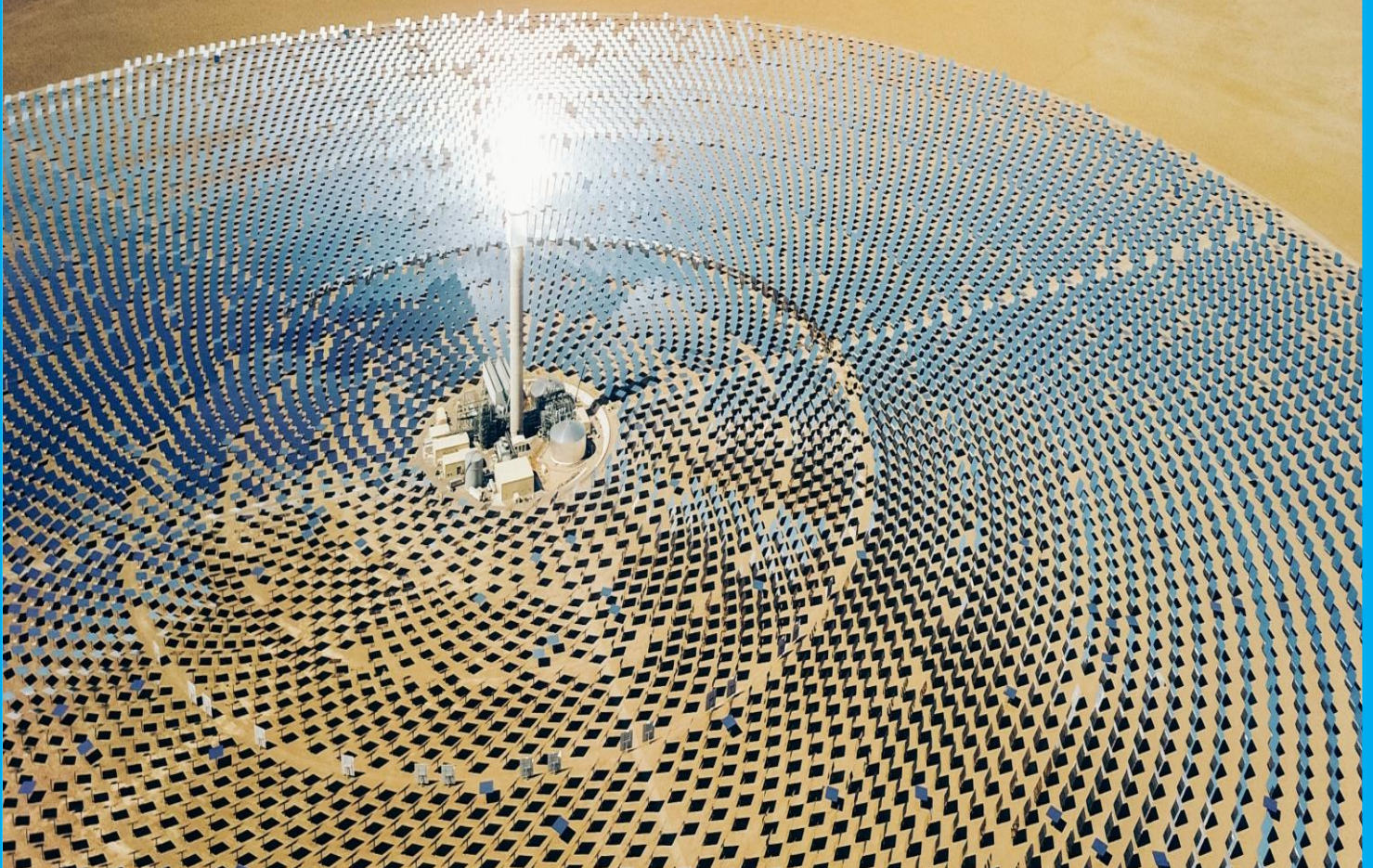




# Transition Realism: Financing Energy Systems That Work

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# Executive Summary: Building an Energy System that Works

A gap is emerging between the rhetoric of climate objectives and the operational realities of current energy systems. So far, the debate has centred on goals and timelines; it now needs to focus on implementation.

All stakeholders are also reassessing earlier expectations. The idea of a smooth transition, implying a near-frictionless shift from one global energy system to another, is being replaced by a more grounded view of the economic and security implications.



## This paper offers four principal insights:

- **Energy addition not substitution:** Despite record renewable deployment, global fossil fuel consumption has never been higher. Driven by the unprecedented power demands of AI, the re-industrialisation of defence, and emerging market growth, we are stacking energy sources rather than substituting them. Any investment strategy predicated on rapid substitution is ignoring the data.
  - **Alpha is now in the infrastructure:** Value creation is now in the physical bottlenecks of the energy system. It is in underinvested energy infrastructure, in new mining and minerals capacity, and in the firming assets required to maintain system reliability.
  - **Electrons and molecules will co-exist:** Alongside electrification, natural gas remains integral to the global energy system, while low-carbon molecules, including ammonia, methanol, hydrogen, and e-SAF expand the decarbonisation toolkit for transport, industry, and long-duration energy storage.
- Energy hierarchy not trilemma:** When energy systems are under pressure, priorities become clear: security of supply comes first, followed by affordability, with sustainability addressed once the basics are assured. The energy trilemma is, in practice, a hierarchy - investment must reflect this real-world order to endure.

# Net zero: Financing the reconfiguration of energy, industry and infrastructure

The world is attempting something without precedent in economic history: the simultaneous transformation of its energy, industrial, and electrical systems.

- Energy systems evolve according to engineering constraints, cost structures, and installed infrastructure.

**This is not a conventional transition driven by technology substitution.** It is a capital-intensive restructuring of the physical economy that must occur under tight time constraints, in the face of rising global energy demand, strained supply chains, geopolitical fragmentation, and chronic underinvestment in critical infrastructure<sup>1,2,3</sup>.

**The binding constraints are system integration and industrial capacity.** Power grids are congested. Materials supply is constrained. Permitting and construction bottlenecks are systemic. Firm capacity is underbuilt, and, according to the IEA's 2025 World Energy Outlook, renewables are, in some cases, in danger of becoming stranded assets because the electricity system cannot absorb their output<sup>4</sup>.

**The implications are profound.** The transition is evolving beyond a technology theme centred exclusively on wind, solar, batteries, and so forth. Hitherto, a great deal of value has been created via investing in power generation technologies. Today, there is an increasing focus on the grid and associated infrastructure. Going forward, this will be an economy-wide investment into an industrial economy involving mining, electricity transmission infrastructure, storage, and the various aspects of energy systems required to deliver reliable, affordable, and clean energy services to a growing global population. This will inevitably generate substantial volumes of wastes, which in turn requires major investment in environmental remediation and circular economy infrastructure. **Enabling the transition to succeed will require massive and sustained investment in grid resilience, mining, industrial capacity, and flexible generation.**

Energy transition is not a conventional technology swap – it is a capital-intensive, economy-wide restructuring. The decisive investment opportunities lie in enabling infrastructure, industrial capacity, and system integration. Value will be created by solving bottlenecks in grids, mining, and system delivery, where demand is durable and returns are shaped by execution, integration, and capital discipline.

<sup>1</sup> <https://www.energy.gov/gdo/national-transmission-needs-study>

<sup>2</sup> [https://www.allianz.com/content/dam/onemarketing/azcom/Allianz\\_com/economic-research/publications/specials/en/2025/july/2025-07-30-Infrastructure.pdf](https://www.allianz.com/content/dam/onemarketing/azcom/Allianz_com/economic-research/publications/specials/en/2025/july/2025-07-30-Infrastructure.pdf)

<sup>3</sup> <https://www.mckinsey.com/industries/infrastructure/our-insights/the-infrastructure-moment>

<sup>4</sup> <https://www.iea.org/reports/world-energy-outlook-2025>

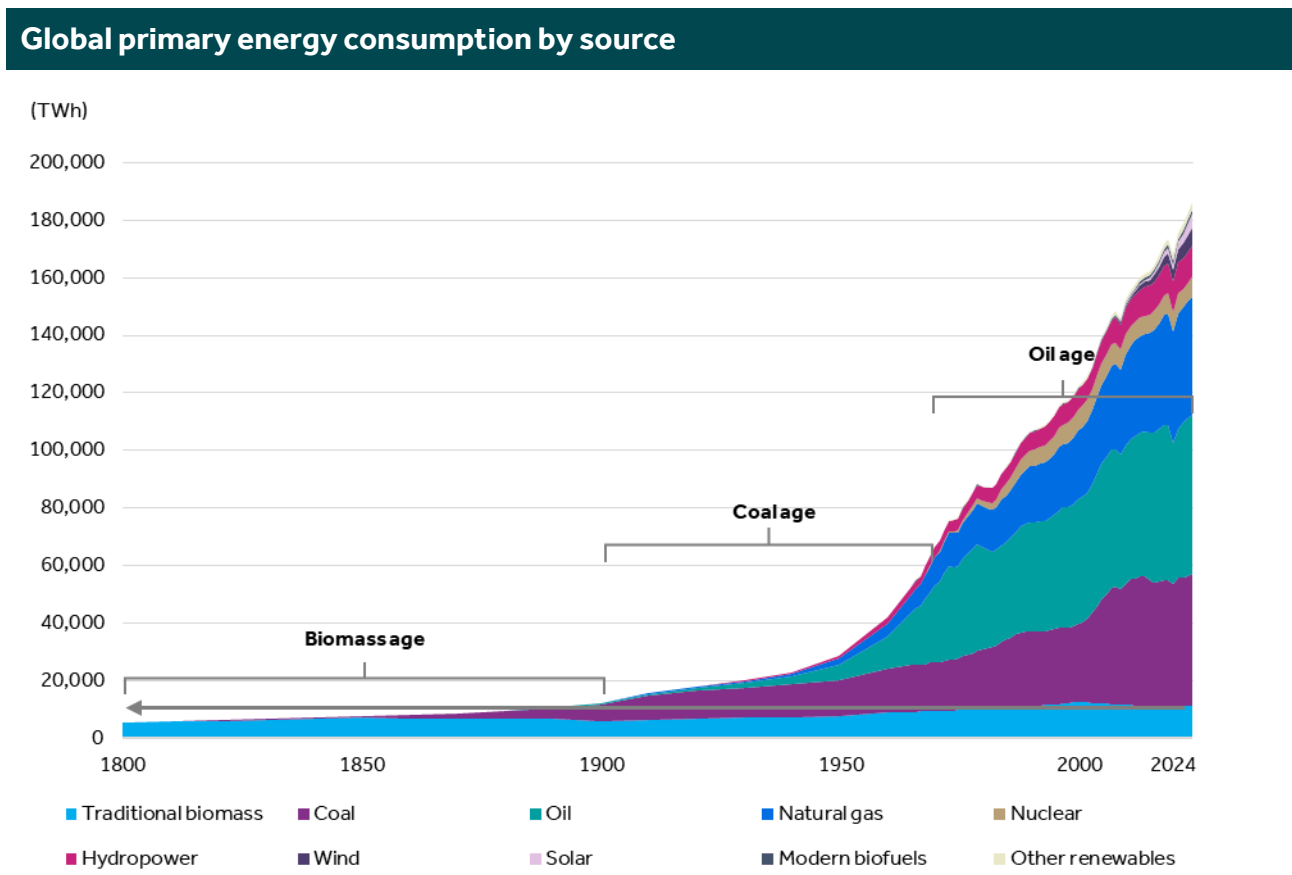
# Addition not substitution: how energy systems evolve

Emissions peaked in the US, EU, and UK substantively, if not exclusively, through fuel switching.

- US, EU, UK primary energy consumption has remained broadly flat for decades, even as emissions declined.
- Globally energy consumption has significantly increased in the same period.
- Energy transitions are additive, not substitutive: new energy sources enter the system, but total energy demand continues to expand.

Modern civilisation rests on a vast, capital-intensive energy and material system whose scale and complexity has expanded continuously for more than a century.

Figure 1: Global primary energy consumption over the past two centuries shows that energy transitions are additive, not substitutive: new energy sources enter the system, but total energy demand continues to expand.



<sup>11</sup> Source: Energy Institute – Statistical Review of World Energy (2025); Smil (2017). Note: In the absence of more recent data, traditional biomass is assumed constant since 2015.

Several observations follow from Figure 1.

**First, the world's energy is overwhelmingly supplied by fossil fuels.** Coal dominated the early industrial period, oil became pre-eminent in the 20th century, and natural gas is now rising rapidly. Today, oil remains the single largest source of global primary energy, with natural gas set to expand over coming decades.

**Second, the energy system changes slowly.** Historically, as can be observed from Figure 1, it has taken 40 – 50 years for a new energy source to grow from 1% to 10% of global supply. This inertia is unsurprising: today's global energy system represents a capital stock valued at roughly \$30–45 trillion, while proven fossil fuel reserves represent an additional \$200–250 trillion. Systems of this scale cannot transform quickly. For context, global nominal GDP in 2024 was roughly \$110 trillion.

**Third, on a global scale, human energy use has been additive rather than substitutive.** When coal arrived, it did not displace biomass at the global scale; it supplemented it. The same pattern characterises oil, gas, and now renewable energy. At the national and sub-national scale, we have observed transitions – such as wood to coal and coal to gas in the UK, but at the global scale, energy use has consistently expanded. Indeed, as can be observed from Figure 1, the world uses more biomass today than it did in 1800.

**Fourth, the long arc of energy history reflects a progression toward higher energy densities.** The shift from biomass to coal, then to oil and natural gas, represents a roughly 3.5-fold increase in mass-based energy density. Nuclear fuels are many orders of magnitude more energy dense<sup>5</sup>.

Energy transitions are additive, not substitutive: new sources supplement, rather than replace, existing ones, and total energy demand continues to expand. The world's energy mix remains fundamentally hydrocarbon-based, with transitions facing structural inertia regardless of policy ambition. For investors, this means long timelines and durable demand for enabling infrastructure, system integration, and materials – focus capital on the bottlenecks that unlock real system change.

<sup>5</sup> The theoretical fission energy of Uranium-235 is ~80,000,000 MJ/kg—roughly two million times that of coal. In practical reactors, only 2–5% of the uranium undergoes fission, yielding 500,000–700,000 MJ/kg of fuel consumed—still around 20,000–30,000 times higher than coal.

# The risk of assuming a monotonic global transition

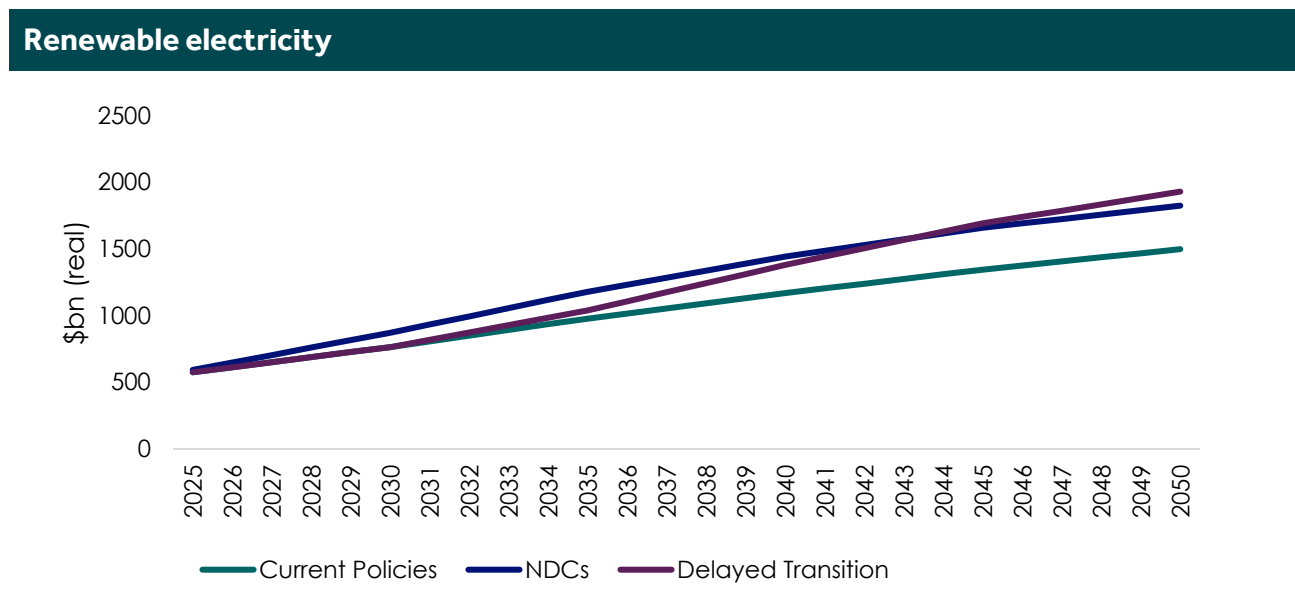
If energy systems evolve slowly and additively, then a single, uniform global transition is neither economically nor politically plausible. There is no single energy transition:

- Contemporary discourse often erroneously frames ‘the’ energy transition as a single, coherent global process.
- Each country is engaged in its own trajectory, constrained by its natural resources, industrial infrastructure, and guided by its strategic interests.

Contemporary discourse often refers to the energy transition, as if the world were undergoing a single, coherent process moving at a uniform pace toward a shared destination. The framing is convenient but misleading.

**Nations prioritise security and affordability, and only then address the environmental externalities of their choices. Energy security is provided by different technologies depending on location, with fossil, nuclear, and renewable energy all contributing. Capital flows already reflect this divergence:** IEA analysis shows that China contributes about one-third of all global clean-energy investment today, and when measured over the past several years, it has driven roughly 60–70% of the growth in global clean-energy spending<sup>6</sup>.

Figure 2: Projected opportunity for renewable energy under a range of scenarios for the period to 2050. Data and analysis from Resilience macroeconomic model (driven by data from NGFS Phase V scenarios, REMIND-MAgPIE energy-economy model, and EXIOBASE multi-region input-output tables



<sup>6</sup> <https://www.iea.org/reports/world-energy-investment-2024/overview-and-key-findings>

Thus, energy security arguments will drive the deployment of renewable energy over coming years. Available evidence, presented in Figure 2 indicates an investment opportunity of between \$1 – 1.5 trillion (real terms) in renewable electricity alone.

This divergence has three direct implications for investors.

**First, global energy demand continues to rise, driven by Asia, Africa, and industrial growth.** This creates multi-decade certainty for fuels, materials, grids, and industrial infrastructure – independent of OECD net-zero trajectories.

**Second, no single technology pathway dominates globally.** The result is a mixed energy system where renewable energy, gas, coal, nuclear, and liquid fuels all retain regional relevance. Importantly, we anticipate a greater diversification in the molecular dense energy carriers that are deployed beyond conventional hydrocarbons. Inter alia, alcohols such as ethanol and methanol, as well as ammonia, are well positioned to play an important role in a global energy system that is increasingly prioritising energy security. Assets that provide flexibility, storage, balancing, and reliable baseload retain economic value even as renewables scale.

**Third, geopolitical fragmentation increases the premium on supply-chain security:** domestic mining, refining, grid equipment, energy storage, power-electronics manufacturing, and firm generation. These segments exhibit strong policy support and increasingly attractive risk-adjusted returns.

From an investor perspective, this means the transition is not a uniform global story but a variety of regional opportunity sets, each with distinct risk profiles, return dynamics, and bottlenecks. Capital should flow to the constraints, not to the narratives.

There is no single global energy transition—each country follows its own path, shaped by resources, industrial structure, and strategic priorities. For investors, this means opportunity lies in understanding regional divergence, targeting bottlenecks unique to each market, and building portfolios resilient to geopolitical and policy fragmentation. Capital should flow to constraints and enablers, not generic narratives.

# Grid constraints: The hidden barrier to electrification

Electricity is an important, but not preeminent source of energy:

- Electricity is becoming cleaner, but not materially larger within the energy system.
- The bottlenecks now lie in grids, permitting, financing, and system integration, not in the cost of photovoltaic panels.

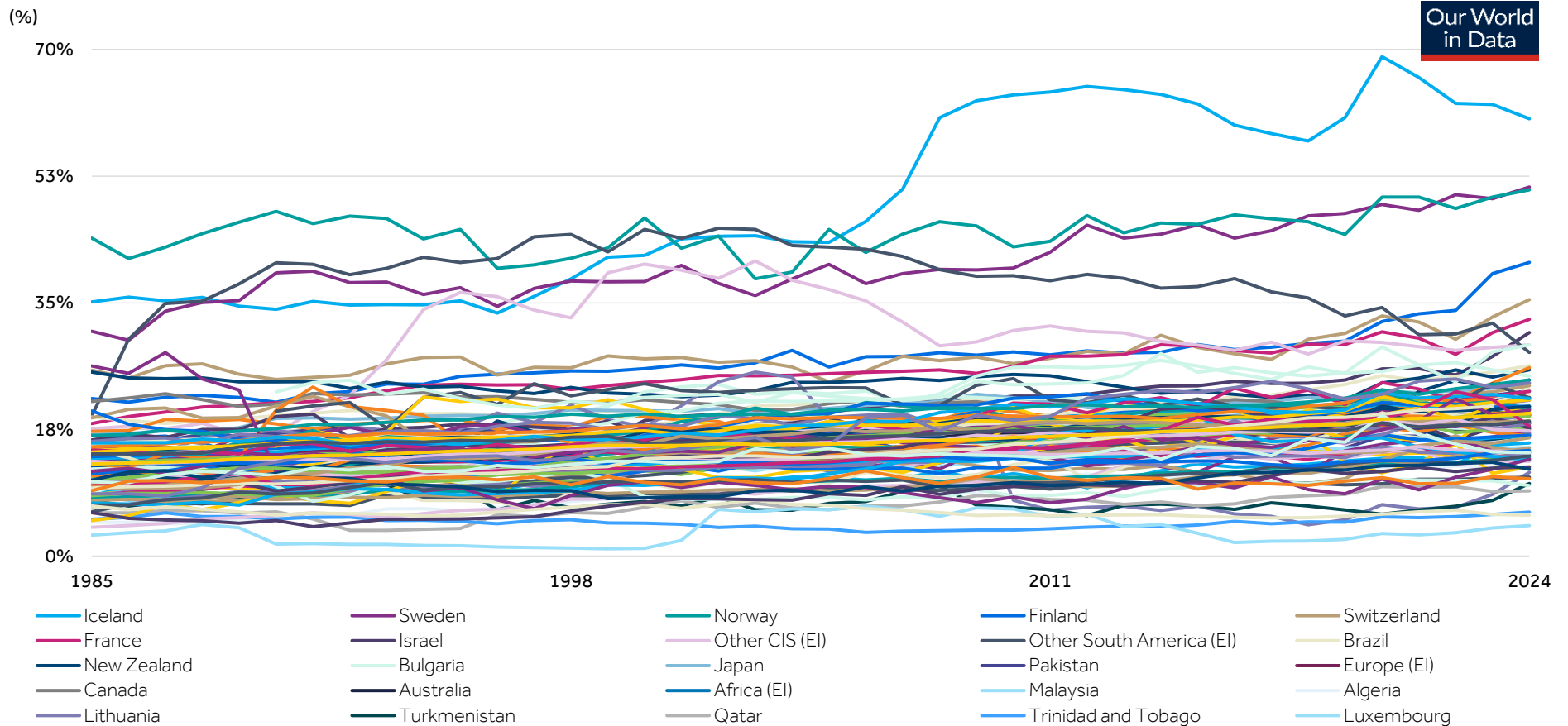
It has been suggested that we are now living in an age of electricity<sup>7</sup> with the implied conclusion is that electricity will steadily expand its share of global energy and that clean generation will displace fossil fuels<sup>8</sup>.

<sup>7</sup> <https://www.iea.org/reports/world-energy-outlook-2025>

<sup>8</sup> <https://about.bnef.com/insights/clean-energy/liebreich-the-pragmatic-climate-reset-part-i/>

Figure 3: Electricity has held a roughly 5–25% share of global final energy for decades.

### Electricity as a share of primary energy, 1985 to 2024<sup>(9)</sup>



Share of electricity generation as a percentage of total, direct primary energy consumption.

<sup>9</sup> Source: Ember (2025): Energy Institute – Statistical Review of World Energy (2025).

However, as illustrated in Figure 3, the empirical record tells a different story. The share of electricity has remained broadly stable for decades. Globally, the share of electricity has increased as a share of primary energy from 13% to 20% in the period 1985 to 2024 – a CAGR of ~ 1.11%. Total primary energy demand has increased by a CAGR of 1.76% in the same period. Thus, whilst electricity is becoming cleaner, it is not becoming proportionally larger within the energy system<sup>10</sup>. This reflects several structural constraints. One central reason is physical infrastructure. In many advanced economies, the growth of transmission grids has been minimal – over the past decade, the USA has added only 3%, and other countries, such as Japan, have observed a slight contraction<sup>11</sup>. Slow grid expansion, not technology cost, is the binding constraint on electrification.

Second, a common claim is that inexpensive wind and solar will inevitably displace thermal generation. This relies on levelised cost of electricity comparisons which omits the value of dispatchability. Power systems modelling<sup>12</sup> consistently demonstrates that a combination of renewable energy and firm capacity, i.e., dispatchable thermal and energy storage, is integral to a reliable and affordable power system.



**The divergence highlights a structural feature of modern energy systems: the cost of the hardware may fall, but the cost of delivering reliable electricity does not necessarily follow. The result is that the world is discovering that cheap modules do not automatically translate into cheap delivered power. The bottlenecks now lie in grids, and system integration - not in the cost of solar panels.**

It will also be critical to recognise the continued importance of foundational industrial sectors. Heavy industry relies on high-temperature heat that electricity cannot currently provide directly or efficiently<sup>13</sup>. These are fundamental material constraints: iron ore must be reduced, and limestone calcined. Thus, both electrons and molecules will remain fundamental to the global energy system. Natural gas will continue to play a central role in balancing power grids, supplying industrial heat, and supporting energy security in fast-growing regions. Concurrently, a broader set of dense energy carriers, including ammonia, methanol and other alcohols, and synthetic hydrocarbons, will become increasingly important. These molecular fuels extend the system's flexibility and optionality: they enable aviation, shipping, heavy industry, and long-duration storage in ways that electrons alone cannot. As a result, the long-term energy system will be hybrid, with both electrons and molecules underpinning

<sup>10</sup> <https://ourworldindata.org/grapher/electricity-as-a-share-of-primary-energy>

<sup>11</sup> IEA, "Electricity Grids and Secure Energy Transitions", 2025

<sup>12</sup> Heuberger, Staffell, Shah, and Mac Dowell, Energy Environ. Sci., 2016, 9, 2497-2510

<sup>13</sup> Smil, Vaclav. (2017). Energy and Civilization: A History. Cambridge, MA: The MIT Press

reliable and affordable energy services. **Thus, large portions of the global energy system will continue to depend on molecules rather than electrons well into the future.**

Electricity is becoming cleaner, but its share of total energy remains broadly constant. The real bottlenecks are now in grids, permitting, financing, and system integration – not in the cost of generation hardware. For investors, the most resilient opportunities may lie in enabling infrastructure, flexible capacity, and industrial solutions that address the physical limits of electrification and unlock system-wide value.

# From Energy trilemma to energy hierarchy

## The energy trilemma concept needs to be revised:

- The “energy trilemma” concept was well-suited to stimulate investment when it was first introduced, but it needs to be revised to consider the world as it is.
- When physical constraints bind and systems come under stress, governments and voters prioritise energy security and affordability. Opportunities where providing security and affordability concurrently provide sustainability co-benefits are most durable.
- Energy policy priorities are not equally weighed but are ordered hierarchically in response to system stress, political constraints and affordability pressures.

**The popular energy trilemma (security–affordability–sustainability) implies equal weighting of its components. Real-world behaviour tells a different story.** When systems come under stress, governments and voters<sup>14,15,16,17</sup> prioritise security of supply first, affordability second, and sustainability third. The European energy crisis, rapid coal restarts, emergency consumer subsidies, and repeated policy reversals across OECD economies make this hierarchy explicit. Whilst there is broad societal acceptance of the need to mitigate climate change, and some willingness to pay, the willingness is modest and highly conditional<sup>18,19</sup>, and resistance to top-down mandates is strong<sup>20</sup>.

National behaviour during the 2021–23 energy crisis made the hierarchy even more explicit. Following Russia’s invasion of Ukraine, Europe did not maintain sustainability commitments when supply was threatened; it suspended them. Over €1 trillion in public money was mobilised to shield households and firms from high prices, emphasising the importance of affordability.

It is vital to recognise that energy security is not delivered by any single technology, but by the resilience of the overall energy system. The Winter Storm Uri in Texas, USA – an example of the type of extreme weather event that climate science suggests is becoming increasingly common – triggered a cascading failure across an energy system that was inadequately prepared for such conditions. It was found that the dominant cause of the lost power was the

<sup>14</sup> <https://www.reuters.com/world/europe/thousands-protest-germany-demanding-solidarity-energy-relief-2022-10-22/>

<sup>15</sup> <https://www.context.news/just-transition/why-are-europes-low-emission-zones-fuelling-unrest>

<sup>16</sup> <https://www.theguardian.com/commentisfree/2023/nov/17/five-years-gilets-jaunes-class-climate-ulez-london-heat-pumps-germany>

<sup>17</sup> <https://cast.ac.uk/wp-content/uploads/2025/03/CAST-the-centre-for-climate-change-and-social-transformations-cast-briefing-28-how-not-to-transform-learning-from-the-backlash-against-low-carbon-heating-policy-in-germany.pdf>

<sup>18</sup> [www.eib.org/files/documents/climate-hackathon-analytical-report-group-2.pdf](http://www.eib.org/files/documents/climate-hackathon-analytical-report-group-2.pdf)

<sup>19</sup> [www.sciencespo.fr/psia/chair-sustainable-development/wp-content/uploads/2025/11/climate-hackathon-analytical-report-group-3\\_compressed-1.pdf](http://www.sciencespo.fr/psia/chair-sustainable-development/wp-content/uploads/2025/11/climate-hackathon-analytical-report-group-3_compressed-1.pdf)

<sup>20</sup> Palm, et al, “Don’t Tell Me What to Do”: Resistance to Climate Change Messages Suggesting Behaviour Changes”, *Weather, Climate, and Society*, 2020, 12(4), 827 - 835

failure of the natural gas power system – from frozen wells, compressor stations, and the gas-fired power plants themselves. These failures were compounded by feedback effects as power outages further disrupted gas supply. By contrast, some whilst wind turbines were also iced, wind generation losses were materially smaller than thermal outages. This experience therefore demonstrates that energy security depends less on technology labels and more on system preparedness and integration. Once installed, renewable generation such as wind can meaningfully contribute to energy security as part of well-designed and resilient energy systems.

In practice, energy security and affordability consistently take precedence over sustainability when systems are under stress. For investors, this means that assets and technologies which enhance system reliability or lower delivered energy costs are more likely to retain political and regulatory support across cycles. In considering the management of risk and capturing durable value consideration should be applied towards prioritising investments that align with this real-world hierarchy

# Investing in the energy transition: Global divergence and regional opportunity sets

Despite global heterogeneity, two structural forces consistently shape where capital can be deployed with scale and durability:

- Grid expansion and system-resilience constraints are a dominant global bottleneck to energy access and energy transition.
- The defining macro themes of this decade - climate, AI, and defence - are all, at their core, reindustrialisation and mining & metals stories.
- For investors, this implies that the energy transition is not one global allocation, but a set of regional opportunity systems, each shaped by different policy priorities, resource endowments, and execution risks, but underpinned by common physical constraints.

Energy transitions are not unfolding uniformly. For investors, this is not one global transition, but a set of regional opportunities with a common set of enabling constraints.

**The first common denominator across all regions is grid and associated enabling infrastructure.** Regardless of development status, scaling electrification and power generation capacity, renewable or otherwise, depends on transmission and distribution networks, associated power electronics, and energy storage. These are now the binding constraints in almost all markets. **Returns will be shaped by grid access, curtailment risk, and congestion.**

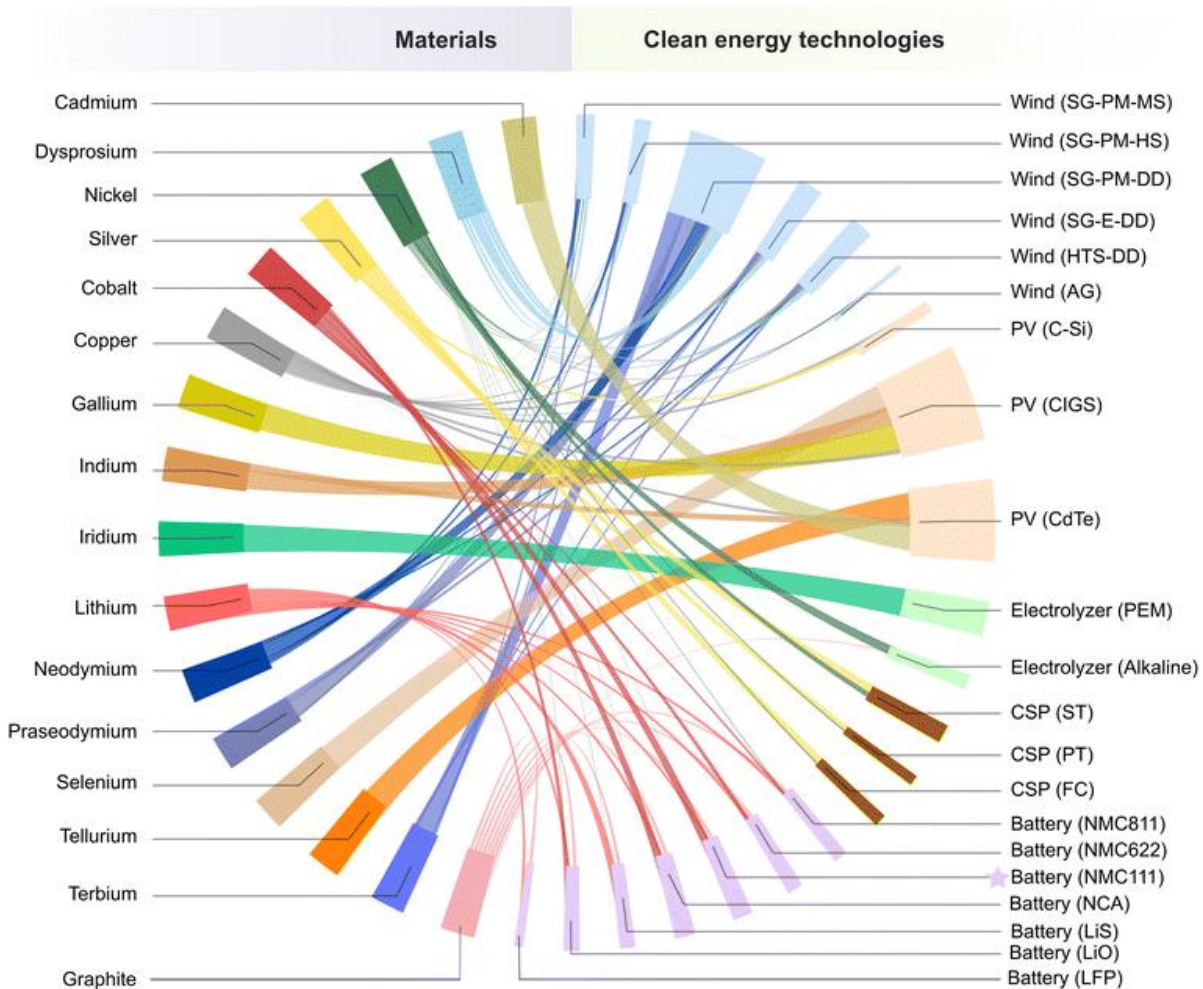
**Stranded-asset risk** is no longer confined to one part of the system<sup>4</sup>. Thermal plants can be impaired by carbon pricing, emissions standards or shifting merit-order dynamics. Equally, renewables can be stranded where interconnection queues, curtailment or insufficient firming capacity impairs their ability to deliver value<sup>4</sup>. The common driver is system integration - assets are vulnerable when the surrounding infrastructure is misaligned.

**This is highlighting that the transition's bottlenecks increasingly sit in the integration layer, not simply at the point of generation.**

**A chronically neglected dimension is that the transition is a commodities and industrial-capacity story.** The energy transition presupposes equally large-scale expansion in mining, refining, and processing<sup>21</sup>. When electrification, hydrogen, renewables, grid infrastructure, and energy storage are translated into upstream material demand, the result is sustained growth in the production of critical minerals.

<sup>21</sup> Rostami, et al., "[Assessing the realism of clean energy projections](#)", Energy Environ. Sci., 2024, 17, 5241-5259

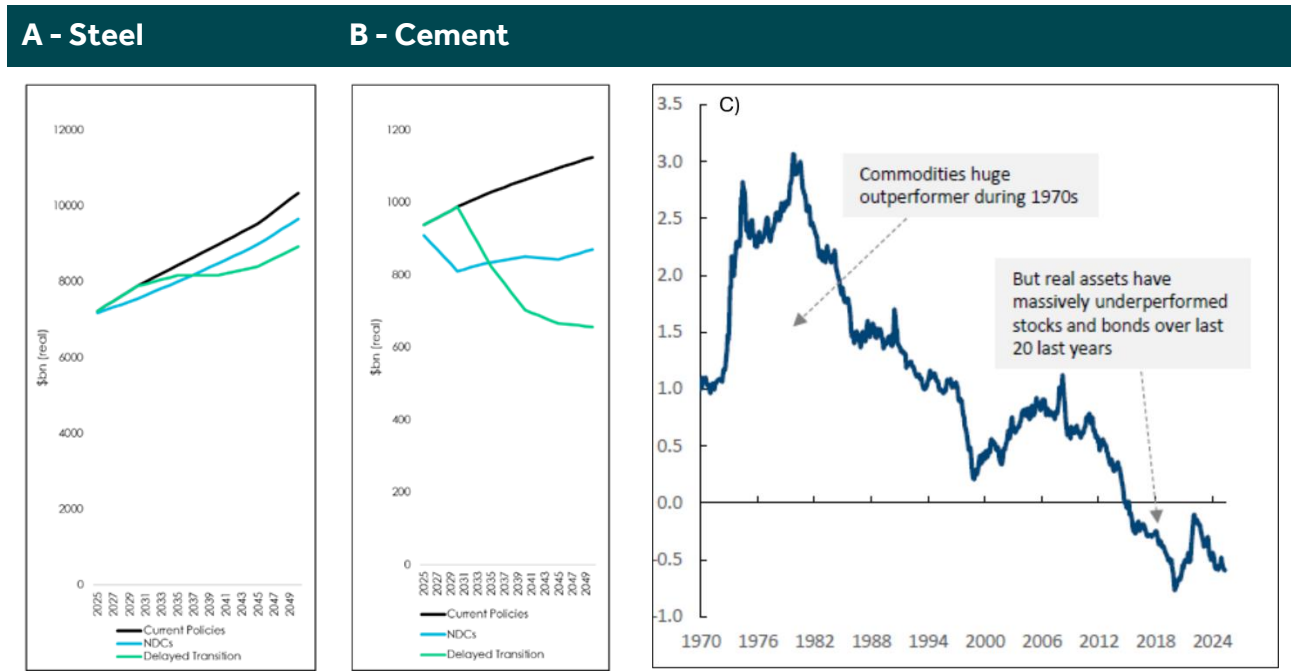
**Figure 4:** Links between materials (left-hand side) and clean energy technologies (right-hand side), based on material intensity values in 2020. The width of the ribbons is proportional to material intensity values. Reproduced from Rostami, et al.<sup>21</sup>



In parallel, societies will have to manage and remediate the wastes and legacy liabilities associated with these systems: decommissioned blades and solar modules, spent batteries, industrial by-products, and mine tailings. **This indicates a broad, durable opportunity set not just in mining and refining, but also in midstream processing, recycling, environmental services, and remediation platforms.**

This is also true for the base commodity set. Available data indicates that commodities are under-owned as illustrated in Figure 5C), even though demand is expected to grow (Figure 5A and B).

**Figure 5:** Subplots A and B. Projected demand for steel and cement in the period to 2050 under a range of scenarios. Data and analysis from Resilience macroeconomic model (driven by data from NGFS Phase V scenarios, REMIND-MAgPIE energy-economy model, and EXIOBASE multi-region input-output tables). Subplot C uses data from the Bloomberg Commodity. Index vs 50/50 S&P and USTs (Scaled to 1 in 1970) and shows that Commodities are ultra-cheap historically compared to equities and bonds. Periods of high inflation are when commodities can dramatically outperform other asset classes.



In combination, these regional dynamics and cross-cutting enablers imply that the transition should be seen as uncoordinated in real time and a multi-vector industrial expansion rather than a single linear decarbonisation path. Demand for energy, metals, grids, enabling technologies, and remediation is rising globally, but with different policy drivers and risk profiles by region.

The energy transition is not one global story, but a series of regional opportunity systems shaped by local constraints. Yet common bottlenecks - grids, commodity materials, and system integration - define where capital can scale. As renewable penetration rises, under-connected projects are becoming the new stranded-asset class. Investors should be aware of the bottlenecks that unlock system-level scale, with the most durable value accruing to platforms that enable delivery, secure materials, and solve integration challenges across regions.

# Conclusions

The conventional narrative on the energy transition no longer holds:

- **Value is shifting from generation to integration.** The areas that may receive the most interest are shifting from headline generation assets to the infrastructure and integration layers; grids, storage, transmission, industrial heat, logistics, and digitalisation.
- **Returns will accrue to bottlenecks.** Outcomes are likely to be shaped by identifying system bottlenecks, securing exposure to critical materials and enabling infrastructure.
- **Capital must navigate a plural, contested, and evolving global energy landscape, not a single global pathway.**
- **Resilience to physical climate risks,** increasingly frequent extreme weather events imply that investments in adaptation to ensure resilient energy systems will become more important.

**The energy transition is the largest capital reallocation in history, but its complexity and scale demand discipline and realism. For investors, several themes stand out:**

## 1. System Bottlenecks Create Value:



The most attractive opportunities may shift from headline generation assets to the infrastructure and integration layers. These are the areas that will likely define the next cycle of returns and where private capital can unlock value.

## 2. Mining, Metals, and Materials Supply Chains:



The three dominant macro themes - climate, AI, and defence - are converging into a single industrial-capital cycle. All three rely on grids, firm capacity, metals, materials processing, and resilient supply chains.

## 3. Reliable Power Demand in the OECD:



The rapid expansion of artificial intelligence and data centres is set to drive significant new electricity demand in advanced economies. This is accelerating the need for reliable, dispatchable power. Combined with renewable energy, gas turbines and dispatchable thermal generation are

experiencing a renaissance as the essential bridge to meet peak loads and ensure system reliability.

#### **4. Stranded-asset risk is becoming system wide:**



Historically, stranding meant coal plants. Today, renewables facing multi-year interconnection queues, curtailment, and congestion risks are increasingly likely to be impaired. This opens consideration to a new class of distressed energy-transition opportunities in under connected renewables via options like additional storage or firming, upgrading grid connection, or consolidating portfolios from capital-constrained developers.

## Report Author

- Niall Mac Dowell, Head of Climate Technology, and Professor of Energy Systems at Imperial University

## Report contributors

- Daniel Hanna, Global Head of Sustainable Finance
- Gwen Safa, Global Head of Sustainable & Transition Finance Advisory
- Marie Freier, Head of Sustainability, Group
- Isabelle Millat, Head of Sustainable Finance Global Markets & Barclays Europe
- Oliver Morning, Head of Carbon & Environmental Products Trading
- Jonathan Noble, Head of Portfolio Sustainability
- Gregory Cass, Sustainable Banking Group
- Joseph Pigott, Co-Head of Sustainability Strategy and Policy
- Rupert Rink, Sustainable & Transition Finance Advisory

## About Resilience:

[Resilience](#), as data provider for certain source material noted in this paper, is a climate and nature risk analytics company that helps global businesses transition to the low-carbon economy. The Resilience-powered platform, Riise, delivers financially quantified analytics to turn climate and nature risk and opportunity into clear, actionable strategies and measurable plans.

## Disclaimer

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