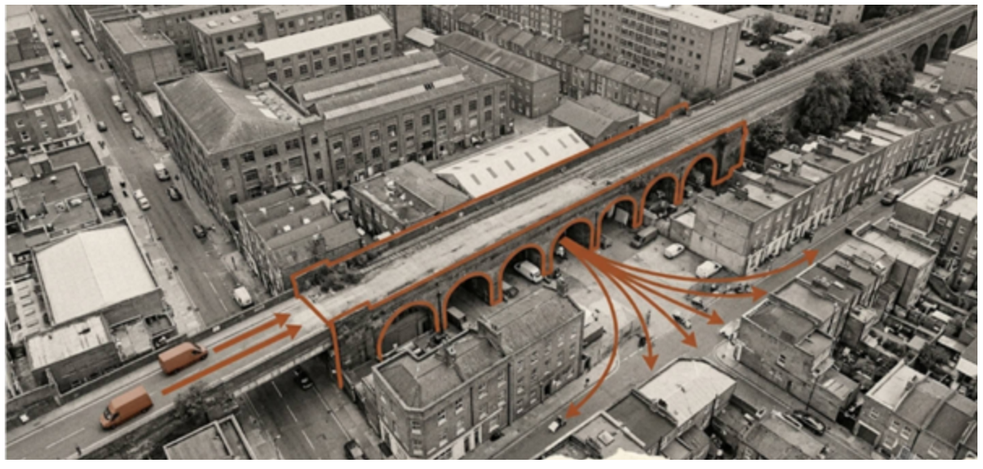
Amsterdam is the proposed demonstration site; the initial service focuses on business deliveries, whose standing contracts and predictable schedules are more compatible with booked access than on-demand consumer parcels.

Before the Wall proposes three connected layers: a consolidation hub at the zero-emission zone boundary, neighborhood microhubs in reused buildings, and a counterweighted connector from microhub to curb. Trucks unload outside the zone; smaller electric vehicles and cargo bikes serve local demand. The connector would use descending loads to lift returning containers. Booked curb slots address scarce street space, with reserved access for small shops so that the transition is workable for them, not only for large carriers.

A neutral operator would protect carriers' commercial data. Public capital would fund construction, with carrier fees intended to cover operations. A €55,900 initial test precedes a roughly €383,000 first-year pilot. Expansion requires at least 120,000 parcels a year, costs no higher than €1.40 per parcel and three active carriers. The next gate lowers the cost ceiling to €1.10 and requires the connector to outperform the van leg it replaces; the hub network could continue without it.

Heat stress, weaker zone enforcement and packaging reuse are tested. These pressures interact: charging and packaging washing compete for grid capacity, while reduced freight volumes and packaging returns change space requirements. Grid capacity and anchor carriers must therefore be secured before commitment. The target is a 70% reduction in vehicle entries per 1,000 parcels, benchmarked against another city. Amsterdam's baseline, lease costs and connector capacity remain to be verified.

Proposed neighborhood microhub in reused railway arches.



STAGE	PROPROSED DEPLOYMENT AND DECISION GATE
Initial test	One bike, one rider and one microhub-to-curb link over a year; test actual carrier use and daily operation before a larger pilot.
Months 1–14	Confirm power and carrier demand; open by month 6. At month 14: at least 120,000 parcels/year, cost ≤€1.40/parcel and three active carriers.
Months 15–38	Add two microhubs; obtain detailed connector costing. At month 38: cost ≤€1.10/parcel and a measurable advantage over the van leg.
Months 39–60	Proposed replication to two boundary hubs and nine microhubs. If the connector underperforms, the hub network can proceed without it.

2ND PLACE

Tambak Sarioso: A Nurture-Based Solution Approach

Tambak Sarioso proposes a community-based polder for Tambak Langon, a settlement within Surabaya's industrial fringe. The problem combines tidal flooding, rainfall, river flows and subsidence. Elevated roads and industrial platforms constrain drainage, while groundwater extraction and soft soils add to sinking-ground risks. The team's response joins physical protection with arrangements for land, alternative water supply and maintenance. Its central proposition is that the institution responsible for keeping the system operational should be established before the principal works begin.

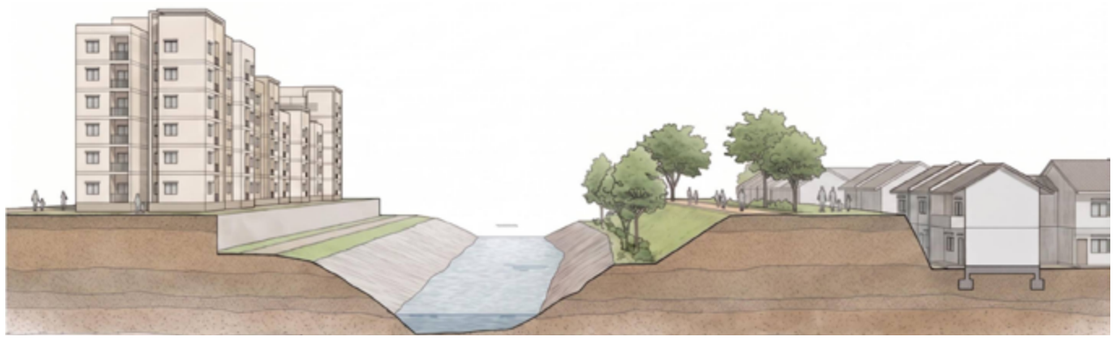
The design would use streets and alleys for twin-pipe drainage, separating rainwater from household wastewater. Rainwater would enter retention storage; wastewater would be treated before entering the pond. Earth embankments, pumps and negotiated retention capacity in productive aquaculture ponds would manage flows to the Kali Branjangan river. The protection target is a 1-in-50-year flood together with annual tidal flooding, subject to periodic reassessment as conditions change.

Residents would map flood depth, duration and coping routes, help inventory existing assets and choose between configurations that meet professional safety standards. The Community-Based Polder Body would hold the mandate and manage funds; local crews would undertake paid maintenance and report failures. The financing model favors local public service agency status (BLUD), while the roadmap also mentions a cooperative form. Either arrangement would need explicit authority to retain revenue and pay for recurring services.

Government would provide initial investment, regulatory powers and links to city drainage and spatial planning. Industries benefiting from reliable access would contribute to maintenance and shift away from groundwater abstraction. Pond owners would provide agreed storage capacity; farmers and fishers would represent water quality and fish stocks. Annual monitoring would inform revisions and, where ecological thresholds are breached, provide grounds to stop works.

The main target is to reduce tidal-flood days per household from a stated four to five annually in 2026 to zero in 2040. Supporting indicators cover water salinity and biochemical oxygen demand, the share of recurring costs paid from the body's own revenues, and proximity of rehousing. These measures connect engineering performance to daily life, ecological conditions and institutional durability; they remain proposed monitoring criteria.

Proposed river section with nearby rehousing, embankment and settlement drainage.



PERIOD	PROPOSED MILESTONES
2026–28	Establish the Polder Body, settle tenure, record the household flood baseline and test one twin-pipe alley block.
2029–32	Commission embankment, retention, pumping and wastewater treatment; deliver replacement supply before ending groundwater abstraction.
2033–36	Evaluate performance against the initial baseline and transfer recurring costs to the body's own-source revenues.
2037–40	Replicate in Greges Barat if subsidence remains below 30mm/year; otherwise move towards staged retreat of the lowest strip.

3RD PLACE

A Subsea Data Infrastructure Ecosystem

The project proposes a modular subsea data center off Fécamp, Normandy, connected to dedicated renewable electricity, a coastal operating base and two carbon-removal activities. The aim is to address power, cooling and land constraints while preserving the ability to maintain and upgrade computing equipment. The wider system would include an offshore energy partner, marine service providers, the port, data-center tenants and independent environmental verification.

At a proposed depth of 30–50 meters, individually retrievable compute cartridges would sit inside pressure hulls and share standard power and data interfaces. A resident remotely operated vehicle (ROV) would exchange cartridges without raising the entire capsule. Servers would use single-phase dielectric liquid immersion, transferring heat through titanium exchangers to seawater. The team models power usage effectiveness at 1.07 and no freshwater use for cooling; these are design assumptions, not measured operating performance.

A non-biocidal silicone coating would limit biological attachment without relying on copper leaching. Its greater cleaning requirement would be assigned to the same ROV fleet used for servicing. This combines two maintenance functions, but also makes the availability of that fleet a material dependency. Liquid immersion and retrievable cartridges aim to accommodate higher-density AI equipment, at the cost of more complex marine engineering.

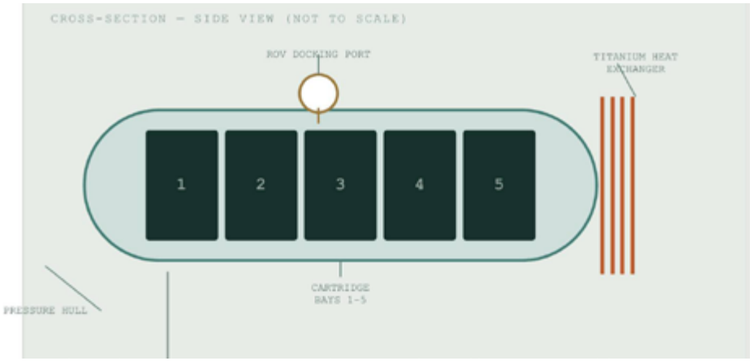
The proposed safety framework calls for marine classification of hulls and moorings, design for site-specific 100-year storm conditions, protected cables, secondary containment of dielectric fluid and emergency isolation coordinated with the port. It also envisages tenant separation and alignment with French cybersecurity and data-protection requirements.

A roughly 5 MW pilot in 2026–28 would test capsule engineering, ROV servicing, renewable power pairing and algae biomass burial. Expansion to 20 MW in 2028–31 would add seagrass restoration, informed by pilot thermal data. The 2031–35 phase envisages commercial operation and partial blue-bond refinancing after two to three years of verified data. Initial funding would combine equity and infrastructure debt; refinancing benefits remain conditional on evidence and financing terms.

Scenarios test stricter carbon scrutiny, higher AI rack density and tighter marine spatial planning. The team's responses are, respectively, separate carbon audits; modular servicing and liquid cooling; and independently permitted phases with coastal brownfield siting. Each adaptation introduces costs or delays, so technical flexibility must be considered alongside insurability and commercial demand.

The proposal combines 200 hectares of seagrass, modeled at 1,000 tons of annual sequestration, with 50 hectares of algae ponds, modeled at 5,000 tons of annual removal through drying and burial. Seagrass would be kept outside the capsule's thermal zone and assessed through independent sediment sampling below the biologically mixed layer. Algae burial would require checks on depth, permanence and site integrity. Modeled annual carbon income ranges from $80,000 to $1.05 million after algae production costs, making it a supplementary revenue stream.

Proposed modular capsule with cartridge bays, ROV docking and heat exchanger.



20MW COMPARISON	TEAM'S MODELED RESULT
Capital cost	About USD140 million above a land facility, based on a 1.5× construction multiplier and an additional 8% contingency.
Annual operating costs	Land: USD38.47 million; subsea: USD27.71 million. Difference: USD10.76 million, including the modeled insurance cost.
Payback	13 years from operating savings alone; 12.4 years in the base case including carbon revenues.
Year 15 cumulative balance	Conservative: - USD42.1 million; base: +USD29.7 million; optimistic: +USD80.0 million. Conservative payback: 18.7 years.

FIVE KEY CONDITIONS OF SUCCESS FOR INFRASTRUCTURE TRANSITION

Infrastructure transitions are ultimately a test of our capacity for long-term collective action. The challenge is not simply to mobilize technology and capital, but to align public authorities, regulators, operators, investors and users around transformations whose costs begin today, whose benefits unfold over decades and whose precise course cannot be known in advance. The pathway matters as much as the destination: the choices made along the way will determine not only whether transition objectives are met, but whether they strengthen competitiveness, resilience and sovereignty – or instead create higher costs, new vulnerabilities and dependencies.

Success therefore depends on combining strategic direction with the capacity to learn and adjust – sustaining confidence in the destination even as the route evolves. Too little direction delays investment and perpetuates incumbent systems; too much prescription can lock capital and policy into choices that later prove costly to reverse. The objective is neither certainty nor perfect planning, but a decision framework capable of accelerating transformation while preserving the capacity to adapt as conditions change. The five conclusions below set out how governed acceleration becomes operational in practice.

1. Set a durable destination and align incentives around it.

Ambition matters because it gives long-lived investment a direction. The target should be tied to a durable need and a credible horizon, but the stronger test is whether the incentives acting on the same system point toward that destination. Measures can each pursue a legitimate objective and still pull the same business case in opposite directions. Success therefore begins with a destination clear enough to arbitrate between individually desirable actions, not simply to accumulate them.

2. Govern technology, pace, sequence and retirement through evidence.

A target sets the destination, not the route. Technology, pace, sequence and the evidence for retirement should remain explicit and revisable as uncertainty is eliminated. The pathway is credible when decisions can adapt without reopening the objective itself, and when incumbent capacity is retired only after the functions it still performs have demonstrably been replaced. Pilots, phased deployment and decision gates create value because they convert uncertainty into evidence before the largest commitments are made.

3. Design the system around the asset – and select solutions it can absorb.

An asset is investable only within the configuration that makes it useful: physical interfaces, revenue model, institutional responsibilities, users and territory. These elements should be considered together, not sequentially. Solutions also need to be mature not only technically, but in the surrounding system, institutions, financing arrangements, contracts and territory, while preserving future options. Coordination can create value through shared resources, capacity, learning or skills, but that value should be assessed net of the dependencies it creates.

4. Make rules stable, credible, coherent and predictable.

Long-lived investment requires rules to remain as stable as possible over time. Where change is necessary, it should follow a credible and predictable process. Review timing, evaluation criteria, adjustment methods, treatment of committed assets, verification and exceptional routes should be clear before uncertainty materializes. Credibility also depends on coherence across policies: instruments affecting the same system should not send contradictory economic signals. The objective is a framework that provides durable visibility for investors while retaining the capacity to adapt when circumstances genuinely require it.

5. Allocate residual risk through one consistent risk story.

Not every risk can be removed or efficiently carried by the asset owner. What remains should be described consistently across the commercial contract, regulatory decision and financing plan: the event, the bearer, the maximum exposure, the permitted adjustment and the point at which responsibility moves. Allocation is credible when the actor carrying a risk has either the control to mitigate it or the capacity to absorb it, and when the same exposure is not implicitly assigned to different parties in different documents.

BIOGRAPHIES OF EXPERTS

JEAN-MICHEL BLANQUER

Jean-Michel Blanquer served as France's Minister of National Education, Youth and Sports from 2017 to 2022. A jurist by training, he is currently the president of Terra Academia, the school and accelerator of ecological transformation launched by Veolia in March 2024, which trains people for the professions of the environmental transition. Earlier in his career he held a series of academic and public-service roles, including director of the Institut des Hautes Études de l'Amérique Latine, rector of the académies of Guyane and Créteil, director-general of secondary and junior school education at the Ministry of Education, and director-general of the ESSEC business school. He holds a doctorate in law from Université Panthéon-Assas and a master's in political studies from Sciences Po, and is today a professor of public law at Université Paris-Panthéon-Assas.

CHRISTOPH BRUGUIER

Christoph Bruguier is Chief Investment Officer and Partner at Vauban Infrastructure Partners, and a member of the firm's Executive Committee. Since joining Vauban in 2019 as Senior Investment Director and Partner, he has been involved throughout the investment lifecycle, from deal sourcing and structuring to asset management, with a strong emphasis on value creation across digital infrastructure, energy transition infrastructure, mobility, and social infrastructure. He spent the first part of his career at the investment bank HSBC, holding various positions between Paris, New York, and Tokyo for 22 years, where he was involved in originating, structuring, and executing infrastructure transactions, capital markets deals, and structured financings. Before joining Vauban, he previously served at InfraVia Capital Partners.

ANNE-CHRISTINE CHAMPION

Anne-Christine Champon was appointed co-Head of Global Banking and Investor Solutions at Societe Generale in May 2023, jointly overseeing the Group's Financing & Advisory, Global Markets, Transaction Banking, and Securities Services businesses, as well as the COO function for this division. She is a member of the Group Executive Committee. Prior to joining Societe Generale, Anne-Christine Champon spent 20 years at Natixis Corporate & Investment Banking, where she held various positions spanning Financing & Advisory, including Head of Infrastructure & Project Finance, Head of Distribution & Portfolio Management and then Head of Real Assets, responsible for investment banking activities in Energy, Infrastructure, Real Estate, and Aviation. She was appointed co-Head of Natixis CIB and a member of the Natixis Management Committee in 2020. Anne-Christine is a member of the Board of Colas, Bouygues Group. She is a graduate of the École Normale Supérieure de Lyon in France and of the Stanford Executive Program.

SAMUEL CHAMPION

Samuel Champion is Chief Financial Officer at Veolia Italia since 2021, the Italian arm of the Veolia group, a global specialist in water, waste, and energy management services, where he also sits on the board of directors. He began his career with Paribas in 1998 and then in 2000 joined the Veolia Group at Veolia Water Systems Egypt as project finance manager, before joining Dalkia in 2002, where he held a series of finance roles in M&A and International Financial Control before becoming Chief Financial Officer for Spain from 2012 to 2014. He subsequently served as Chief Financial Officer of Veolia Spain and Veolia Japan before taking up his current position in Italy. He was also President of Veolia Industria Italia from 2021 to 2026. He is a graduate of Sciences Po Rennes and HEC Paris.

ANNA CRETI

Anna Creti is Professor of Economics at Université Paris Dauphine-PSL, where she directs the Climate Economics Chair and the Natural Gas Economics Chair, run jointly with the Toulouse School of Economics, IFPEN, and the École des Mines. She is also a Senior Research Fellow in the Department of Economics at the École Polytechnique and an external affiliate of the University of California Energy, Environment and Economics center at Berkeley. Her research covers the competition and regulation of network industries and the links between energy, climate, and environmental policy. She is co-editor of the journals Energy Economics Journal of Environmental Management and Journal of Economics, Energy and Environmental Policy. She holds a PhD in Economics from the Toulouse School of Economics and completed a post-doctorate at the London School of Economics.

VINCENT CUVILLIER

Vincent Cuvillier is Chief Strategy Officer at Cellnex, Europe's largest independent operator of wireless telecommunications infrastructure. Previously, he was CEO of Cellnex France (2019–2023) and as Group Business Development and Country Coordination Director at Cellnex (2018). Earlier in his career, he was Chief Financial Officer at SANEF (2015–2017), Head of M&A at Abertis Infraestructuras (2008–2014) and a financial auditor at EY Luxembourg. He is currently Chairman of the French Chamber of Commerce and Industry in Barcelona (CCIFB) and a member of the International Advisory Board of IÉSEG School of Management. He holds a master's degree from IÉSEG School of Management.

SÉBASTIEN FRAISSE

Sébastien Fraisse is the CEO and President of the Executive Board of Indigo Group, a global leader in parking, individual mobility, and urban services. He has been CEO since 2022 and became President of the Executive Board in April 2023. He began his career at the French Ministry of Equipment, in charge of road projects, then moved into the motorway sector, holding executive positions at Autoroutes du Sud de la France between 2007 and 2012 before joining Indigo in 2012 as Deputy Managing Director for France. He is a graduate of École Polytechnique and École Nationale des Ponts et Chaussées.

BIOGRAPHIES OF EXPERTS

PATRICE GEOFFRON

Patrice Geoffron is Professor of Economics at Université Paris-Dauphine-PSL, where he directs the Centre for the Geopolitics of Energy and Raw Materials (CGEMP) and heads the university's energy-climate research team. Holding a doctorate in industrial organization, he has been a professor at Paris-Dauphine since 2002 and served as the university's international vice-president and, in 2020, as its interim president. His research focuses on the economics of the low-carbon energy transition, including renewables, smart grids, and smart cities. He is copresident of Le Cercle des économistes, one of France's most influential economic think tanks, and has been a visiting professor at institutions including Bocconi University in Milan, Fudan University in Shanghai, and the University of Tokyo.

ANA GIROS

Ana Giros i is Executive Vice President in charge of Strategy, Development and Corporate Social Responsibility at Equans, a global leader in energy and services and part of the Bouygues Group, Executive President of its Belux, Latin America and Iberian Peninsula business unit. She began her career at Alstom in 1996, where she spent twenty years in various national and international positions, joining the executive committee of Alstom Transport in 2009 as CEO of the Services division and being appointed CEO France in 2013. She joined Suez in 2016 as CEO for Latin America, and from 2019 served as Executive Vice-President in charge of the group's international activities until joining Equans in 2022. Since 2017 she has been an independent member of the Board of Directors of Bureau Veritas, where she chairs the Corporate Social Responsibility Committee. Since 2026 she is an independent member of the Board of Directors of Alstom. She is a graduate of the ETSEIB engineering school in Barcelona, with post degree education in INSEAD, and IMD.

ERIK JONES

Erik Jones is Professor and Director of the Robert Schuman Centre for Advanced Studies at the European University Institute (EUI), a position he has held since September 2021, and a Non-resident Scholar at Carnegie Europe. Before joining the EUI, he spent nearly two decades at the Johns Hopkins School of Advanced International Studies (SAIS), where he was Professor of European Studies and International Political Economy and Director of European and Eurasian Studies. A specialist in the European economy, politics, and transatlantic relations, he is the author of several books, most recently From Club to Commons: Enlargement, Reform and Sustainability in European Integration (2025, with Veronica Anghel), and co-editor of the journal Government & Opposition. He holds an AB from Princeton University and an MA and PhD from Johns Hopkins SAIS.

HAZAL DENIZ KAYA

Hazal Deniz Kaya is a PhD researcher at the Faculty of Architecture and the Built Environment of Delft University of Technology, where her work examines how public infrastructure organizations navigate sustainability transitions and translate long-term ambitions into strategic and operational change, with a particular focus on the policy and organizational challenges of coordinating across multiple actors and infrastructure sectors.

Her research is conducted within the ADEPT (Adaptable Design Pathways for Transitions) project, funded by the Dutch Research Council under the Next Generation Infrastructures program. Within this research, she studies sustainability transitions and interdependencies among energy, transport, and water infrastructure systems in close collaboration with Dutch infrastructure partners. She holds a BSc in Civil Engineering and MSc in Construction management, where she studies system dynamics of strategic decision-making of digitalization in modular construction projects.

ROLAND KUPERS

Dr. Roland Kupers is an independent adviser and author specializing in complexity, resilience, and energy transition. A theoretical physicist by training, he holds a PhD in complexity and policy and spent a decade each at AT&T and at Shell in various senior executive functions, including Vice President for Sustainable Development and Vice President Global LNG, where he was closely involved with strategy and scenario planning. He has since become an author and lecturer, and an adviser to global organizations including the Environmental Defense Fund, the World Resources Institute, and the Rockefeller Foundation, as well as initiator and lead architect of UNEP's International Methane Emissions Observatory. His books include Complexity and the Art of Public Policy (Princeton, 2014) and A Climate Policy Revolution (Harvard, 2020).

ROSELINE LEGRAND

Roseline Legrand is Director of Concessions, Institutional Relations and Key Accounts at Bouygues Construction, a global player in construction, infrastructure, and public-private partnerships, having led the group's Concessions division since 2023. She began her career in the French Ministry of Ecology (2003–2006), before serving as adviser on transport and sustainable urban development at the French Embassy in China (2006–2010). In 2011, she joined the Syndicat des transports du Rhône et de l'agglomération lyonnaise (SYTRAL) as Deputy Director General (2011–2015). She later joined the Bouygues Construction group in 2015 through its property-development subsidiary Linkcity Sud-Est before taking charge of concessions. She is a graduate of the École Normale Supérieure de Paris and the École Nationale des Ponts et Chaussées.

BIOGRAPHIES OF EXPERTS

FABRICE LEPOUTRE

Fabrice Lepoutre is President of Coriance, a leading French company specialising in urban heating and cooling networks powered by renewable and recovered energy sources such as geothermal energy and biomass. He joined the group as Chief Executive Officer in December 2025 and succeeded Yves Lederer as President in March 2026. He previously spent fifteen years leading Effia, the Keolis (SNCF) subsidiary specialising in parking and mobility infrastructure management, where he developed extensive experience in long-term contract management and partnerships with local authorities. At Coriance, his priorities include strengthening network performance, accelerating growth, and supporting local authorities and industry in their decarbonization efforts.

SUSANNE NIES

Susanne Nies is an electricity, energy and climate professional and political scientist, specializing in European electricity systems, EU energy governance, and Eastern Europe. She is project lead at the Helmholtz-Zentrum Berlin, where she heads the Green Deal Ukraïna project supporting the development of sustainable energy systems in Ukraine. From 2020 to 2023 she was General Manager for Germany and the DACH region at Smart Wires, and previously headed the Corporate Affairs Section of ENTSO-E, the European Network of Transmission System Operators for Electricity, from 2015 to 2020. She is Chair of the Board of Fraunhofer IEE in Kassel and a lecturer at the Technical University of Berlin and the College of Europe in Bruges. Her publications include work on European electricity interconnections and, as editor, The European Energy Transition: An Agenda for the Twenties. She holds a PhD from the University of Bonn, a habilitation from the Free University of Berlin and Sciences Po Paris, and a degree in economics from the London School of Economics.

DIDEM NISANCI

Didem Nisanci is Senior Fellow for Climate and Geoeconomics at the Global Climate Policy Project at Harvard and MIT, which she joined in December 2025, where she works at the intersection of climate, finance, and geoeconomics. From 2021 to 2025 she served as Chief of Staff to US Treasury Secretary Janet L. Yellen, helping lead the Department's domestic and international agenda and establishing its first Climate Hub. She was also a founding executive of the Financial Stability Board's Task Force on Climate-related Financial Disclosures (TCFD). Earlier, she was Chief of Staff of the US Securities and Exchange Commission and Staff Director of a US Senate Banking Committee subcommittee. She is a graduate of Smith College.

NICOLAS NOTEBAERT

Nicolas Notebaert has served as CEO of Concessions at VINCI since November 2024, overseeing the group's airports, motorways, highways, railways, stadiums, and public-private partnerships. He is also a member of the VINCI Group Executive Committee. He began his career in 1994 as a consultant to the World Bank and later held various positions in the French Ministry of Public Works and served as a cabinet member of the French Minister for Transportation and Infrastructure. He joined VINCI in 2002 as Head of Operations for the road concession Cofiroute, became President of VINCI Airports in 2008, leading it to become the world's largest private airport operators, and was appointed CEO of VINCI Concessions in 2016. He is a graduate of the École Polytechnique and the École Nationale des Ponts et Chaussées.

MICHAEL NOWAK

Michael Nowak is Managing Director and Global Head of Infrastructure Coverage at Crédit Agricole CIB, a role he has held since 2022, leading teams based in London, Paris, Madrid, Milan, New York, and Singapore. He began his career in 2006 at Scotiabank in Toronto in the bank's structured credit business, before moving to London in 2007 as a founding member of its European Infrastructure Finance & Advisory team, working as a financial adviser and debt arranger with investors and large corporates across the EMEA region. In 2014 he joined Mediobanca in London, becoming Co-Head of the Infrastructure & Transportation M&A group, advising on many of the largest transactions in Europe, and was later appointed Head of Infrastructure & Sovereign Wealth Fund Coverage.

SADIE MORGAN

Sadie Morgan is the Founding Director of My Critical Friend and Founder of the Quality of Life Foundation, and one of the UK's most influential voices in the built environment, recognized for advancing design quality and social equity across infrastructure, development, and regeneration. With over two decades of experience, she has played a leading role in advising major infrastructure projects and serving as a commissioner for the UK's National Infrastructure Commission, now NISTA. For 30 years she was a co-founding director of dRMM, the Stirling Prize-winning architectural practice known for innovative and people centered design. She is a Professor at the University of Westminster and a former Mayor's Design Advocate for Greater London. Recognized for her contribution to architecture and design advocacy, she is an Honorary Fellow of the RIBA and holds honorary doctorates from London South Bank University and the University of the Built Environment. In 2020, she was awarded an OBE for services to design in the built environment.

APPENDIX 1

BIOGRAPHIES OF EXPERTS

THOMAS REYNAUD

Thomas Reynaud has been Chief Executive Officer and a director of the iliad Group since May 2018, and since 2024 has also served as Chairman of the Board of Directors of Tele2, a telecoms operator active in Sweden and the Baltic states. He joined the iliad Group in 2007 as Head of Business Development, before becoming Chief Financial Officer in 2008 and Deputy Chief Executive Officer in 2010. Over that period, he played a crucial role in bringing Free Mobile to market, France's fourth mobile operator. He also oversaw the Group's expansion outside France with the launch of iliad Italia in 2018 and the acquisitions of Play (2020) and UPC (2022) in Poland. He is a graduate of HEC Paris and New York University.

GABRIELE TODESCA

Gabriele Todesca has been Head of Infrastructure Investments at the European Investment Fund since January 2024. He joined the EIF in 2006 and has held various roles covering both investments and business development. Earlier in his career, he worked at Francisco Partners, a technology-focused private equity firm, in Menlo Park and London, and as an associate at Soros Private Equity Partners in London, having begun as an investment banker at Citigroup in London. He holds an LLM in Banking and Finance from the London School of Economics, and law degrees from the Università degli Studi di Trento, Italy, and the Universitat Autònoma de Barcelona, Spain.

APPENDIX 2

GLOSSARY

ABF	Advanced Bioenergy Fund
AI	Artificial intelligence
APU	Auxiliary power unit
ARENH	Accès régulé à l'électricité nucléaire historique
ARPA	Advanced Research Projects Agency
AUD	Australian dollar
BEVs	Battery-electric vehicles
CACIB	Crédit Agricole Corporate and Investment Bank
CATI	Crédit Agricole Transition Infrastructure
CBAM	Carbon Border Adjustment Mechanism
CIB	Corporate and investment bank
CIP	Copenhagen Infrastructure Partners
DANA	Depresión aislada en niveles altos (isolated high-altitude depression)
DARPA	Defense Advanced Research Projects Agency
DGT	Duisburg Gateway Terminal
DICE	Dynamic Integrated Climate-Economy model
DSO	Distribution system operator
ECB	European Central Bank
EIF	European Investment Fund
EIOPA	European Insurance and Occupational Pensions Authority
ELISA	Elektrifizierter, innovativer Schwerverkehr auf Autobahnen (electrified innovative heavy goods transport on motorways)
ENTSO-E	European Network of Transmission System Operators for Electricity
ERS	Electric road systems
ERTMS	European Rail Traffic Management System
e-SAF	Synthetic sustainable aviation fuel produced using electricity-derived hydrogen
ESG	Environmental, social and governance
ETCS	European Train Control System

GLOSSARY

ETS	Emissions Trading System
ETS2	Emissions Trading System for buildings, road transport and additional sectors
EU	European Union
EV	Electric vehicle
G20	Group of Twenty
G7	Group of Seven
GDP	Gross domestic product
GIC	GIC Private Limited (Singapore's sovereign wealth fund)
GPUs	Graphics processing units
GVA	Gigavolt-ampere
GW	Gigawatt
GX	Green Transformation
HPC	High-performance computing
HSR	High-speed rail
HTS	HTS Group (inland shipping and logistics group)
HVDC	High-voltage direct current
IAMs	Integrated assessment models
IEA	International Energy Agency
IMF	International Monetary Fund
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
ITC	Investment tax credit
KPIs	Key performance indicators
kW	Kilowatt
kWh	Kilowatt-hour
LAMES	Laboratoire Auscultation, modélisation, expérimentation des infrastructures de transport
LED	Light-emitting diode
LSEG	London Stock Exchange Group
MSCI	MSCI Inc. (formerly Morgan Stanley Capital International)

GLOSSARY

MVA	Megavolt-ampere
MW	Megawatt
MWh	Megawatt-hour
NATO	North Atlantic Treaty Organization
NESO	National Energy System Operator
NOBIL	Norwegian charging-station database
NOx	Nitrogen oxides
OECD	Organisation for Economic Co-operation and Development
PPPs	Public-private partnerships
PSA	PSA International (port and terminal operator)
PV	Photovoltaic
R&D	Research and development
RIIO-2	Second price-control period under the Revenue = Incentives + Innovation + Outputs framework, developed by Ofgem (Office of Gas and Electricity Markets), Great Britain's energy regulator
RIIO-3	Third price-control period under the Revenue = Incentives + Innovation + Outputs framework, developed by Ofgem (Office of Gas and Electricity Markets), Great Britain's energy regulator
RIP	Réseaux d'initiative publique (public-initiative networks)
SAF	Sustainable aviation fuel
SDGs	Sustainable Development Goals
SFDR	Sustainable Finance Disclosure Regulation
SMEs	Small and medium-sized enterprises
TAVD	Terra Academia pour la Ville Durable (Terra Academia for the Sustainable City)
TEN-T	Trans-European Transport Network
TWh	Terawatt-hour
UK	United Kingdom
UN	United Nations
UNOPS	United Nations Office for Project Services
US	United States
USD	United States dollar
VAT	Value added tax

APPENDIX 3

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