LSE Grantham Research Institute on Climate Change and the Environment

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The global growth story of the 21st century:

driven by investment and innovation in green technologies and artificial intelligence

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Policy insight

January 2023

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Authors and acknowledgements

This paper was prepared at the suggestion of Klaus Schwab by a team from the Grantham Research Institute on Climate Change and the Environment, LSE, and Systemiq under the leadership of Professor Nicholas Stern (IG Patel Chair of Economics and Government, London School of Economics and Political Science) and Dr Mattia Romani (Partner, Systemiq). Those involved were: Amar Bhattacharya, Danae Kyriakopoulou, Hans Peter Lankes, Jeremy Oppenheim, Isha Patel, and Katherine Stodulka. The authors are very grateful for discussions with Demis Hassabis and James Manyika, in their individual capacities. They are also grateful for the guidance of Saadia Zahidi. Neither LSE nor Systemiq are responsible for the views expressed. No conflict of interest was reported by the authors.

This paper was first published in January 2023 by the Grantham Research Institute on Climate Change and the Environment and Systemiq.

Suggested citation: Stern N and Romani M (2023) *The global growth story of the 21st century: driven by investment and innovation in green technologies and artificial intelligence*. London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science and Systemiq.

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Summary

- **The world has in its hands a new growth and development story driven by investment and innovation in green technology, boosted by artificial intelligence (AI)**; it is a much more attractive and inclusive story than the dirty and destructive paths followed in the past.
- **This new growth story is beginning: in the next five years more than half of the tipping points for crucial green technologies will have been met, making them competitive in key markets.** The process of structural and systemic change will be multi-decadal. But this decade is decisive to limit the risk of greater climate instability. Acceleration of action now is essential. AI is creating real opportunities for this acceleration.
- **The faster growth of emerging markets and developing economies (EMDEs) relative to richer countries and the location of renewable energy sources will change the world's industrial geography and patterns of trade.** If managed well, these changes can make supply chains more diverse and less fragile; multiple sources of key products and inputs will be necessary. The race has started, with countries across the world competing in investment support to gain dynamic comparative advantage, such as the $1 trillion US Inflation Reduction Act with its strong focus on green technologies.
- **Major investment across the world is needed for the transition to rapid, sustainable growth: some $5–7 trillion a year globally in gross investment for clean energy and digital transformation.** Part of this investment will be additional; the necessary global increase in investment will be around 2–3% of GDP, less in richer countries, more in EMDEs. The aggregate world macro position makes this increase in investment possible; there is no global savings constraint. This investment can give impetus to a strong and durable recovery from the current crises and pre-empt a lost decade for development.
- **The new, technology-driven, sustainable growth story represents the greatest investment opportunity since the Industrial Revolution.** The private sector will provide most of this investment but public–private partnerships in policy, innovation and finance are essential. The opportunities are there for all countries.
- **There are also immediate challenges of climate vulnerability.** All countries are affected but poorer countries have already suffered particularly severe losses from the impacts of climate change. There should be strong international support in their efforts to build resilient economies.
- **An international, shared strategic agenda, including on goals, finance and trade, will enhance the confidence necessary for investment – and for technology, particularly AI.** Cooperation around the international financial system and the flow of both private and public investment in EMDEs is crucial. The substantial expansion and reform of the multilateral institutions will be at the core of this finance.

1. Opportunity: the drivers of the future economy

Large-scale deployment of low-carbon technologies, enabled and accelerated by artificial intelligence (AI) and digital enablers, will transform energy, transport, production, built environment, land-use and ocean systems over the next 25 years. The race is already taking shape and will drive a wave of creative destruction. Countries, companies and investors who understand and act on these trends will be greatly advantaged for what could be an era of unparalleled prosperity, although the transition itself requires strong investment and the changes will involve disruptions which must be managed.

The deployment of low-carbon technologies is accelerating, with key technologies expected to reach tipping points before 2030 – which in turn will trigger their scaling-up to mass market.[1] A significant tipping point has already occurred in the energy sector, when the levelised cost of energy generation (LCOE) for solar and wind power fell below that of new coal and gas in 2018. A second tipping point, whereby the LCOE includes the cost of short-term battery storage, is expected to be reached in the United States in 2023, quickly followed by other countries. This rapid cost reduction led solar and wind to account for more than 75% of energy capacity additions globally in 2021.

We are seeing similar trends in other sectors (Systemiq, 2021). Unsubsidised Battery Electric Vehicles (BEVs) are expected to reach cost parity with Internal Combustion Engine (ICE) vehicles in all light vehicle segments by 2025–26 in major regions (BloombergNEF, 2021; ICCT, 2019, 2021). The same is happening with agricultural fertilizers, where pioneering projects have brought down costs of green ammonia and are enabling the largest fertilizer producers to launch industrial-scale plants this year; green ammonia production is now projected to be economically viable within the next decade. Green hydrogen, vital for a range of industries and activities, is also taking off, with policies and major projects expanding rapidly around the world (IEA, 2019a).

The prospects for AI are even more wide-ranging, and AI is likely to further accelerate green technology. With continued progress on foundation models, AI is increasingly recognised as the next general-purpose technology, boosting *general intelligence,* accelerating tipping points and the deployment of breakthrough technologies across economic sectors – such as fusion and solar, quantum chemistry, alternative protein design and many others. AI will also have increasingly powerful implications for data analytics, modelling and predictions, and for ramping up efficiency and productivity in production processes and supply chains. These applications are already being used in the fight against climate change, including in crop analysis to increase both agricultural productivity and resilience (X, n.d.), in analysis of complex interactions between climate change and Arctic sea ice loss (Dungate, 2021), and energy demand management, where AI is critical to improving prediction of demand.

AI-based approaches not only increase short-term system agility (e.g. enabling batteries and demand management to act as virtual power plants) but also enable longer-term demand and supply matching across the energy system. AI applications are increasingly being integrated into industrial systems to improve energy efficiency and reduce peak demand, as well as being used to maximise renewables in meeting peak demand.

AI can also help on resilience: AI is being used to improve climate disaster alert systems for vulnerable countries (Matias, 2022), where deep-learning algorithms will continue to improve early warning about climate tipping points in real-world systems with greater sensitivity and specificity to help people better prepare for major changes. Foundation models like ChatGPT (large, pre-trained language models that create the ability for anyone to produce text and code

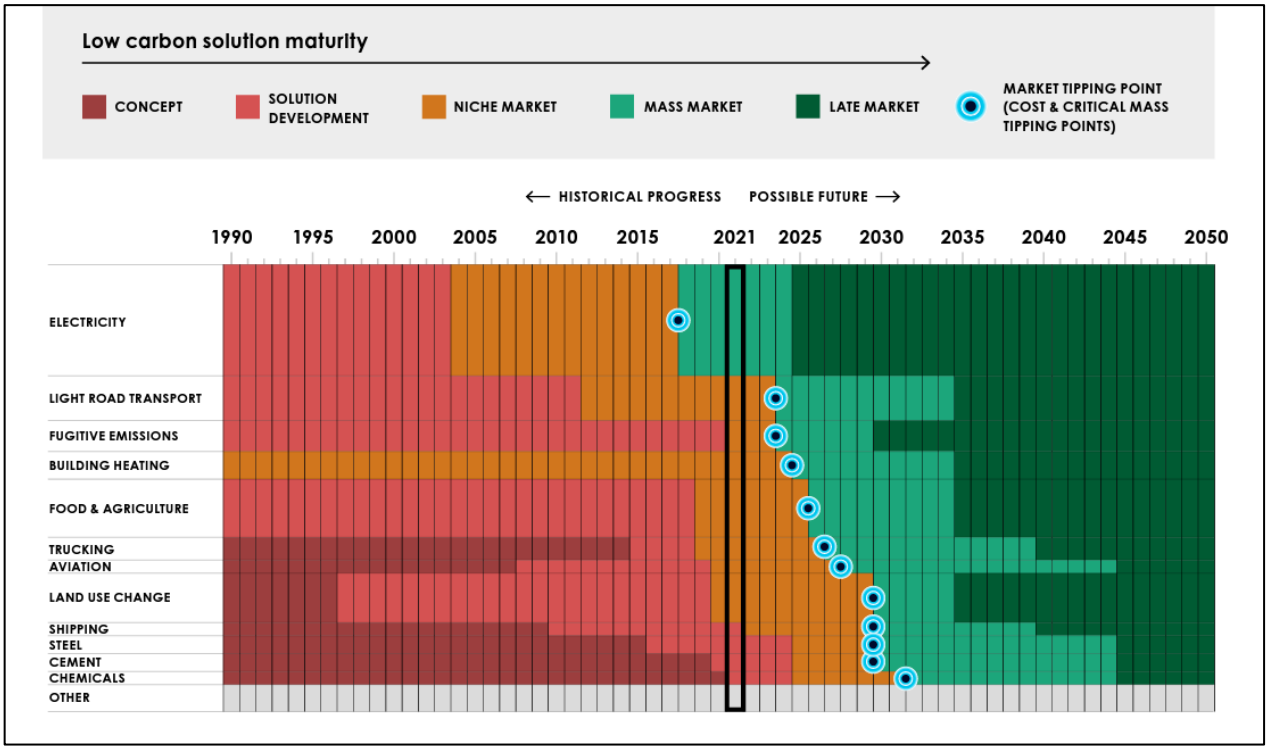
[1] Socioeconomic tipping points exist when a set of conditions are reached that enable new technologies or practices to out-compete incumbents.

on command) are a major tipping point for AI, with the potential to transform work and how we communicate, unlocking new sources of productivity and growth. A recent PwC study estimates that AI technologies could increase global GDP by $15.7 trillion by 2030 (PwC, 2017). With economic payoffs as large as this, we can expect a rapid scale-up of and increased investment into AI.

Many of the new climate and AI technologies are 'horizontal', shared by production functions and supply chains throughout the economy, and as such their scale-up can have powerful synergistic effects. Growing deployment of these technologies will increase economies of scale, further driving down costs. As prices fall, new sectors and technologies become commercially viable, further strengthening the feedback loops and generating rapid exponential change. For instance, the expansion in renewables and hydrogen production capacity will also drive down the costs of green ammonia, which in turn facilitates the storage and transport of hydrogen, opening opportunities to green industries such as steel and chemicals. And AI can turbocharge the process of innovation itself, across every sector. As a global leader on AI has put it, "AI can deliver scientific advance at digital speed" (verbal communication from Demis Hassabis).

The comprehensive technological transformation of energy, transport and production processes is at the heart of the 21st century growth story. Figure 1 below is the latest update on the historic and estimated progress of key zero-emissions solutions by sector, showing how quickly these tipping points are advancing. There is a major opportunity here for governments and the private sector to focus resources towards bringing this transformation forward in time. Realising that opportunity will require a large step-up in investment (private and public), supportive policies, and collaboration.

Figure 1. Tipping points by sector – historical progress and indicative future timeline



Notes: Tipping points exist when a set of conditions are reached that allow new technologies or practices to out-compete incumbents. After a tipping point is crossed, reinforcing feedback loops take hold that drive self-reinforcing progress, so that greater deployment of the solution encourages even faster deployment. Source: Systemiq (2021).

2. Global momentum and a new geography of growth: the race is on

The race is already on for leadership of the key technologies, capabilities and assets associated with the drivers of future growth. This race is likely to have profound implications for geopolitics, economic and industrial geography and trade flows, but also structural dislocations.

The energy transition is redrawing the geography of trade and industry and will speed up further as a result of energy security concerns following Russia's war on Ukraine. Other drivers of the technology transformation, such as AI, will also redraw the map over time. While industrial location in the past was shaped by endowments of coal, oil, iron ore and other raw materials relative to demand markets, future choices – factoring in the possibilities of direct and indirect electrification of industrial processes – will give greater weight to the availability of reliable, low-cost, low-volatility renewable power. There are also possibilities for tapping differences in geographic endowments (e.g. wind in northern Europe and sun in the south) and for integrating renewable energy within and across countries, as India's Prime Minister Modi has proposed through his 'one world, one sun, one grid' initiative. The result will be a different energy and industrial production map, especially in emissions-intensive trade-exposed industries such as steel, aluminium and base chemicals.

The outcomes of recent renewables auctions suggest that the Global South overall is well positioned to gain market share as a low-cost zero-emissions power producer, with the Middle East and North Africa establishing themselves as the most competitive regions (IEA, 2019b). But some of these economies face a challenge in terms of a policy framework that can attract low-cost capital into renewables, which risks undermining their natural advantage (Figure 2). The map in Figure 2 also indicates where some of the most significant pilot investments in green hydrogen, green ammonia, green steel and low-carbon aluminium are located. This list is not intended to be comprehensive, but it shows that some countries are rapidly taking advantage of their renewable energy potential to establish themselves as early leaders. Chile, Brazil, Saudi Arabia, UAE, Mauritania, Namibia and Kazakhstan, for example, are all developing landmark projects that could see them evolve as strong players in net zero industry.

Major economies are already competing to secure their position in this future geography of growth. China's 14th Five-Year Plan on Modern Energy System Planning, the EU's Green Deal, India's Union Budget, Energy Access and Green Hydrogen policies (Garg, 2022), and the U.S. Inflation Reduction Act (IRA), all combine incentives and finance for green technology and investments with legal, regulatory and policy support.

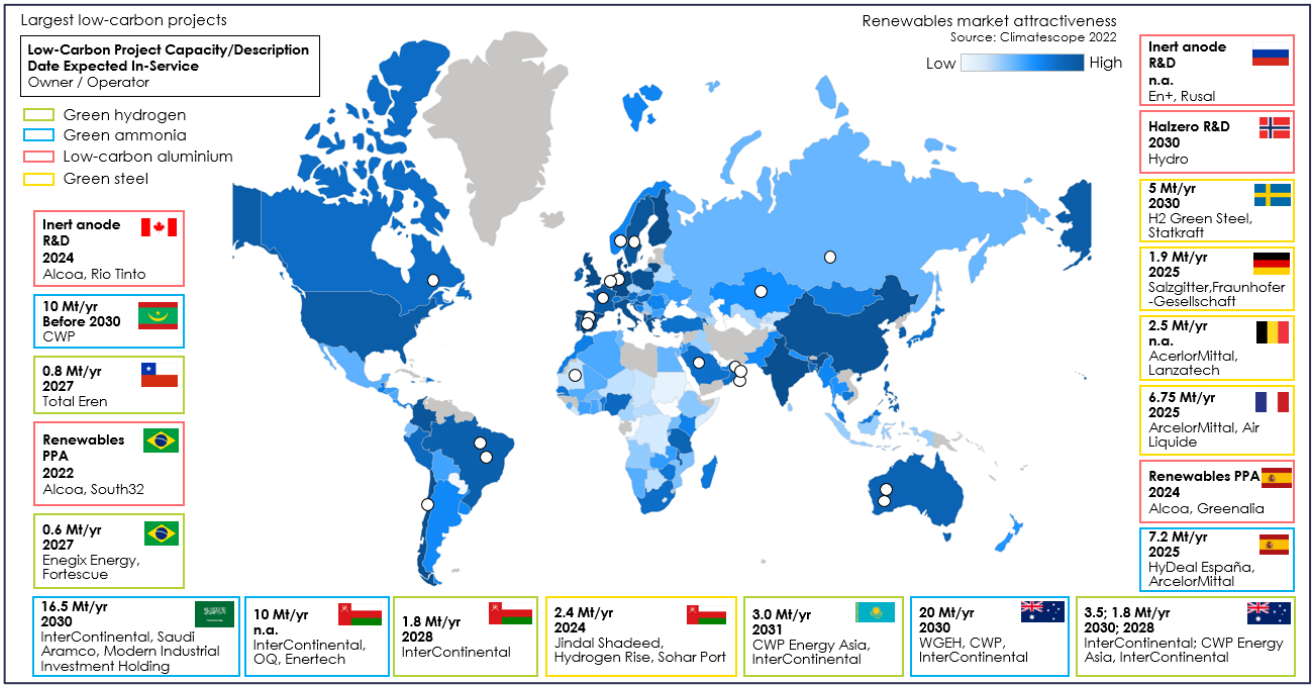
Investments are moving quickly in all these locations. They are not alone – similar steps are being taken throughout the world.[2] Warts and all, these initiatives are shaping the new geography of growth and providing momentum to the low-carbon transition. For instance, China's leadership in the manufacture of solar panels and batteries has played a key role in bringing solar PV costs down by 85% over the last decade (RMI and Energy Transitions Commission [ETC], 2021). The EU Hydrogen Strategy aims for cumulative investments of $200–500 billion in renewable hydrogen by 2050 (European Commission, 2020; IEA; Systemiq analysis for ETC).[3] India is seeing one of the fastest expansions in renewable energy anywhere, with a 2030 target of 500 GW representing four times current capacity. The U.S. Investment Reduction Act (IRA) may lower the financing costs for key climate technologies by 40% on average, enabling a rapid scale-up (Systemiq analysis; CTVC, 2022). As multiple sources at reasonable cost become available, competition and

[2] The Climate Change Laws of the World database details 2,998 climate laws from virtually all countries, many supporting the climate transition: **https://climate-laws.org/**

[3] This is a large share of the estimated $1 trillion global investment required.

innovation should increase – contestable supply of key inputs will be essential for the overall robustness of supply chains. These developments will imply new perspectives on and new patterns of globalisation.

Figure 2. Large low-carbon industrial projects announced across the globe, bolstered by attractive renewables markets and growing capacity



Source: Systemiq analysis, 2023.

3. Scale of investment required

There is no doubt about the direction the world is moving in. But the challenge and dangers of climate change imply a need for greater urgency and speed, meaning the world must step up the pace of investment and innovation.

The investment that can create the new growth story will be in four forms of capital: physical, human, natural and social. They are all necessary and complementary.

- Major increases in **physical capital** investment will be required for the new low-carbon infrastructure in energy and transport, cleaner and more efficient cities, and new forms of production of services and goods. Global gross investment needed for this broad energy-system and digital transformation will be an estimated $5–7 trillion per year by 2030 (Songwe et al., 2022); part of this investment will be additional. This is a significant increase from today's annual investments of around $1.5–2 trillion, but will also be accompanied by reduced fossil fuel investments and inputs over time.
- The costs of loss and damage from the impact of climate change are significant, and investment in adaptation and resilience is unavoidable. For example, 20% of GDP was lost due to climate change impact in Vulnerable Twenty (V20) economies over the last two decades (V20, 2022). A massive ramp-up is needed in investments in adaptation and resilience, and the faster it is done, the lower future loss and damage will be. The kind of investment in technologies for emission reductions described in this paper, as well as improvements in predicting and preventing future losses (where AI technologies can help), will reduce the cost of adaptation, but significant investment will still be required. This could be in the range of $0.5–$1 trillion per year by 2030. There should be strong international support for these efforts to build resilient economies.

- A total of around $3 trillion per year by 2030 is also required in **human capital**. The challenges of the COVID-19 legacy and major demographic change will put pressure on health services and on education, given existing gaps and as some populations age and the population of the developing world other than China increases by almost 2 billion over the next three decades, primarily in Asia and Africa.
- As the world transitions away from fossil fuel-based sectors, up to 5 million jobs could be lost in those sectors (Cozzi and Motherway, 2021), even though net jobs resulting from higher investment and reconfigured supply chains will almost certainly grow in number.
- Our **natural capital** and ecosystems constitute the ecological environment in which we must live and are closely intertwined with climate change, water systems, air, and much more. Protecting and restoring these ecosystems will require an estimated total of $275–400 billion per year by 2030 (Songwe et al., 2022).
- Investing in **social capital** is less about direct additional resources and more about the quality of institutions and the distribution of prosperity and assets. The fundamental change in the structure and systems of our economy implies that we must focus on the management of change and of potential dislocation of lives and livelihoods. For example, protecting and reinvesting in natural capital will require capacity-building and supportive institutional arrangements, especially to enable indigenous communities (who act as stewards for a significant proportion of the world's biodiversity and its most critical biomes) to have more voice and control over their collective assets.

This may sound like a daunting challenge.[4] For we as a world collectively to succeed, global investment levels must be restored and raised by around 2–3% of GDP p.a. above pre-pandemic levels over this decade (Stern, 2021), excluding human capital – more in the Global South, less in the Global North and China.

However, while the scale of necessary investment is large, it should be feasible from a macroeconomic perspective. Since the 1990s, global planned saving has generally exceeded planned investment, which has been associated with low interest rates, low investment and low growth, including low productivity growth (Goodhart and Pradhan, 2020). Some speak of 'secular stagnation'. In fact, if we go back to the decades before the 2008 financial crisis, investment as a proportion of GDP was much higher than now. OECD member countries specifically have seen investment fall from 26% to 22% of GDP since 1980 (World Bank, n.d.). Public investment accounts for a disproportionate share of the decline, reflecting attempts to rebalance fiscal accounts and control public debt, as fiscal consolidation tends to come at the expense of capital outlays.

Thus, while a big push on investment is crucial for the future of the planet, for recovery, and to create the new growth story, it is not an impossible stretch. A step-up in public investment by 1–2% of GDP should be at the heart of this investment push, as it provides direction and lays the ground for private investment; this would represent a natural shift from the public consumption spending during crisis. By increasing economic productivity and reducing climate risk, this public investment would lay the foundations for a stronger medium- and long-term fiscal position.

Given that so much of the investment and innovation must be in the private sector, the policies and institutions shaping the investment regime will be fundamental. Strong country leadership to credibly signal the future pathway will provide confidence in driving a big investment push. To be credible and trusted, public commitments must be supported by strong institutions: those that are consistent across government and well-resourced with the right skills and expertise. They are

[4] This is true irrespective of the climate path taken, given growing populations, particularly in the Global South. Studies by McKinsey, OECD and IRENA have estimated the proportion of additional incremental infrastructure investment needed under a net zero scenario compared with a business-as-usual scenario over the same period, with estimates ranging from $0.6–1.1 trillion annually.

effective when they combine some degree of independence with credible monitoring, and when they are embedded in the political system, while harnessing technocratic effectiveness and the ability to directly engage with the private sector and civil society.

4. Collaboration on finance, technology and trade

To effectively drive growth and prosperity, the investment push and deployment of technology must be global. This will necessarily involve both competition as countries and companies vie for leadership in key new technologies and markets, and strengthened collaboration around shared goals on climate action, public health, prosperity and peace.

Collaboration on financing the necessary investment in the Global South will be critical. EMDEs other than China will need to spend around $2.4 trillion per year by 2030 (6.5% of GDP) for all climate-related investment necessary to transform their economies (Songwe et al., 2022). This is a significant increase on today's investments of about $0.7 trillion a year (although such a step-up will be accompanied by savings from reduced fossil fuel investments and input, which will accrue over time). But the cost of capital in EMDEs is too high for a significant step-up in long-term investments, partly for structural reasons and partly because of debt levels. Addressing debt vulnerabilities to reduce the cost of capital for new investments must be an immediate priority. This will require collaboration on strengthening mechanisms for resolving debt, building on and enhancing the effectiveness of the G20 Common Framework.

As argued by the recent report of the Independent High-Level Expert Group on Climate Finance (Songwe et al., 2022), in order to ensure a reasonable cost of capital new public debt should be financed on terms similar to those offered by international financial institutions (IFIs). New debt might include mechanisms to provide low-cost finance for climate-vulnerable countries; and adopting climate contingency debt contracts such as the natural disaster clauses piloted in Barbados. Finance from the Multilateral Development Banks can and must scale up by a factor of three over the coming years (Yellen, 2022) and offer concessional solutions for global public goods. Country platforms for purposeful collaboration can bring all actors, public and private to the table; if modelled on Just Energy Transition Partnerships (JETPs) being piloted in South Africa, Egypt, Indonesia and Vietnam, they can be powerful tools to create new highways for finance to flow at scale to accelerate the transition.

Collaboration on technology is imperative. R&D coordination is necessary in some key areas, for instance where AI can be applied to accelerate research into gene-editing, synthetic biology, fusion, carbon capture, utilisation and storage (CCUS) and even geoengineering, where it is critical to work on international science policy and governance. Efforts are required to support greater technology innovation and diffusion capacity in developing economies, linking up firms, governments and civil society (Aghion et el., 2021).

More generally, collaboration, public and private, could be based on countries' shared national interests in the growth of green production and conditions for smooth trade. Governance initiatives are emerging, with several shepherded by the World Economic Forum, and overarching goals provided by the Glasgow Breakthrough Agenda. Collaboration can take the form of joint innovation (such as through Mission Innovation), converging around standards (such as through the International Partnership for Hydrogen and Fuel Cells, or the Global Cement and Concrete Association), creating buyers' clubs or coordinated green procurement programmes for pioneering products and processes (such as through the First Movers Coalition or the Industrial Deep Decarbonisation Initiative), or agreeing rules of the game for state support (Stern and Lankes, 2022).

Enhanced collaboration on trade has an important role to play in breaking down perceived zero-sum competition over innovation and in seeking, where possible, mutually beneficial growth of new industries and approaches – through smooth trade in a wide range of green products and

necessary materials, technology diffusion and financial support (Quitzow et al., 2014). New international standards and data protection models will also be needed as AI applications become pervasive and inevitably spill over international borders, making it critical for states to agree new rules of the game for AI-based, digitally-intensive economies.

In today's geopolitical context, the shift in trade patterns will inevitably raise new questions around the reliability of supplies. There must be enough competition across key supply chains to avoid capture and the formation of new exploitative oligopolies. While localisation and friend-shoring may seem attractive, creating the conditions for broader global production and competition will be a more effective and resilient strategy. There is an urgent need for clear principles for preserving and encouraging competition across crucial supply chains (WTO, 2022).

5. Creating the future

This future story of growth is emerging and is within our grasp. The potential reach and rewards of the technical change we are witnessing – in terms of quality of life, productivity and jobs – are enormous.

Turning technology, innovation and investment into a new growth story and a road out of crisis requires a shared understanding of the possibilities and of the strategies that are necessary for action. From there, it needs stepped-up investment, major innovation, and collaboration – collaboration both between the public and private sector, and across countries. International institutions will have a key role to play. This investment can give impetus to a strong and durable recovery from the current crises and pre-empt a lost decade for development.

Investment and innovation require optimism about and confidence in future possibilities and a recognition of the necessity of change. These are there and growing. A shared vision is crucial to crafting reality. The coming decades will be decisive for the planet, and investment and innovation embodying new technologies, together with the drive to net-zero will yield *the growth story of the 21st century*.

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