ENHANCING RESILIENCE IN A CHAOTIC WORLD
The Role of Infrastructure

edited by **Carlo Secchi** and **Alessandro Gili**

with the knowledge partnership of McKinsey & Company

ISPI

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Enhancing Resilience in a Chaotic World. The Role of Infrastructure

Edited by Carlo Secchi and Alessandro Gili
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This study is an initiative of the ISPI's Centre on Infrastructure, promoted with the knowledge partnership of McKinsey & Company. The Centre on Infrastructure focuses on how geopolitical and economic trends shape and are shaped by investment decisions on infrastructural projects. It aims to analyse global trends (new technologies, mobility, sustainability, etc.) and monitor major projects, also with a view to gauging their complementarity/competition and financing channels. Specific attention is devoted to the role of key economic and political players at all levels – from local to global – including regional and international development banks, whose "political" agenda is often crucial to foster public and private investment.

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PART II - CHALLENGES

Introduction

Since the days of the ancient Romans, resilience has played a key role in human evolution. It is no coincidence that the first civilisations were also the best prepared to build architectural and engineering wonders such as the Roman bridges and arenas or the everlasting Egyptian pyramids.

The fact that costly materials and complex construction techniques were used to build infrastructure in the ancient world testifies to the long-term vision of the public authorities in those days, as well as their willingness to make substantial investments and their stringent control over public works. It is worth noting, moreover, that the ancient Roman title of “Pontifex Maximus”, assigned to the High Priest of the College of Pontiffs, originally meant “maker of roads and bridges”, bearing witness to the almost holy status of infrastructure builders.

In homage to these builders of old, the cover of this report features a picture of Ponte Milvio, the world’s oldest Roman-built bridge, which still stands today as an enduring monument to resilience.

Nevertheless, after World War II, the longevity of infrastructure began to reduce, due to the need to quickly rebuild the cities destroyed by the war, inevitably with less durability and care. The potential of reinforced concrete was widely used, partly thanks to its cheapness and speed of construction, perhaps paying little attention to the useful life-cycle of this material. The maintenance and upgrading of the existing well-planned infrastructure was gradually abandoned in favour of building new infrastructure more "cheaply" and "quickly". The unpredictability of certain phenomena, whether natural (floods, earthquakes, pandemics) or caused by geopolitical or human decisions, was underestimated. Indeed, these phenomena were rarely included in risk analyses, except with the benefit of hindsight. The combination of all these factors (physical infrastructure deterioration, in conjunction with political and natural phenomena) has now brought the issue of resilience back to the centre of the debate, with the focus on new grants and loans envisaged by the Next Generation EU, and in particular in the Recovery and Resilience Facilities (RRF).

Over the last few years, the multi-faceted concept of resilience has emerged as a buzzword in contemporary society and international debate. Geopolitics, economics, trade, energy and climate have been affected by several shocks: countries and international organisations have tried to formulate fully-fledged plans to tackle the main issues affecting their economic performance and undermining national security with a forward-looking perspective. Their goal is to increase present and future resilience to mitigate the adverse effects of future negative shocks. Following the Covid-19 shock to economies and societies and further to the recent energy crisis caused by the Ukraine war, many countries are renewing investment in existing infrastructure as a stimulus measure. Such investments present a golden opportunity for governments to address complex and interconnected infrastructure challenges through targeted maintenance spending, while seizing the opportunity to embed resilience, adapt to climate change and prepare infrastructure for an uncertain future. In the current context of constrained finance, ageing facilities and rising demand, optimising existing infrastructure assets upgrades the existing asset stock, making it more effective, cheaper and longer lasting.

Against a backdrop of major transformations and accelerations, the resilience approach is of utmost importance. Firstly, Brexit was an indisputable example of how a geopolitical event could have disruptive economic consequences for regional value chains and the global economy as a whole, testing the resilience of the EU common market and challenging the UK's economic outlook. Secondly, the pandemic hit global value chains, causing a swift reconfiguration and prompting deep changes in international logistics. The case of the Ever Given ship in 2021 in the Suez Canal – whose obstruction disrupted global supply chains and had a significant negative impact on trade between Europe, Asia and the Middle East – bears witness to the fragility of global critical infrastructure and highlights the need for enhanced resilience. Thirdly the war in Ukraine exacerbated the existing shortcomings, by introducing pressure on the energy, raw materials and food markets. The war also diverted trade flows between East and West, thereby shifting the spotlight to new trade routes and transport infrastructure in Central Asia. The EU reacted to the disruption unleashed by the war by establishing solidarity lanes, aimed at reinforcing transport connectivity and trade flows between Ukraine and the rest of Europe. Finally, the climate crisis itself could foster the development of shorter, more regional value chains, which reduce transport costs and emissions.

These multiple challenges have accelerated processes that were already underway, strengthening the importance of the linkage between industry and infrastructure (in particular transport, digital and energy). Re-shoring, friend-shoring and near-shoring are the pillars that underpin new national and regional economic strategies aimed at ensuring resilient value chains, especially in strategic sectors such as advanced technologies, clean tech, chips, raw materials and pharmaceuticals. Western economies have introduced several plans to secure their supplies: in August 2022 the US launched the Inflation Reduction Act (IRA) and the Chips and Science Act, which are designed to boost US industrial competitiveness and re-shore and near-shore critical and high-tech production, especially through new subsidies and local content requirements. In 2023, the EU responded with the Green Deal Industrial Plan, the Net Zero Industry Act and the EU Critical Raw Materials Act, all aimed at raising the EU's share in the production of critical clean-tech technologies. However, these industrial plans cannot be successful without a strong infrastructure and logistics base. The US Bipartisan Infrastructure Bill, the G7 Partnership for Global Infrastructure Investment (PGII) and the Global Gateway are Western plans to increase infrastructure competitiveness in relation to other infrastructure plans, such as the Chinese Belt and Road (BRI). For the EU, the ongoing revision of the Trans-European Transport Network (TEN-T) is also critical in this respect: enhancing the resilience of TEN-T infrastructure - notably in fields such as adaptation to climate change (especially for waterborne transport and bridges), safety, security (civilian-military dual use requirements) and civil protection, as well as ensuring high structural infrastructure quality in view of the age of many existing assets - is an important challenge under political discussion. The EU as a whole - for example within the framework of the current process of revision of TEN-T networks and in a Council proposal[1] - is setting out the main elements to enhance the resilience of critical infrastructure. The European Investment Bank (EIB), in particular, is making substantial investments in strengthening the resilience of the EU infrastructure network, both within internal borders and in the neighbourhood. Digitalisation is at the core of the Bank's efforts to increase the resilience of EU infrastructure, with the EIB investing about 2.5 billion euros in digital infrastructure and cyber security annually.

The first part of the Report will therefore investigate the above issues and the role of infrastructure in the context of fast-changing economic and trade relations. It includes chapters on the main strategies being pursued to increase infrastructure resilience in the US, China, the EU as a whole and its individual member states, and Japan. The leading economic powers are also intervening in the economy to secure critical sectors and

[1] Council of the European Union, Council Recommendation on a Union-wide coordinated approach to strengthen the resilience of critical infrastructure, Brussels, 9 December 2022.

infrastructure, i.e. by preventing foreign entities from acquiring majority shares in national critical industries and networks or barring national companies from exporting cutting-edge technologies. This focus on securing critical value chains could lead to new forms of globalisation, where trade is more focused on blocs of neighbouring or politically aligned countries. The Mediterranean area is an outstanding example of how the pivot towards shorter, regional and more resilient value chains is changing economic, trade and logistics relations in the basin, with boosted north-south industrial cooperation and a strong increase in traffic for the Mediterranean ports. Attention will also be paid to the role of cybersecurity in strengthening the resilience of critical infrastructure, with a case study on how Taiwan has implemented policies aimed at fostering cyber-infrastructure resilience.

Electricity networks, telecommunication cables, as well as pipelines, constitute the backbone of our economies. Nevertheless, such an integrated and interconnected system has an intrinsic fragility; a single nefarious event has the power to disrupt and stop its whole functioning. The consequences of the Nord Stream pipeline explosion, for instance, could have put in danger the entire European energy provision, ultimately endangering the productivity of the continent and its people's livelihoods (although the natural gas flows both on Nord Stream 1 and 2 were already stopped at that time). Technology improvements applied to energy systems and network interconnections do have the potential to boost resilience in this field, enhancing better-off production systems and countries' strategic autonomy. Moreover, the digital domain itself is at risk: physical infrastructure, such as submarine cables where almost all international digital data flows, could be damaged in case of hostile acts or natural events; data servers and centres could be designed as targets for cyber attacks.

The second part will examine the vital importance of resilience and how it could affect different economic sectors and society. Logistics is at the core of game-changing transformations. The role of digitalisation and technology is more and more crucial for logistics and will be crucial to decarbonisation and resilience in this sector, especially to adapt to the reshaping of global value chains, as well as to multiple and recurrent shocks. As empirically demonstrated in this part of the report, the technological competition around global logistics will reshape industry and global value chains over the next ten years, and it is relevant to consider how this will entail new possible market complexities. Sustainability and resilience are intertwined concepts and play a key role in the development of new solutions for climate adaptation and mitigation. Moreover, quality and resilient infrastructure are the backbones of sustainable logistics, and they are very powerful tools to adapt but also mitigate the disruptive effects of climate change. From this perspective, the use of new materials in infrastructure building will make a vital contribution to enhancing infrastructure resilience. New construction materials released in the market, in addition to increasing overall infrastructure resilience, are climate-friendly and have proved to be able to reduce pollution.

To conclude, this report will focus on the international coordination needed to enhance effective resilience. Firstly, a common definition of resilience will be needed to frame and plan steps in advance, in a concerted and constructive manner. Global Platforms such as the G7 and G20 will be crucial to work on new high-level standards for infrastructures to keep them safe and resistant to our ever-changing world. In this respect, international efforts should reformulate and draw inspiration from the ancient Roman model of everlasting infrastructure. Only global coordination will ensure the high standards and reduced costs we need from our future infrastructure. However, we live in a time when polarisation and global value chain disruptions can hinder this process. Given the international efforts and promising new technology improvements, hope remains for building back better, more resilient infrastructure, for the world.

Carlo Secchi, Alessandro Gili

PART I

STRATEGIES

1. Supply Chains at a Crossroads. What's Next?

Amitendu Palit

Several global supply chains have become heavily concentrated in their sourcing patterns. The World Trade Organisation (WTO) estimates such concentration to be present in nearly a fifth of global exports that have large market shares but depend critically on a limited number of sources for supplies.[1] The vulnerabilities of this pronounced concentration were exposed during the Covid-19 pandemic.

The pandemic inflicted both supply-side and demand-side disruptions on supply chains. The onset of the pandemic led to severe shortages of raw materials and intermediate inputs, along with logistic failures caused by transport disruptions and delayed deliveries. The negative externalities of these supply-side shocks were later exacerbated by demand-side disruptions, when recovery from the pandemic led to massive surges in demand that the supply chains were unable to respond to. With the global economy normalising at varying paces across the world, supply chains continue to struggle to anticipate upcoming demand, conditioned by changing consumer preferences.

The aftermath of the pandemic has focused global attention on the urgency of making supply chains *resilient* and capable of withstanding shocks. The World Economic Forum (WEF) defines resilience as "…the ability of a global supply chain to

[1] R. Ossa, "Today's supply chain disruptions reaffirm the importance of a multilateral trading system based on WTO rules", WTO Blog, 2 June 2023.

reorganise and deliver its core function continually, despite the impact of external and or internal shocks to the system".[2]

A flurry of initiatives have been launched for enhancing the resilience of supply chains. The core objective of all these efforts is to reduce concentration by diversifying sourcing. Attempts to lower dependencies on specific countries as sourcing locations can be broadly grouped into national initiatives for increasing local production capacities and multi-country initiatives for friend-shoring supply chains. These efforts have been given momentum by concern over some countries' sourcing monopolies empowering them to "weaponise" their comparative advantages for geo-political benefits.

This chapter studies the motivations behind the reconfiguration of global supply chains by differentiating disruptions caused by the Covid-19 pandemic from other systemic supply-side shocks and considering the urgency to diversify for greater resilience prompted by the former. It analyses the geopolitical context behind the imperative for resilience and diversification. It moves on to discuss major initiatives for increasing resilience, including the notable multi-country Indo-Pacific Economic Framework for Prosperity (IPEF). The paper concludes by arguing that common actionable ideas on resilience among IPEF and major global bodies like the G7 and G20 can be expanded to a broader inclusive multilateral agenda aligned with the global trade rules of the WTO.

The Impact of Covid-19 and the Urgency for Resilience

Supply chain breakdowns were not uncommon before Covid-19. The outbreak of the SARS virus in China, East, and Southeast Asia during 2002 adversely affected supply chains. The Fukushima earthquake and tsunami in Japan in 2011 and

[2] World Economic Forum (WEF), "Building Resilience in Supply Chains", January 2013.

Hurricane Sandy in the US in 2012 caused severe disruption to electronics, automobile and energy supply chains. The extreme weather events that led to famines in the Horn of Africa in 2012 badly affected regional food supply chains.[3] In more recent years, IT disruptions, cyberattacks, enterprise data breaches, telecommunication breakdowns and transport network issues have caused significant disruption in hi-tech and data-intensive industrial supply chains in the Asia-Pacific region.[4]

Disruptions from the Covid-19 pandemic, however, were characteristically different from these systemic supply-side shocks. The most important difference was the widespread and prolonged nature of the former. Disruptions caused by extreme weather events and systemic factors like IT breakdowns and cyberattacks are short-lived and largely localised in their impacts, compared with the extensive and protracted breakdowns that supply chains experienced after Covid-19.

The deeper and wider disruption inflicted by Covid-19 is significantly attributable to the impact of the pandemic on China. First detected in Wuhan province in December 2019, the pandemic led to extensive lockdowns in China, leading to the mass closure of factories and production facilities. The jolt to supply chains was severe, with Wuhan being a prominent sourcing hub for several Fortune 500 companies.[5]

The lockdown of Wuhan was a vivid example of a single sourcing location turning into an active disruptor of multiple supply chains. As the pandemic spread from China to other countries in East and Southeast Asia, such as Japan, Korea, Taiwan, Vietnam, Malaysia, and Thailand, countries that play active roles in various industrial supply chains, disruptions were experienced by vital industries like semiconductors, affecting supplies to major global chip users (e.g. Apple).[6] China imposed

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[3] Ibid.

[4] UNESCAP, *Asia Pacific Trade Facilitation Report 2021*, Asia Development Bank October 2021.

[5] E. Braw, "Blindsided on the supply side", *Foreign Policy*, 4 March 2020.

[6] "Apple results hit by supply chain woes, Cook says holiday quarter impact will

lockdowns again in 2021 due to resurgence of the virus. These controls adversely affected industrial production in the country, reintroducing shortages for various supply chains.

The effects of the Covid-19-induced supply-side shocks originating in China and the rest of the Asia-Pacific region continue to linger. The movement of goods and people by both air and sea are affected by smaller numbers of aircraft and containers, along with fewer technical and operational staff, following capacity compressions during the pandemic. Occasional surges in Covid cases ensure that human illness continues to affect business efficiencies. The latter are also impacted by the hurried transition to digital modes that several enterprises were forced into following Covid. Business efficiencies are further impaired by high demand for several items following post-pandemic economic recoveries that have witnessed burgeoning consumer demand for both goods and services.

Compared with the disruptions caused by the SARS virus in the early years of the current century, the damage caused to supply chains by Covid-19 was far more severe. The extent of the damage pointed to the enormous importance of China in the world economy – an importance that has grown phenomenally in the years that followed the SARS outbreak of 2002. China's large share in world trade and the global economy over the last two decades has led to several global industries developing critical dependencies on China for sourcing parts and components, raw materials, and finished products.[7] The devastating effect of China's lockdown on supply chains therefore is hardly surprising.

A fundamental understanding that emerged from the impact of the pandemic was the need to reduce sourcing dependency on a single location. As mentioned in this paper earlier, nearly 20% of global exports exhibit high supply chain concentration, which has increased sharply over the last two

be worse", *Reuters*, 29 October 2021.

[7] P. Haren and D. Simchi-Levi, "How Coronavirus Could Impact the Global Supply Chain by Mid-March", *Harvard Business Review*, 28 February 2020.

decades. Heavy dependence on China has been a prominent aspect of global sourcing for several industries. This dependence makes these industries vulnerable to risks of destabilisation following interruptions in sourcing. Sourcing disruptions contain significant economic security risks for many countries, particularly if critical supply chains like pharmaceuticals, food, electronics, semiconductors, and automobiles are affected. Efforts to de-risk by diversifying sourcing, therefore, have become integral to the objective of making supply chains resilient.

The Politics Behind Diversification and Resilience

The imperative to diversify sourcing from China through pursuit of a "China plus one" strategy[8] for making supply chains resilient has been influenced by China's worsening political relations with the US and several other major countries.

US-China strategic competition became manifest in the bilateral trade sphere of the two countries in 2018, with the US slapping punitive tariffs on Chinese imports and China retaliating in response. Friction then spilled beyond trade to the much larger arena of bilateral relations between the two countries, with growing mutual mistrust following China's role in the origin and spread of Covid-19. This mistrust showed up in China's deteriorating political relations with major US partners and allies in the Indo-Pacific region – Australia, India, and Japan – who, along with the US, comprise the strategically influential "QUAD" group in the Indo-Pacific.[9] Europe's relations with China too became significantly complicated after Covid-19.[10] A major factor behind China's worsening ties with

[8] "China Plus One Strategy – An Imperative to Achieve Supply Chain Resilience", Beroe Inc, 11 April 2023.

[9] S.A. Smith, *The Quad in the Indo-Pacific: What to Know*, Council on Foreign Relations, 27 May 2021.

[10] P. Le Corre and E. Brattberg, *How the Coronavirus Pandemic Shattered Europe's*

the US, Europe and other global powers was apprehension over a geopolitically assertive China "weaponising" its economic command over global trade and critical supply chains to its geopolitical advantage.[11]

Apprehensions over "weaponisation" are no longer confined to China. They have widened following the Taliban regime's takeover of Afghanistan in 2021 and the Russian military aggression in Ukraine from early 2022. Afghanistan's untapped wealth of critical materials (e.g. lithium, rare earth elements) and strategic minerals (e.g. copper, lead, iron ore) make it capable of exercising a prominent role in the smooth functioning of supply chains[12] for smartphones, electric vehicles and electronic products that use these materials and minerals extensively. Similarly, Russia's command of vital energy resources (e.g. crude oil, natural gas) and a major food product like wheat, puts it in a position to utilise global trade and supply chains of these items to its geopolitical advantage.

The "weaponisation" concern expanded the notion of de-risking by diversifying to that of decoupling, implying substantial disengagement from the sourcing locations. The urge to decouple led to multi-country initiatives aimed at "friend-shoring" supply chains by relocating them from China and its allies to friendly countries. An instructive view in this regard is obtained from the European Commission's Industrial Strategy unveiled after breakdowns in supply chains following Covid-19. The Strategy proposes combining resources for building alternative supply chains with "closest allies and partners" in case of "common dependencies" on sourcing locations:[13] in this context, the Strategy specifically identified shared EU and US

Illusions of China, Carnegie Endowment for International Peace, 9 July 2020.

[11] "US Worries China Will Use Supply Chains as Weapon", *BARRON'S*, 8 March 2023.

[12] A. Palit, *What China-Taliban Ties mean for the US, Canada and the World*, Macdonald Laurier Institute, 21October 2021.

[13] European Parliamentary Research Service (EPRS), "Resilience of Global Supply Chains", Briefing, PE698.815, 25 November 2021.

dependencies on the sourcing of pharmaceutical ingredients and critical inputs required for green transition and digitalisation.

With time, however, decoupling from China has emerged as far more challenging than envisioned. This is due to the difficulty of forcing supply chains, which have embedded into China on the grounds of economic efficiency, to relocate elsewhere. China is currently ranked 1st in global merchandise trade and 3rd in global commercial services trade,[14] underlining its preeminent position in global manufacturing and services. It is difficult for supply chains, including in ostensibly critical industries (e.g. electronics, automobiles, pharmaceuticals, chemicals) to move out from China, even if such decoupling is arguably justified on geo-political grounds. Geopolitical pressure to shift supply chains can militate against the core economic logic of their organisation.

The G7 Hiroshima Communique's reflection "It is necessary to cooperate with China, given its role in the international community and the size of its economy, on global challenges as well as areas of common interest" underlines the bloc's shifting policy for engaging with China.[15] The shift captures the emphasis on de-risking as opposed to decoupling. In this respect, the Hiroshima Communique further indicates: "We are not decoupling or turning inwards. At the same time, we recognise that economic resilience requires *de-risking* and *diversifying* (italics added). We will take steps, individually and collectively, to invest in our own economic vibrancy. We will reduce excessive dependencies in our critical supply chains".[16]

De-risking, diversifying, and reducing dependencies are essential for enhancing the resilience of supply chains. The common objective of the G7 and several other major economies, such as Australia, India and Korea, who are working with the G7 for furthering resilience, is to make sure that supply chains do

[14] "China – Member Information", World Trade Organization (WTO).

[15] The White House, "G7's Hiroshima Leaders Communique", Washington DC, 20 May 2023.

[16] Ibid.

not suffer the kind of damage they did following Covid-19. It is useful in this regard to take a close look at the various national and collective efforts that various countries have initiated for safeguarding supply chains.

National Initiatives

Country-specific efforts to enhance supply chain resilience have focused on enhancing domestic capacities in order to reduce dependence on imported inputs. The thrust of policies in this regard has been to financially incentivise new investments.

The US has legislated the CHIPS and Science Act of 2022[17] for attracting investments in semiconductor production. The Act aims to significantly increase the US's current share in global chip production and to reduce dependence on imports from East Asia. It intends to do so by providing $52 billion financial support, three quarters of which are incentives for manufacturing, and the remaining for R&D and workforce development.[18] The EU has also proposed €43 billion investments through the European Chips Act for strengthening local chip-making facilities and increasing the EU's market share in global chip production.[19]

Japan, Australia, India, and South Korea are other major global economies that have announced policies for encouraging investments in expanding domestic capacities. Japan's measures include offering generous incentives to its businesses for relocating from mainland China to either Japan or Southeast Asia.[20] Australia's sovereign manufacturing capability plan identifies vulnerabilities in supply chains for critical products

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[17] The White House, "FACT SHEET: CHIPS and Science Act will Lower Costs, Create Jobs, Strengthen Supply Chains and Counter China", Washington DC, 9 August 2022.

[18] Ibid.

[19] European Commission, "European Chips Act".

[20] "Japan is paying firms to make things at home. But China's pull is still strong", *The Business Times*, 26 September 2020.

(e.g. agriculture, personal protective equipment) and incentivises greater domestic investments in these products.[21] India's efforts include announcing production-linked incentives (PLIs) for financially incentivising new investments in several strategic industries (e.g. automobiles and auto components, active pharmaceutical ingredients [APIs], telecom and networking products).[22] Korea too has announced a variety of incentives for increasing local manufacturing in hi-tech industries, including U-turn subsidies for reshoring overseas production.[23]

The Indo-Pacific Economic Framework for Prosperity (IPEF) and Other Efforts

Collective efforts for making supply chains resilient have seen countries coming together for friend-shoring supply chains. A noteworthy initiative in this regard is the IPEF. Led by the US and comprising 14 countries from the Indo-Pacific region – Australia, Brunei, Fiji, Japan, Korea, Malaysia, New Zealand, India, Indonesia, Philippines, Singapore, Thailand, Vietnam, and the US – the IPEF was announced on 23 May 2022.[24] Structured as the latest regional rules-making initiative in the Indo-Pacific region, the IPEF, with four of the largest global economies as its members, accounts for around two-fifths of global economic output.

Supply chains are a core focus of the IPEF, which is designed as a new and modern approach for tackling "XXI century" economic challenges. By initiating and establishing regional rules along with its allies in the Indo-Pacific, the US aims to

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[21] "Sovereign Manufacturing Capability Plan", Commonwealth of Australia, July 2021.

[22] "Production Linked Incentive (PLI) Schemes in India", *Invest India*, March 2020.

[23] *Supply Chains: A Shifting Indo-Pacific - South Korea*, Asia Society Policy Institute (ASPI).

[24] The White House, "FACT SHEET: In Asia, President Biden and a Dozen Indo-Pacific Partners Launch the Indo-Pacific Economic Framework for Prosperity", Washington DC, 23 May 2022.

counterbalance China's influence in the region.[25] Repositioning strategic supply chains among close allies for safeguarding them is a core goal in this regard.

Exactly a year after its announcement, the IPEF has moved fast to deliver on supply chains with the group reaching a consensus on a supply chain agreement.[26] This includes a framework for understanding risks to the chains by identifying critical sectors; crisis coordination and response mechanisms; greater business preparedness for resolving supply chain bottlenecks through better logistics and infrastructure; investment facilitation and regulatory transparency in critical sectors with implications for national security and public health; ensuring the availability of skilled workers in critical sectors; expanding technical assistance and capacity building in supply chains; protecting confidential business information and minimising market distortion; and promoting labour rights and secure worker benefits in supply chains by making them more resilient.

The IPEF Agreement also proposes establishing a Supply Chain Council for developing action plans for critical sectors, including the diversification of sourcing, better logistics, trade facilitation and infrastructure development. Two further proposals include establishing a supply chain crisis response network for information sharing and faster response, and a Labour Rights Advisory Board for promoting labour rights across supply chains.

The IPEF's plans for enhancing resilience are consistent with those identified by research as essential to corporate resilience. Collaboration, close communication, and information-sharing are fundamental[27] as they help firms in various supply chain

[25] A. Palit, *IPEF's early fanfare masks risks in the US approach*, Hinrich Foundation, 26 October 2022.

[26] US Department of Commerce, "Press Statement on Substantial Conclusion of IPEF Supply Chain Agreement Negotiations", 27 May 2023.

[27] F.S. Hsieh, "Dynamic configuration and collaborative scheduling in supply chains based on scalable multi-agent architecture", *Journal of Industrial Engineering International*, vol. 15, 2018, pp. 1-21

layers to anticipate potential disruptions and stay prepared. In this respect, the IPEF's business focus is noteworthy. Concerns, though, have been raised over whether detailed information-sharing, especially confidential business information, might enhance members' national security risks.[28]

The IPEF proposals are also noteworthy for their emphasis on logistics and infrastructure and the identification of critical sectors. The proposals attempt to combine company-specific efforts for resilience with the imperative of eradicating supply-side bottlenecks by strengthening logistics and infrastructure. Both perspectives are compounded by an emphasis on economic security through efforts to preserve labour rights and national security by identifying critical sectors. The key challenge for the IPEF will be to ensure that the agreement is implemented effectively among all its members, many of whom differ in regulatory standards and logistic capacities. There might also be disagreement among members on identifying critical sectors. It would also be interesting to check how the IPEF's supply chain reorganisation impacts trade and the economic relations of its members with China and other countries outside the bloc.

Collaborative partnerships on critical goods (e.g. semiconductors, critical minerals), stronger communication, and resilient critical infrastructure, especially digital modes, have also been highlighted by the G7 in its latest proposals on enhancing supply chain resilience.[29] The G20 has also emphasised the importance of resilient supply chains in its reflections on global food, energy and health securities.[30] Compared with both global bodies though, the IPEF, till now, has come out with more substantive proposals on enhancing resilience. An important reason behind the greater progress

[28] C. Butler, *G7 China Statement could enhance global economic stability*, Chatham House, 22 May 2023.

[29] The White House, "G7 Leaders' Statement on Economic Resilience and Economic Security", Washington DC, 20 May 2023.

[30] G20 India, Foreign Ministers Meeting, Chair's Summary and Outcome Document, New Delhi, 1-2 March 2023.

of IPEF is the proactive leadership of the US inspired by geo-economic and geo-political reasons to make Indo-Pacific supply chains more resilient by diversifying them from China.

Is a Multilateral Approach to Resilience Possible?

The current global reshuffling of supply chains, premised on de-risking through the greater diversification of sourcing and friend-shoring, is likely to see some of the chains being relocated within specific blocs, such as the IPEF. Pursuit of a comprehensive "China plus one" strategy for reducing over-dependence on Chinese suppliers by locating alternative suppliers in "friendly" countries can set in motion a reorganisation of the global trade order into distinct blocs, identified by geo-political alignments around the US-China competition, and the Ukraine conflict. Such an outcome, produced by the reconfiguration of supply chains, however, has significant negative externalities.

The WTO's estimates indicate that the division of the world economy into rival blocs along geopolitical lines will reduce global GDP by more than 5%, with particularly adverse implications for low-income, least developed countries (LDCs). In contrast, both the revival of multilateralism and "open" plurilateral cooperation will yield greater economic gains with the former delivering the most.[31]

There is little doubt that an inclusive global trade regime with transparent and well-defined rules and the least restrictions on cross-border trade of goods and services offers the best prospect for diversification and lower concentration in supply chains. It will enable countries to effortlessly access alternative supplies in the event of disruption in specific sources. However, current global politics are unlikely to facilitate implementation of a multilateral approach to fostering resilience.

[31] J. Métivier, M. Bacchetta, E. Bekkers, and R. Koopman, "International Trade Cooperation's Impact on the World Economy", WTO, Staff Working Paper, ERSD 2023-02, 24 January 2023.

The IPEF, G7 and G20 are deeply engaged in enhancing the security of supply chains. Several members of these groups – individually and collectively – are pursuing efforts to diversify and de-risk supply chains.[32] Decisions by these groups should reflect convergence given the common members across all three bodies. The most optimistic "multilateral" scenario for enhancing the resilience of supply chains appears to be the prospect of these bodies, and the bulk of their members, adopting similar rules and standards for safeguarding supply chains. These standards, hopefully, will not be exclusive to the groups and their members and will be open to further adoption by the global trade community, particularly low-income countries, in order to achieve greater resilience in global supply chains.

[32] Japan, Australia, and India are also engaged in a trilateral supply chain resilience initiative. "Australia, Japan and India form supply chain initiative to counter China", *The Straits Times*, 28 April 2021.

2. The Trade-Industry-Infrastructure Nexus. Is Europe Ready for the Race?

Alessandro Gili, Francesco D'ambrosio Lettieri, Roberto Italia

The Covid-19 pandemic, the war in Ukraine and the tensions between China and the United States: these three shocks, together with the narrative about decoupling/derisking, have been putting the dynamism of globalisation and the resilience of Global Value Chains (GVCs) to the test, potentially increasing the attractiveness of re-shoring, near-shoring and friend-shoring arrangements. Policy pressure to relocate supply chains according to a "West versus China" paradigm is mounting day by day.

New patterns in trade may not immediately result in a significant change in standard aggregate data. Yet, corporate earning calls and business surveys capture changing sentiments. For instance, in an analysis of S&P 500 earnings call transcripts, Bank of America said mentions of the term "reshoring" were up 128% in the first quarter of 2023 compared to the same time a year ago. UBS also examined the trend by polling more than 1,600 executives in different areas: 78% of the executives surveyed in Europe intend to move parts of the supply chain closer to home, 70% in the US and 54% in China plan to do so.[1] In addition, a survey conducted by the US-China Business Council in June 2022 found that 87% of respondents (US

[1] L. Handley, "Firms are bringing production back home because of the Ukraine war, China's slowdown – and TikTok", *CNBC*, 1 June 2023.

multinationals in China) declared that US-China tensions are having an impact on their operations and investment decisions, with 26% shifting away from industry segments in China, 29% developing separate US and China-specific value chains and 24% disinvesting in China. A similar survey conducted by the EU Chamber of Commerce in China in April 2022 noted that geopolitical tensions were negatively affecting European investments in China, with 7% of surveyed firms considering disinvesting in China because of the war in Ukraine, and 33% declaring that geopolitical tensions were decreasing China's attractiveness.[2]

Trade diversion is also emerging. China's export shares to the US are declining and those to ASEAN countries increasing. US efforts to diversify its imports and reduce reliance on China since the beginning of the trade war are driving purchases towards lower-cost alternatives in other Asian countries (Vietnam, India, Taiwan and Malaysia). Central and Eastern Europe could increase their participation within European value chains, while certain Latin American countries, notably Mexico, could do the same in US value chains.

Obviously, rearranging value chains with the goal of reducing "dangerous" dependencies, and increasing national security in a sustainable fashion will take time due to sizeable economic and social costs and technological challenges. This is particularly true for critical raw materials and green technologies, which are the future engines of the agriculture, IT, automotive, energy, and food industries. It seems a daunting task for certain regions, especially Europe. In fact, production and processing operations are highly concentrated in a small number of countries, like China**.** Although investment in supply source diversification is rising, most near-term output growth for many minerals is still expected to come from today's major producers, implying an even higher degree of concentration in the years ahead. This high level of concentration means that the system is particularly

[2] European Commission, *Winter 2023 Economic Forecast*, 13 February 2023.

vulnerable to disruptions – caused by geopolitical events, global pandemics, earthquakes or other weather events, or shutdowns associated with adverse environmental, social or governance incidents. Any disruption that interrupts operations at a large facility or group of facilities can have a major impact on supply availability, and therefore on prices across the world.

To reduce harmful dependencies and increase resilience, in June 2023 the EU launched the European Economic Security Strategy. The strategy is underpinned by three main pillars: promoting competitiveness; enhancing security and resilience from economic security risks; and partnering with the broadest possible range of "like-minded" countries, i.e. sharing the same interests and concerns on economic security. The infrastructure challenge is a core aspect of the broader European Economic Security strategy, as it mentions the Global Gateway as a key tool to shape standards, make supply chains more resilient and strengthen EU resilience, including through new infrastructure and connectivity partnerships with third countries.[3]

Infrastructure Investments: The Great Reallocation of Capital Is Underway

In order to build resilience, it is necessary to invest in infrastructure and connectivity between developed and developing regions. The G7 leaders, who gathered in May 2023 in Hiroshima, Japan, reaffirmed their commitment to the Partnership for Global Infrastructure and Investment (PGII), launched at the G7 Elmau Summit in 2022. The objective is to mobilise up to $600 billion by 2027 and deliver energy, physical, digital, health, and climate-resilient infrastructures in the developing world. The focus is also on quality infrastructure and on the promotion of international standards and principles for transparency, good governance, anticorruption, labour, environment, and climate as well as

[3] European Commission, "European Economic Security Strategy", 20 June 2023.

financial and debt sustainability, such as the G20 Principles for Quality Infrastructure Investment.

Under the PGII, the group of like-minded states sends a clear and strong message towards China's Belt and Road Initiative, which has grown to encompass 147 countries. Yet, the Chinese global endeavour has met with mixed success and is facing a recalibration: while infrastructural investments have indeed expanded Chinese influence abroad and have made the country the world's largest creditor, the cracks of years of signing often-opaque, risky, even economically questionable deals with low and middle-income countries are showing up in debt traps. Out of a claimed total of 1 trillion, about $78.5 billion of loans from Chinese institutions to roads, railways, ports, airports and other infrastructures around the world were renegotiated or written off between 2020 and the end of March 2023, according to figures compiled by Rhodium Group. This is more than four times the $17bn in renegotiations and write-offs recorded in the three years from 2017 to the end of 2019.[4] It should not come as a surprise that Beijing has extended an unprecedented volume of "rescue loans" to prevent sovereign defaults: it has doled out $230 billion of emergency support in the past decade to foreign governments and central banks through new loans, rollovers of old loans and currency-swap agreements with the People's Bank of China.[5] A slowdown in global and Chinese growth, rising interest rates and record-high debt levels do not bode well for the BRI and for its members.

In such a scenario, Western action is necessary. In a time of heightened competition between the US and China, the Biden Administration has put forward ambitious plans for infrastructure. At the domestic level, for decades the US has suffered from underinvestment and deterioration of national

[4] J. Kynge, "China grants billions in bailouts as Belt and Road Initiative falters", *Financial Times*, 28 March 2023.

[5] S. Horn, B. Parks, C. Reinhart, and C. Trebesch, *China as an International Lender of Last Resort*, Working Paper #124. Williamsburg, VA: AidData at William & Mary, 2023.

roads and bridges. The Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL) and enacted into law in November 2021, is devoted to addressing these issues. Secondly, the Inflation Reduction Act (IRA), signed in August 2022, is the first major federal spending response to climate change and will put the US on a path to reduce greenhouse gas emissions to 40% less than 2005 levels by 2030, according to several independent analyses. Investments under the two bills will amount to $1.25 trillion across the transportation, energy, water resources, and broadband sectors for the next five to 10 years.

At the international level, the Biden Administration was the first promoter of the PGII through the launch of the Build Back Better World (B3W) in 2021. The B3W was an elaboration of the Blue Dot Network (BDN), in which the US joined forces with Japan and Australia to support investment in high-quality infrastructure projects around the world. In addition, last year the US and the other QUAD members – Japan, India and Australia – announced they would allocate an additional $50 billion to infrastructure investments in the Indo-Pacific.[6] For instance, the QUAD Partnership for Cable Connectivity and Resilience aims at developing safe cable systems and establishing improved internet connectivity in the region.[7] The Persian Gulf is another key area for US interests. Indeed, the US promoted, through the I2U2 forum, rail connection projects in the Gulf,[8] while US National Security Advisor Jake Sullivan visited Saudi Arabia in April to strengthen the partnership on connectivity,[9] followed by Secretary of State Antony Blinken in June.

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[6] ANI, "Quad to give over 50 billion USD infrastructure, investment push in Indo-Pacific in five years", *ThePrint*, 25 May 2022.

[7] The White House, *Quad Leaders' Summit Fact Sheet*, Briefing Room, 20 May 2023.

[8] D. Fiorentini, "I2U2: Israele, India, USA e UAE ampliano le relazioni economiche con un nuovo memorandum", *BetMagazine Mosaico*, 2 May 2023.

[9] L. Berman, "Senior US official in Saudi Arabia to discuss massive rail project with UAE, India", *The Times of Israel*, 7 May 2023.

EU's Global Gateway: The Race Is On

Last but not least, Europe is the region most exposed to a shift in the economic paradigm of globalisation. To achieve strategic autonomy and reduce external dependencies and vulnerabilities, it is crucial for the EU to strengthen resilient value chains and infrastructures. Global Gateway is the European Union's action plan under the PGII framework to build and improve sustainable energy, transport, digital, and other forms of infrastructure. It builds on the existing connectivity strategies, namely the 2018 EU-Asia Connectivity Strategy,[10] the 2019 EU-Japan Connectivity Partnership on Sustainable Connectivity and Quality Infrastructure[11] and the 2021 EU-India Connectivity Partnership.[12]

Global Gateway aims to raise 300 billion euros by 2027 on a global scale. As announced during the EU-African Union Summit in February 2022, Africa will benefit from half of the financing committed, or 150 billion. The strategy also focuses on the Western Balkans and Ukraine, as well as Asia, Latin America and the Caribbean. Global Gateway has started 90 projects worldwide in 2023. Two examples are worth mentioning. In Namibia, the EU is providing guarantees for private investments in green hydrogen. The initiative will be reinforced by investments in a strategic regional transport corridor, linking Maputo-Gaborone-Walvis Bay. The goal here is twofold: to ensure clean energy for the country itself and generate new revenue by allowing it to export the green hydrogen, for example, to the EU block. Meanwhile, in the Philippines, the EU is connecting its Copernicus satellites to

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[10] European External Action Service, "Connecting Europe & Asia: The EU Strategy", 26 September 2019.

[11] European External Action Service, "The Partnership on Sustainable Connectivity and Quality Infrastructure between the European Union and Japan", 27 September 2019.

[12] European External Action Service, "Factsheet: EU-India Connectivity Partnership", 22 April 2022.

build the first earth observation system in Southeast Asia.[13]

Aiming at creating sustainable, resilient and inclusive transport systems, Global Gateway supports networks that establish connectivity with the Trans-European Transport Network (TEN-T).[14] Through TEN-T, the EU aims to establish an efficient and high-quality multimodal transport network throughout the region, promoting sustainable transportation of people and goods, guaranteeing access to jobs and services and fostering trade and economic growth. Moreover, building efficient transport systems, it has a strong potential to enhance the EU's social, economic and territorial cohesion. Sustainability and climate resilience are at the core of the whole activity and funding of the European Union: it is mandated that 30% of the 1074 billion euros of the Multiannual Financial Framework (MFF) 2021-2027 and 37% of the 750 billion euros in the Next Generation EU will be allocated to investments to enhance climate resilience, in particular through climate-resilient infrastructure.[15]

The war in Ukraine has reshaped the geopolitical order and has revealed the fragilities of the EU in dealing with unexpected events occurring outside its borders. To strengthen EU connections with neighbouring partners, in July 2022 the European Commission proposed amendments to its December 2021 proposed revision of the TEN-T regulation.[16] Firstly, the Commission proposed to extend four European Transport Corridors to the Ukrainian and Moldavian territories to foster transport connectivity, facilitate trade, connect people and businesses as well as reconstruct the Ukrainian transport

[13] European Commission, *Statement by President von der Leyen at the Partnership for Global Infrastructure and Investment event in the framework of the G7 Summit*, 20 May 2023.
[14] European Commission, "Questions and Answers: The revision of the TEN-T Regulation", 14 December 2021.
[15] Council of the European Union, "Long-term EU budget 2021-2027 and recovery package", 14 March 2023.
[16] European Commission, "Commission amends TEN-T proposal to reflect impacts on infrastructure of Russia's war of aggression against Ukraine", 27 July 2022.

infrastructures once the war is over. Moreover, it proposes to remove Russia and Belarus from the TEN-T maps and downgrade the last km of the trans-border links between the EU and Russia/Belarus from a "core" to a "comprehensive network".

Considering the recent acts of sabotage against critical EU infrastructure, such as the one against the North Stream, and the risks deriving from the Russian aggression of Ukraine, the European Council adopted, in December 2022, a recommendation to strengthen the resilience of critical infrastructure, especially those with cross-border relevance, the disruption of which could significantly impact other Member States[17]. It focuses on key sectors such as energy, digital infrastructures and space and it covers three priority areas, namely preparedness, response, and international cooperation, especially among EU Member States. Particular attention must be paid to critical infrastructure outside the territory of Member States, such as undersea critical infrastructure and offshore energy infrastructure. Member States are thus called to coordinate and use all available tools to strengthen physical and cyber resilience.

The EU's Effort To Build Resilience in Africa, Latin America and Central Asia

At the February 2022 Summit between the African Union and the European Union, the EU's strong intention to launch a regional investment plan for Africa, within the framework of the broader Global Gateway, was immediately clear. This plan is intended for public and private investment within the broader *Global Gateway Africa - Europe Investment Package*, with the goal of fostering Africa's growth and the transformation of

[17] Council of the European Union, COUNCIL RECOMMENDATION of 8 December 2022 on a Union-wide coordinated approach to strengthen the resilience of critical infrastructure, Eur-Lex, 1 January 2023.

the Continent. The strategy – as mentioned above - aims to mobilise up to 150 billion euros of investment in the African continent.[18]

Regarding transport infrastructure, the primary goal is to integrate the European and African multimodal transport networks, especially through the creation of strategic corridors and the harmonisation of regulatory frameworks and standards for infrastructure construction and operation. These networks should form the backbone of the economic potential for a free trade area involving the entire African continent. Eleven strategic corridors have been identified so far, and as of April 2023 87 key projects have been prioritised: they will have to enhance connectivity between the European Union and Africa in a sustainable manner, facilitating trade and mobility both within the continent and between Europe and Africa. These corridors will therefore be crucial for the development of new value chains, from which African and European industries will benefit. In this regard, the EU and the African Union Commission have identified 95 regional value chains in 23 sectors that show promise for fostering sustainable industrialisation and trade between African countries with the EU. Finally, the EU is developing bilateral partnerships with African countries to create value chains for raw materials as part of the broader strategy outlined by the EU Critical Raw Materials Act. The plan is directed at increasing the resilience of European supplies and enabling these countries to diversify their economies and integrate their resources into global value chains.

Energy will be at the centre of Global Gateway's commitments to Africa, with planned investments of up to €15 billion. The main goals will be to increase the production of green energy and access to energy for African citizens, supporting the integration of the different national markets and improving

[18] European Commission, "EU-Africa: Global Gateway Investment Package", 28 November 2022.

interconnections between different electricity grids. Focus on reforms to encourage private investments will also be key. EU energy investments in the continent are aimed to increase energy production both for domestic consumption and for export to Europe: in this sense, the plan targets to ensure win-win cooperation that could increase resilience and economic security for European and African countries. To this purpose, the Africa-EU Green Energy Initiative aims to support the development of at least 200 GW of additional renewable energy by 2030 (including at least 50 GW of electricity), ensuring access to electricity for about 100 million people on average. Also central will be the hydrogen strategy, with the goal of creating an electrolysis capacity of at least 40 GW by 2030. In any case, to efficiently match supply and demand as well as places of production and consumption interconnections and transmission networks will be needed under the framework of an African Single Electricity Market. In this view, Just Energy Transition Partnerships (JETs) are poised to help African partner countries in the energy transition and to improve its efficiency. The first Jets have been planned with South Africa (worth €3 billion) and Senegal.

Central Asia, a region of key importance in connecting Europe to the major Eastern markets, is not marginal to infrastructure development plans and the EU Global Gateway investments. However, now more than ever, following the reformulation of global value chains dictated by the war in Ukraine, the region has assumed strategic and logistical value for Europe. Indeed, the countries of Central Asia are proving to be increasingly crucial for ensuring connectivity between China and Europe, with alternative routes that do not include passing through the territory of the Russian Federation. Central Asia has thus become key to increase Europe's strategic option and economic resilience as pursued in its infrastructure, industrial and trade strategies. However, there still remain many challenges to ensure the success of European investments in the region. First of all, there is the limitation of geographic location, which by depriving Central Asian countries of outlets in the ocean, leads to situations of geopolitical and economic dependence of these countries towards major powers such as China and Russia or the influence of neighbours such as Iran and Afghanistan, which are strongly isolated in the international arena.[19] Second, besides competition, a minimum degree of coordination among leading economic powers involved in these countries is unavoidable when it comes to infrastructure investments.[20]

In Kazakhstan, the region's largest country, investments promised by the national infrastructure development strategy, called Nurly Zhol, amount to $9 billion dollars and are directed to the rehabilitation of roads and railways and the construction of new ports, airports and innovative IT infrastructure.[21] These are joined by support from the European Bank for Reconstruction and Development (EBRD) amounting to $2.7 billion for 17 different infrastructure development projects,[22] accompanied by funds from the Asian Development Bank and Islamic Development Bank. The investments seem to mainly involve the hubs of Atyrau, Nur-Sultan and Almaty but are more generally aimed at promoting the growth of the country's economy, also by reconfiguring trade routes between East and West. Key, in this scenario, are the upgrading of the Centre-East Road Corridor between Nur-Sultan and Ust-Kamenogorst and the Centre-West Corridor in the Shalkar and Kandyagash section, with the ambition to make Kazakhstan the major communication route between the Caucasus and the West across the Caspian.[23] Central to the Europe-Asia connectivity

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[19] M. Levystone, "Connectivity in Central Asia at the Crossroads of International Crises. Transport, Energy and Water from Interdependence to New Cooperation Ways", Études de l'Ifri, RUSSIE.NEI.REPORT, no.41, November 2022

[20] P. Krasnopolsky, "China, Russia and Central Asian Infrastructure. Fragmenting or Reformatting the Region?", Palgrave Series in Asia and Pacific Studies, 2022.

[21] International Trade Admnistration, "Kazakhstan-Country Commercial Guide", 9 February 2022.

[22] A. Matveeva, "A New Opening for EU-Central Asia Relations?", Carnegie Europe, 13 April 2023.

[23] The World Bank, "Center West Regional Development Corridor", 30 April

framework is the Trans-Caspian International Transport Route (Titr)-Middle Corridor.[24] This route, an alternative to the Russian one, already connects China to Europe via Kazakhstan, Azerbaijan, and Georgia. With an estimated 80,000 TEUs (Twenty-foot equivalent units) at the end of 2022,[25] the Middle Corridor is not far from reaching its maximum capacity of one hundred and twenty thousand TEUs. However, ongoing projects promise a marked improvement in its infrastructure, making clear the commercial potential of the new links across the Caspian. Moreover, in the aftermath of the Samarkand EU-Central Asia Connectivity Conference, a study has been commissioned to and is being developed by EBRD at the behest of the European Commission that will come to an end in late summer 2023. The study has as its main objective to investigate the possibilities for sustainable transport between Central Asia and Europe with the extension of the Trans-European Transport Networks (TEN-T) in Central Asia, confirming the growing cooperation in the region.[26]

The European exposure in the region is careful and moderate but in its configuration is already enjoying a fair amount of success at the local level. Evidence of this is the joint press release by Uzbek President Mirziyoyev and Charles Michel last October emphasising the "desire to strengthen important interregional cooperation"[27] as well as that of Kazakh Foreign Minister Tileuberdi and Joseph Borrell last February.[28]

2023.

[24] Middle Corridor, "Trans-Caspian International Transport Route".

[25] "EDRB Says Significant Transport, Infrastructure, Investment Needed Across Central Asia & Middle Corridor", Silk Road Briefing from Dezan Shira & Associates, November 2022.

[26] European External Action Service, "The Samarkand EU-Central Asia Connectivity Conference: Global Gateway", 18 November 2022.

[27] European Council, "Joint press statement by H.E. Mr. Shavkat Mirziyoyev, President of the Republic of Uzbekistan and H.E. Mr. Charles Michel, President of the European Council", September 2022.

[28] European External Action Service , "Kazakhstan – EU: Joint statement by Deputy Prime Minister – Minister of Foreign Affairs of the Republic of

In late 2022, Joseph Borrell visited the region and attended the EU-Central Asia ministerial meeting[29] and the EU-Central Asia conference on connectivity[30] both in Samarkand, Uzbekistan. The occasion was relevant to clarify the extent of the European engagement in the region through the Global Gateway plan. The EU already accounts for 42% of the total volume of foreign direct investment in Central Asia, compared to 6% for Russia and 3.7% of China, the main competitors, for a total investment volume of €105 billion.[31] Its burden is now set to grow, focusing on the modernisation and digitisation of interregional trade in addition to transportation diversification.

The governments involved in the Investment Plan play a central role in this, but so does the private sector, with the aim of strengthening cooperation not only at the international level but also locally. A concept stressed by Borrell in the interest of ensuring compliance with international standards for the security of the states involved in the investments.[32] In addition to the aforementioned railroads, which are indispensable for implementing the coveted strategic autonomy from the Russian presence on the global value chains, prominence is also given to satellite connections to improve transportation-related communication and consequently trade. Regarding the sustainability of these connections, the EU Support to Sustainable Energy Connectivity in Central Asia provides an amount of €6.8 million to promote diversification of the energy mix in line with European best practices.[33]

Kazakhstan Mukhtar Tileuberdi and the HR/VP Josep Borrell on the 30th anniversary of the establishment of diplomatic relations", February 2023.

[29] European External Action Service, "Central Asia: 18th EU-Central Asia Ministerial Meeting - finding solutions to common challenges", November 2022.

[30] Delegation of the European Union to Turkmenistan, "The Samarkand EU-Central Asia Connectivity Conference: Global Gateway", November 2022

[31] European External Action Service, "EU-Central Asia relations", May 2023.

[32] European External Action Service, "Opening remarks by High Representative/ Vice-President Josep Borrell at the EU-Central Asia Connectivity Conference: Global Gateway", November 2022

[33] Delegation of the European Union to the Republic of Kazakhstan, "EU

After all, the European presence in the region had begun to take root already a few years ago by exploiting the importance of Europe's various bilateral relations in Central Asia. One important achievement is to have welcomed Uzbekistan in 2021 into the EU's Generalised Scheme of Preferences (GSP+),[34] stimulating the export of 6,200 types of goods to the Union by exempting them from customs duties. This decision inevitably represented a driver for the development of the aforementioned Trans-Caspian International Transport Route (TITR).[35] A stimulus for new investment flows in the already functioning transport route that starting from the Sino-Kazakh borders runs through Turkmenistan, Azerbaijan, Georgia, Turkey and ends in Europe.

Most recently, Latin America has been targeted as one of the regions of top priority for the Global Gateway. Following the proposal of the New Agenda for relations between the EU and LAC for a stronger partnership, the President of the European Commission Ursula von der Leyen visited Brazil, Argentina, Chile and Mexico in June 2023 and pledged to invest up to €10 billion in Latin America, especially in clean and sustainable infrastructure.[36] €2 billion of investment has been announced to support Brazil's production of green hydrogen and to promote energy efficiency in the country. Even more crucial for European economic security is the establishment of a new partnership between the EU and Argentina on sustainable raw materials supply chains. The deal is consistent with the new European industrial policy stance, which is aimed to increase the resilience and security of the EU critical materials supply

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Support to Sustainable Energy Connectivity in Central Asia (SECCA)", July 2022.

[34] European Commission, "Generalised Scheme of Preferences".

[35] Middle Corridor, "Trans-Caspian International Transport Route", https://middlecorridor.com/en/.

[36] European Commission, Joint Communication To The European Parliament And The Council: A New Agenda for Relations between the EU and Latin America and the Caribbean, 7 June 2023.

chain, as well as foster the EU green and digital transition.[37] The New Agenda sets new guidelines for concluding Memoranda of Understanding on energy and includes mutually beneficial partnerships as envisaged under the EU's new Critical Raw Materials strategy. The cooperation between EU and Latin America under the Global Gateway umbrella will focus on the twin green and digital transitions, given that Latin America and the Caribbean's overall electricity generation mix has the largest share of renewables in the world, amounting to 61% in 2021. Further steps of the Global Gateway's projects in Latin America will be decided at the next EU-CELAC Summit, on 17-18 July 2023, which will establish an EU-LAC Global Gateway Investment Agenda.

The Role of Blended Finance in Infrastructure Investments: The Case of Global Gateway

The role of multilateral banks of development is crucial to Global Gateway. To maximise its financial leverage, the European Commission first aims to strengthen public-private partnerships. Secondly, it wants to set up appropriate de-risking mechanisms, including European guarantees, to attract private investors through the reduced risk profile. Leveraging the 2021-2027 Multiannual Financial Framework, the EU will deploy resources through funding schemes such as Horizon Europe, InvestEU and the European Fund for Sustainable Development (EFSD+), which will provide up to €135 billion to the initiative. This is then complemented by €18 billion in grants from the EU budget, as well as up to €145 billion from the various European development finance institutions. In addition, Global Gateway will be able to rely on the EIB's new financial instrument NDICI - Global Europe, which aims to support

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[37] European Commission, Global Gateway: EU and Argentina step up cooperation on raw materials, 14 June 2023.

the EU's external action with a budget of €79.5 billion for the period 2021-27.[38] In December 2022, the EIB launched the Global Gateway Fund (GGF), aimed at fostering private sector investment in developing countries and allocating 40% of the funds to sustainable infrastructure projects, 40% to supporting the growth of small and medium-sized enterprises in those countries, and 20% to project finance.[39] Moreover, at the end of February 2023, the EIB and the European Commission signed an agreement to mobilise €4 billion in loans and guarantees to finance projects in Latin America, the Caribbean and Africa until 2027.[40] Finally, in April 2023, the EIB and the European Commission concluded a further agreement mobilising €18 billion of additional investment under the Global Gateway.[41] As a result, investments of the financial instrument EIB Global reached a total of €31 billion under the Global Gateway, in line with the target of investing €100 billion by 2027.

EU's Resilience: What is Missing

Funding infrastructure abroad, as previously mentioned, could foster the spread of European standards and values around the world, strengthening the goals of the European industrial policy and the market penetration capacity of companies. Finally, it could make it possible to facilitate the achievement of decarbonisation goals, core principles of the European trade, industrial and infrastructure strategies. These goals are key to achieve the desired EU strategic autonomy and, in turn, economic security and resilience. The ambition to go beyond

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[38] European Commission, *International Partnerships*.

[39] European Investment Bank, *Global Gateway Fund (GGF)*, 16 December 2022.

[40] European Investment Bank, "Global Gateway: EIB and European Commission sing agreement to boost private sector investments in Africa, Caribbean and Pacific countries", 28 February 2023.

[41] European Investment Bank, "Global Gateway: Commission and EIB announce funds worth €18 billion to boost investments in climate action and sustainable economies", 28 April 2023.

simply financing investment on infrastructure is confirmed by the involvement in project management of the High Representative for the Foreign Affairs and Security Policy Josep Borrell, as well as of the commissioners for Neighbourhood and Enlargement, and International Partnerships. Global Gateway is thus bidding to become one of the main instruments of the European Union's external action in the immediate future and one of the cornerstones of its industrial and infrastructure policy. Alongside the proposal for a new EU Net Zero Industry Act, the European Economic Security Strategy, the European Green Deal, the Chips Act, the Critical Raw Materials Act, the Strategic Compass and the RePower EU plan, the European Gateway represents a key building block for the realisation of the economic and geopolitical goals of the Union, as well as for strengthening its competitiveness and resilience in a scenario of increasing tensions. However, important obstacles to effective implementation remain. Firstly, the choice of concrete investment projects will be an occasion for possible discord among European countries that traditionally have different foreign policy interests. There is therefore an urgent need for unified governance of the projects, to pay respect to different European sensitivities and priorities. The EU's Global Gateway seems, moreover, an attempt to catch up with major competing plans such as the Chinese BRI. Nevertheless, new funding is largely needed, therefore not simply reformulating nor shifting already allocated funds. Lastly, the private sector needs to be increasingly involved in local investments.

The global economy is at a crossroads. The market, once the main kingmaker of economic decisions in Western countries, has increasingly started to share its decisional burden with geopolitical factors, driven by governments and their agendas for trade, industrial, and infrastructure priorities. A nexus is strongly emerging, and investment decisions will increasingly be affected by security considerations. This is witnessed by export controls and local content requirements in the high-tech sectors of the US IRA as by the new subsidies aimed at boosting clean tech domestic production required by the EU Net Zero Industry Act. The European economic security strategy goes beyond this, envisaging new export controls and an enhanced foreign direct investment screening mechanism for the EU. To achieve ambitious industrial and climate goals, infrastructure plays an indispensable role: without infrastructure and connectivity, no major industrial goals and green targets could be achieved. This is even more true for the European Union, whose production and trade largely rely on international value chains. If a trading blocs approach to globalisation and trade regionalisation prevails, the European Union is called upon to increase the resilience of its supplies and connectivity network. This is the rationale behind the revision of the TEN-T and TEN-E networks, the EU Critical Raw Materials Act, the EU Net Zero Industry Act, the EU Economic and Security Strategy and the Global Gateway: they all share the goal of increasing security, resilience, and competitiveness *vis-à-vis* other leading economic powers, notably China but also the US. Notwithstanding, the market keeps playing a key role in driving investment decisions: without private investments the resilience of the European economy, the energy transition and the EU global connectivity goals remain an exercise of wishful thinking. Uncertain times require ambitious but also realistic solutions, and international cooperation remains unavoidable to tackle the main global challenges that lie ahead. After all, competition and resilience are the buzzwords of the present, but they are not necessarily at odds with a new global cooperative approach for tomorrow.

3. Enhancing the Resilience of the Trans-European Transport Network (TEN-T)

Herald Ruijters

Transport infrastructure has always been a central element in responding to the challenges Europe faces and in meeting the EU's ambitious goals for the future. Regulation (EU) 1315/2013 on Union guidelines for the development of the trans-European transport network (TEN-T)[1] defines a coherent European multimodal and interoperable network of roads, rail, inland waterways and maritime routes, creating a solid foundation towards building the arteries that are needed for smooth passenger and freight transport flows in Europe.

While transport infrastructure has a long service life – infrastructure built over the next decade will remain in service well into the second half of the century and beyond, climate change is already having an impact on assets and infrastructure, and these impacts are expected to intensify in the future. For example, infrastructure in coastal areas could be affected by sea level rise, heat tolerance for railway tracks needs to account for a projected higher maximum temperature rather than historical values, and so on.

Moreover, transport has been one of the sectors hit hardest by the Covid-19 pandemic, with damage stemming from the huge negative demand shocks following the necessary containment

[1] OJ L 348, 20.12.2013, p. 1.

and mitigation measures. This has given rise to, among others, supply chain disruptions and reduced connectivity across the EU.

Since then, the resilience of the European transport network has been put to the test yet again by the devastating impact of Russia's war of aggression against Ukraine. Russia's war of aggression has redefined the geopolitical landscape, bringing to the surface the EU's vulnerability to unforeseen disruptive events beyond its borders. The war's major impacts on global markets and global food security has highlighted the fact that we cannot view the EU's internal market and the transport network in isolation when it comes to shaping EU policy.

What Has the European Commission Done to Respond to These Challenges?

Given these momentous challenges, the European Commission has turned the increased resilience of the European transport network into a priority, and has developed a number of ambitious initiatives, strategies and policy measures to that effect.

Resilience to climate change impacts

The European Green Deal[2] and its follow-ups – the European Climate Law[3] and the new EU Strategy on adaptation to climate change[4] paved the way for Europe's economy and society to become climate-neutral and climate-resilient by 2050 – both minimising their impact on climate change and adapting to its unavoidable consequences. At the heart of the European Green Deal, the European Climate Law recognised adaptation as a key component of the long-term global response to climate change. It requires Member States and the Union to enhance their

[2] COM(2019)640 final.

([3]) Regulation (EU) 2021/1119, OJ L L 243, 9.7.2021, p. 1-17.

([4]) COM/2021/82 final.

adaptive capacity, strengthen resilience and reduce vulnerability to climate change. The Strategy on adaptation to climate change outlined a long-term vision for the EU to become climate-resilient and fully adapted to the unavoidable impacts of climate change by 2050 in line with the Paris Agreement. The Strategy aims to build a climate-resilient society by improving knowledge of climate impacts and adaptation solutions; by stepping up adaptation planning and climate risk assessments; by accelerating adaptation action; and by helping to strengthen climate resilience globally. The Sustainable and Smart Mobility Strategy[5] translated these European objectives into a policy for the transport sector, setting out a clear path for a 90% reduction (from 1990 levels) in transport-related greenhouse gas (GHG) emissions by 2050 while making transport infrastructure climate-resilient by the same date.

While the TEN-T Regulation of 2013[6] was conceived as a sustainable transport policy from the outset, to meet the increased ambition of the European Green Deal, the European Climate Law and the Sustainable and Smart Mobility Strategy, the Commission proposed in December 2021 to revise the TEN-T Regulation[7]. The proposal reinforces EU standards and requirements necessary to realise a modern, fully-fledged European transport network that, among others, aims to ensure that new infrastructure projects on the network are climate-proof and consistent with environmental objectives. The revised TEN-T Regulation aims to make TEN-T infrastructure more resilient to climate-change impacts by introducing, in Article 46, climate-proofing requirements based on the latest available best practices and guidance.[8] New infrastructure projects under the new TEN-T Regulation are required to be resilient to potential adverse impacts of climate change through a climate vulnerability and risk assessment, including relevant adaptation

(5) COM(2020)789 final.

(6) Regulation (EU) No 1315/2013, OJ L 348, 20.12.2013, p. 1-128.

(7) COM(2021) 812 final.

(8) See Article 46 of COM(2021) 812 final.

measures. Moreover, the revised Regulation aims to ensure that TEN-T infrastructure is maintained in such a way as to provide a high level of service and safety during its lifetime, including by taking into account the maintenance needs and costs in both the planning phase of construction and for upgrades of existing infrastructure. The climate-proofing assessment could incorporate innovative resilient materials as part of the measures foreseen. The proposal for a revision is currently at the stage of negotiations between the Council of Ministers and the European Parliament, with adoption of the final text expected at the end of 2023.

The improvement of transport infrastructure resilience in the EU also covers new requirements for infrastructure financing. The Connecting Europe Facility (CEF) for Transport is the funding instrument designed for the purpose of implementing European transport infrastructure policy. It is aimed at supporting investments in building new transport infrastructure in Europe or rehabilitating and upgrading existing infrastructure. Regulation (EU) 2021/1153 establishing the Connecting Europe Facility for the period 2021-27 (the CEF 2 Regulation)[9] included eligibility and award criteria taking into account resilience to the adverse impacts of climate change, whereby the information on climate-proofing of infrastructure should be subject to assessment against the award criteria. Moreover, **Horizon Europe**[10] – the EU's key funding programme for research and innovation**,** is financing several research projects in the field of transport infrastructure resilience.

In spite of such measures, the lack of an overall assessment of the vulnerability of the TEN-T network to the impacts of climate change prevents the Commission from having a solid information basis to assess the potential existing risks posed by climate change, in terms of future investment requirements. Such an assessment would constitute a first step in providing

(9) Regulation (EU) 2021/1153 of 7 July 2021, OJ L 249, 14.7.2021, p. 38-81.

10 https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/horizon-europe_en

a coherent framework to address the challenges posed by climate change impacts on the TEN-T network. That is why the European Commission is planning to conduct a study to identify major climate resilience risks on the TEN-T network, as well as the corresponding adaptation measures and their costs. The study would thus help determine the investments needed to increase the resilience of the TEN-T network to climate-change impacts. The impact of climate change on existing, and ageing, transport infrastructure, will also be accounted for in the study, which will try to identify the measures and investments needed to keep infrastructure operational and maintain its reliability.

To keep freight moving freely and efficiently across the EU at the beginning of the Covid-19 pandemic, in March 2020 the European Commission issued practical advice on the implementation of **"Green Lanes" – border crossings** open to all freight vehicles carrying goods where any checks or health screenings should take no more than 15 minutes. Among others, it included guidance on how to keep freight moving across the EU during the pandemic. Member States were requested to designate, without delay, all the relevant internal border-crossing points on the trans-European transport network (TEN-T) as "green lane" border crossings. In autumn 2020, the Commission proposed to extend the Green Lane approach to ensure that multimodal transport works effectively in areas including rail and waterborne freight and air cargo.[11]

In terms of adapting the infrastructure itself, the proposal for a revision of the TEN-T Regulation provides a greater focus on multimodality and interoperability between modes and transport nodes. The revised TEN-T Regulation creates nine European Transport Corridors (ETCs) of strategic importance for the development of multimodal freight and passenger transport flows, and for the development of interoperable

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[11] EUR Lex, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL AND THE COUNCIL upgrading the transport Green Lanes to keep the economy going during the COVID-19 pandemic resurgence, COM/2020/685 final.

high-quality infrastructure and operational performance. These ETCs will replace the existing Rail Freight Corridors and the current TEN-T Core Network Corridors. The proposal ensures that both sets of corridor instruments are geographically aligned, and further strengthens coordination between them. The integration of the two corridor concepts will help ensure coherence in network development, avoid duplication and increase synergies between infrastructure planning and the operational needs of the network.

Moreover, the proposal promotes and stimulates the deployment of digital tools and new technologies in all modes of transport with a view to improving capacity, efficiency, user-friendliness and security within the whole transport network, including through multimodal digital mobility services. The measures concern, for example, the deployment of traffic management systems in different transport modes and interoperability between freight transport in ports and terminals. The Regulation also promotes security technology, and seeks to protect the network from natural and human-made disasters through digital, cyber-secure solutions.

Responding to the multiple impacts of Russia's war against Ukraine

Given the new geopolitical context following Russia's war of aggression against Ukraine, the European Commission's Communication from 12 May 2022 on the "Solidarity Lanes"[12] identified several major transport infrastructure challenges that the EU and its neighbouring countries need to resolve in order to support Ukraine's economy and economic recovery, enable agricultural and other goods to reach the EU and world markets, and ensure that connectivity with Europe is greatly enhanced for both exports and imports. Chief among these are the different rail gauges used in Ukraine and most of the EU, which significantly hinder rail interoperability, as well as insufficient

[12] COM(2022) 217 final.

transhipment capacity, limited capacity of the Danube ports, which allows them to cover only a small share of total export needs in the face of the Russian blockade of Ukrainian seaports, and limited road freight capacity to replace blocked maritime transport. The Communication demonstrated the importance of interoperability in the transport system, reinforcing the need to increase convergence within the EU network, making it more resilient and strengthening the internal market.

Responding to the challenges identified in the communication, in July 2022 the European Commission modified its TEN-T revision proposal,[13] extending four European Transport Corridors to Ukraine and the Republic of Moldova. By extending these corridors to the territory of Ukraine and Moldova – including the ports of Mariupol and Odesa – the revised proposal will help improve transport connectivity of these two countries to the EU, facilitating economic exchanges and better connections for people and freight traffic. These corridors will also be a key priority in rebuilding the transport infrastructure of Ukraine once the war ends.

The different rail track gauges used in Ukraine compared to most of the EU – a huge obstacle to interoperability – are also addressed in the proposal. The proposal includes measures to build new railway lines and migrate existing railway lines to the European standard track gauge. This also applies to non-standard track gauges within the EU; the difficulties at the Ukraine border have highlighted how this lack of interoperability makes the railway network inside EU territory vulnerable. This is a key measure of the TEN-T revision, because it will contribute to unifying the EU rail system.

In the same vein, Russia's war of aggression has made it imperative to ensure that the European transport infrastructure network has the needed capacity in case of a military conflict. Military mobility depends to a large extent on the availability

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[13] European Commission, Directorate-General for Mobility and Transport, Commission amends TEN-T proposal to reflect impacts on infrastructure of Russia's war of aggression against Ukraine, 27 July 2022.

and quality of the transport infrastructure. Missing links, bottlenecks and insufficient capacity in the infrastructure jeopardises the movement of military forces. The EU therefore needs to develop high-quality infrastructure, capable of allowing short-notice and large-scale movements of military material and troops. To address this challenge and support military mobility, under the Connecting Europe Facility 2021-27 (CEF II), the European Commission is financing projects located on the TEN-T dual-use infrastructure.

Transport infrastructure is vital for the economies of Member States as well as for our armed forces. It is therefore critical to maintain functional transport infrastructure, particularly the infrastructure identified in the Trans-European Transport Network that represents the main arteries of transport throughout Europe and in neighbouring countries. On 11 January 2023, the President of the Commission and the Secretary General of NATO announced the establishment of a dedicated NATO-EU Task Force on the resilience of infrastructure. The Task Force will work on actions of common interest that will contribute to strengthening the resilience of critical infrastructure.

Conclusion

In recent years, several disruptions have significantly challenged the resilience of the Trans-European Transport Network. To address these challenges – ranging from the impacts of climate change to the crippling effects of the Covid-19 pandemic, to the devastating consequences of Russia's war of aggression in Ukraine, the European Commission has introduced ambitious policy measures. It has proposed to revise the main European legislation on transport infrastructure – the TEN-T Regulation – in order to meet the objectives of the European Green Deal[14]

[14] COM(2019)640 final.

and the Sustainable Mobility Strategy[15] by making the TEN-T network greener and more resilient to the impacts of climate change, and providing a greater focus on multimodality and interoperability between modes and nodes of transport. It has adapted its funding tools to the changing circumstances. In an increasingly interconnected and interdependent world, it has aimed to ensure greater connectivity with the EU's neighbours, by extending the TEN-T network to neighbouring countries such as Ukraine and Moldova, and by creating the Solidarity Lanes to facilitate exports from Ukraine via different land routes and EU ports. This increased connectivity between the EU and Ukraine will prepare the ground for the reconstruction of Ukraine after the end of the war and help bring Ukraine closer to the EU. Still more needs to be done – but by providing the right legislative, financing and coordination tools, we have started to create a solid foundation towards making the European transport network more resilient in the coming decades.

[15] COM(2020)789 final.

4. Building Resilience of Critical Infrastructure. The Role of the EIB and the Case for Digital Sector

Gelsomina Vigliotti*

As is well known from the economic literature, innovation is the ultimate driver of economic growth and international competitiveness,[1] and it is a cornerstone of Europe's ability to thrive in a global competitive landscape propelled by cutting-edge technology. The extraordinary growth in the world economy has been achieved by means of economic integration and globalisation of economic activity.[2] Growth is generated by the specialisation of economies according to the principle of comparative advantage. As a result, in a globalised world, national economies have become more and more interdependent. This has been accentuated by the pervasive process of digitalisation, which to a significant extent, relates to the dematerialisation of economic activities.[3] However, recent disruptive events, such as the pandemic and the war in Ukraine, have shown the

* The author wishes to thank Harald Gruber – Head of the Digital Infrastructure Division, Innovation & Competitiveness Department, Project Directorate of the European Investment Bank for his contribution.

[1] P. Aghion and P. Howitt, "The Economics of Growth", MIT Press, 2008.

[2] P. Heimberger, "Does economic globalisation promote economic growth? A meta-analysis", *The World Economy*, vol. 45, no. 6, June 2022, pp. 1649-2031

[3] E. Brynjolfsson and A. McAfee, *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*, New York, WW Norton & Company, 2014.

other side of the coin of globalisation. Excessive dependence of nations or economic regions on products and services from other areas may lead to severe economic costs in the event of economic interchange disruption or undermine the economic structure's resilience. There is a policy concern that Europe has become excessively dependent on other regions, particularly for innovation and digitalisation. This is, for instance, reflected by important investment gaps identified by comparing the EU and other innovative regions of the world, as well as between regions within Europe. The long-standing objective of elevating the EU's average R&D intensity to 3% of GDP remains unattained, although it has increased over the years. Likewise, in digitalisation, Europe is a laggard, especially compared to the main actors in the digital domain, such as Alphabet, Amazon, Apple and Meta. In this global ranking, no European company is in the top 10.[4]

Much remains to be done to redress the situation, while there is also some evidence of progress. The EU hosts many excellent universities, world-leading innovative companies, industrial clusters, and best-in-class telecommunication infrastructures. But Europe cannot continue to depend only on industries where it has been a global leader in the past. It needs to keep evolving, by developing cutting-edge innovative clusters also in the industries and technologies of the future. This pertains in particular to digital technologies that will drive growth in the coming decades.

Recent years have shown that well-established economic and political realities can change rapidly, leaving globally integrated countries suddenly at high economic and social risk. Hence there is a need to balance the globalisation of economic activities with the notion of resilience of individual economies to external shocks to the global political and economic system. As the public bank for Europe, the EIB is deeply involved in

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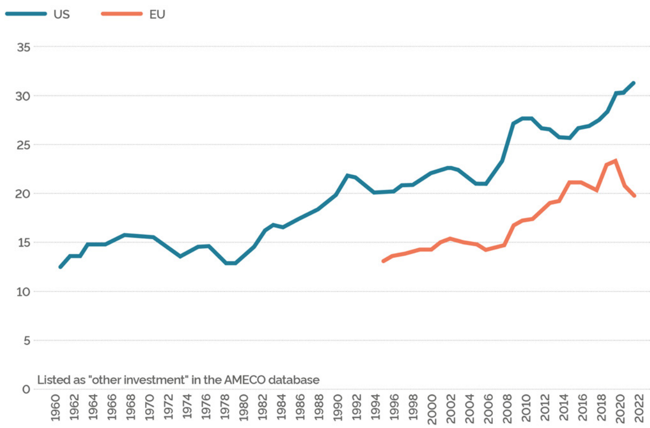
[4] H. Gruber, "Proposals for a digital industrial policy for Europe", *Telecommunications Policy*, vol. 43, no. 2, 2019, pp. 116-27.

supporting the digital transformation of the economy, with a strong focus on areas where the presence of market failures and investment barriers hampers private investment. Important areas of EIB focus include digital infrastructure (very high-capacity fixed and mobile digital networks and space-related infrastructures and services), semiconductors, cybersecurity, digitalisation investments integral to business and public sector R&D and Innovation programs. This paper illustrates how this notion of reliance applies to some specific sectors, in particular digital, and projects where the EIB has long experience and how this is implemented in practice.

Role of Digitalisation

One of the biggest changes in modern economies is the move from largely tangible to largely intangible capital stocks. Intangible capital takes the form of assets that underpin the knowledge or learning economy, such as intellectual property (IP), research, technology and software, and human capital. Unlike tangible assets, investments in intangible assets are typically listed as operational expenditures by firms and are not generally capitalised into book assets. Intangible assets have grown more quickly than tangible assets, and by most measures they currently represent 20% of total investment in 2022 in the EU and 30% of total investment in 2022 in the US, as shown in the figure below.

Fig 4.1 - Intangibles* (R&D, software, databases) as a share of total fixed investment (%)



Source: European Commission AMECO Database

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As far as investment in digitalisation is concerned, increases in an economy's digitalisation are typically accompanied by commensurate increases in intangible investment as a percentage of total investment.[5] Investment in intangibles results in higher growth rates, as proved by a recent study that demonstrates that sectors that have invested more in intangibles have grown at a rate almost one-third higher than other sectors in terms of gross value added.[6]

The 2021 EIB investment survey provides supportive insights on the relationships between investment in ICT and investment in intangibles, as investment in ICT is a prerequisite for

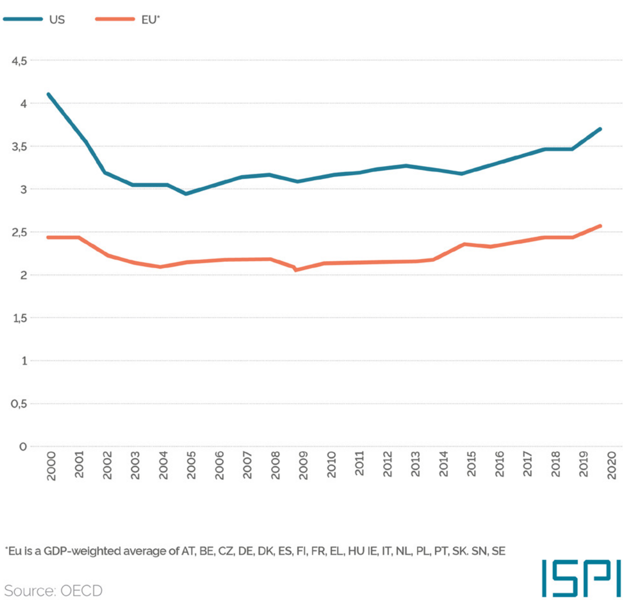
[5] European Central bank (ECB), "The digital economy and the euro area", ECB Economic Bulletin, Issue 8/2020, 2021.

[6] European Commission, "Science, Research and Innovation performance of the EU 2022 report", 4 July 2022.

digitalisation, and hence a prerequisite for more investment in intangibles, such as re-skilling of labour and better management practices.

As illustrated in the figure below, the EU underinvests in ICT compared to other major economies such as the United States and Japan. In 2016-20, the EU invested around 2.5% of GDP in ICT, compared to 3.5% in the United States and about 3% in Japan. This results in an investment gap in digitalisation (relative to the US) of around €130 billion annually. As a result, the ICT sector itself is smaller in the EU (at 4.2% in 2020) than in the US (6.1%) and China (4.9%)[7]. The underinvestment in digitalisation leads to lower performance in terms of economic growth.

Fig. 4.2 - Investment in ICT (hardware, software and databases) as a percent of GDP



[7] Ibid.

The EU not only suffers from underinvestment in digitalisation but is also characterised by substantial variation in digitalisation intensity across regions, sectors and individual firms. On a regional level, digitalisation is, on average, lower in Eastern and Southern Europe. Similarly, at company level, there are notable gaps in both digitalisation and productivity between the EU's innovation leaders and a long tail of low-adoption laggards. The "winner-takes-all" nature of digitalisation may further widen this gap as the champions continue to invest more than the laggards in their digital transformation. Broad-based support for digitalisation across EU countries, regions and firms is therefore essential both to boost innovation-led growth at EU level and ensure that growth is equitable and socially sustainable.

A substantial portion of economic gains from digitalisation is expected to come from the industrial side. Here, the window of opportunity is particularly large for Europe, because its deep industrial base means that artificial intelligence, the Internet of Things and the application of software and services to advanced manufacturing can play a key role in re-industrialising Europe and contributing to innovation and productivity growth throughout the economy. In business, the benefits of digitalisation have become decisive in sustaining competitiveness. Performance improvements, an ever-broadening range of products and services and falling prices have led to mass adoption of digital technologies.

At present, several leading digital technology companies are based in the United States or China. The EU has fallen behind in the digital services transformation race, but it could take up leading positions in new races. This will depend on Europe's ability to seize the opportunities arising from automation, artificial intelligence and other emerging digital technologies. Research and development (R&D) expenditure in the European Union lags that of peer economies and is over-dependent on the automotive sector.

Any attempt to boost its competitiveness should focus on two areas: firstly, catching up technologically with the leaders in all areas of digitalisation, in terms of mastering the necessary technologies; and secondly, fostering rapid adoption of digital technologies throughout all sectors of the economy (and society). Evidence from the EIB Investment Survey[8] shows that European firms currently lag in adopting digital technologies, particularly in the construction sector and the Internet of Things.

Lack of access to finance is also a barrier to adopting digital technologies in the EU, especially for SMEs. An EIB study[9] observes that SMEs suffer more than larger firms from financial constraints in their digital transition. The perception of venture capitalists, banks and other financiers is that 5G-based business models are inherently risky due to their dependence on the timely deployment of the necessary infrastructure in target markets. Information asymmetries further aggravate this perception. For example, for 5th generation (5G) mobile telecommunications, the complexity of such business models and underlying technologies can be challenging to understand for generalist investors, thus limiting their ability to evaluate the risk factors of 5G ventures. The resulting funding gap in EU-based SMEs developing 5G-enabled applications is estimated at €4.6 to 6.6 billion annually compared to the US.

Critical Infrastructure in the Digital Domain

The pandemic offered a preview of what the crisis triggered by the war in Ukraine has since amplified, namely that certain vulnerabilities of the EU, such as excessive dependence on imports of critical goods and services, whose supplies can be disrupted at crucial moments, impose high economic costs.

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[8] European Investment Bank (EIB), *EIB Investment Report 2022/2023. Resilience and renewal in Europe*, 28 February 2023.

[9] European Investment Bank (EIB), EIB InnovFin Advisory, "Accelerating the 5G transition in Europe – How to boost investments in transformative 5G solutions", 2021.

Likewise, geopolitical tension may have drastic consequences for critical infrastructure.

The term "critical infrastructure" denotes systems, assets and networks deemed vital to a society's functioning and economy. These are typically physical or virtual assets that are crucial for the delivery of essential services and the maintenance of public health, safety and security. Examples of critical infrastructure include energy systems (power plants, pipelines and transmission lines), water and wastewater systems (treatment plants, storage facilities and distribution networks), and transportation systems (highways, bridges, railways, ports and airports). The critical infrastructure for digital infrastructure concerns the whole broadband telecommunications system (e.g., fibre networks, transmission towers, data storage centres, etc.).

The Bank has supported infrastructure resilience measures in more than 140 civil infrastructure projects over the past four years. The EU's internal Security Agenda has evolved quickly over the past few years, tapping into the global technology industry, and focusing, among other things, on civilian protection and strengthening resilience in areas such as telecommunication networks and security measures designed to protect public and energy infrastructures against terrorist or bio-threats. In the transport sector, projects include security measures at passenger transport infrastructure, security fencing and sophisticated scanning equipment in ports, as well as access infrastructure and security equipment for border and customs facilities. In the energy sector, fencing and security measures are required for all power plants, including high-security measures for nuclear and hydropower projects.

Digital infrastructure is one area with significant regional differences in investment. The 2022 European Innovation Scoreboard[10] shows that the average share of enterprises with fast broadband access is still only 52% in the EU. While the highest

[10] European Commission, Directorate-General for Research and Innovation, "European innovation scoreboard 2022", Report, 14 September 2022.

percentages are observed in Denmark, Sweden, Portugal and Spain, with at least 70% of enterprises having fast broadband access, ten EU countries still have percentages at 40% or less.

Higher speed and higher capacity digital networks enable new innovative applications and services across various sectors. Very high capacity (VHC) fixed telecommunications networks are the backbone of digital infrastructure, and Europe needs to sustain its upgrade from slower legacy networks, especially outside urban areas. Today around one-third of EU households subscribe to ultrafast broadband of at least 100 Mbps, with considerable variation across Member States. Fibre optic networks account for only around one-quarter of the "last mile" market, which connects the VHC network to households and businesses, a notably lower share than frontrunners such as South Korea.

Regarding mobile networks, most European countries now have high 4th generation coverage in both urban and rural areas (except for some low-population regions in Central and Eastern Europe). In contrast, the rollout of 5G networks is still in the early stages. Only around 2.5% of mobile networks in Europe are 5G, compared with 15% in the US and 30% in China, both of which are accelerating their deployment.[11] Technological first-mover advantages imply that countries that take the lead in rolling out 5G are also more likely to retain technological leadership, including in downstream innovation that depends on 5G infrastructure.

Recognising the importance of modern digital infrastructure for innovation and economic competitiveness and resilience, the EIB has average annual lending volumes of around €2.5 billion for digital infrastructure. The EIB thus has more exposure to the digital economy sector than any other international financial institution.

[11] "Europe's digital targets are bold, but delivery falls short", *Financial Times*, 13 December 2021.

Along with the increase in data traffic, demand for data storage is increasing at a high rate. For the purposes of data security and integrity, the jurisdiction in which the data centre is located plays a crucial role. The data centre market is evolving rapidly as firms increasingly outsource their in-house capacity to cloud providers. To alleviate companies' concerns regarding data security, such outsourced data centres must comply with very stringent data security standards. One of Europe's policy concerns is that its leading cloud data centre providers – the so-called hyper-scalers, namely Google, Amazon and Microsoft – are all from the US. For instance, an issue of sovereignty may emerge if US Courts mandate that these companies must provide access to data physically stored in Europe, should they need it. This has induced the European Commission to stimulate the emergence of large European-based data handling infrastructure such as Gaia-X. Its stated aim is to link different elements via open interfaces and standards to connect data and make them available to a broad audience. Gaia-X also reportedly seeks to enable the creation of different types of innovation platforms.

Data Security

The rapid digital transition of our economies and consequent surge in data volumes gives rise to an increasing need for trust and security. Lack of existing cybersecurity infrastructure and technologies risks being the Achilles' heel of digitalisation in Europe. Successful cyberattacks across a wide range of geographies and sectors demonstrate the vulnerability of digital assets and undoubtedly justify the trend for more investment in cybersecurity.

The cybersecurity sector has been recognised as strategically important for the EU, especially in the current climate of rising geopolitical tensions.[12] New security challenges have arisen,

[12] European Union Agency for Cybersecurity (ENISA), "ENISA Threat

and Europe is confronted with a rapidly evolving environment where disruptive emerging technologies and the pervasiveness of information, such as artificial intelligence (AI), are fundamentally changing security threats. These developments have resulted in a rising profile for security and defence matters on the EU agenda. In particular, cybersecurity is of the utmost importance to protect our ever-growing digital economy. Sovereignty in this domain is a must and a prerequisite for resilience.

Furthermore, the background of EU policy includes several instruments, such as the NIS Directive (Directive on the security of network and information systems from 2016), which is the first piece of EU-wide legislation on cybersecurity that provides legal measures to boost the overall level of cybersecurity in the EU; the EU Cybersecurity Act, forming part of the Cybersecurity Package (adopted by the Commission in 2017) and the EU Cybersecurity Strategy (May 2020), aimed at achieving "a stronger industrial and technological presence in strategic sectors, including artificial intelligence, cybersecurity, supercomputing and cloud", and "increased cyber resilience".

The European Commission recognises that making cybersecurity a mainstream feature is key to enabling more resilient and sustainable development. The European Commission is also implementing the European Union's 5G toolbox – which provides a model for ensuring supplier diversity and mitigating the dangers of high-risk vendors – in all its external funding, both directly and via international financial institutions. The Bank asks its promoters to apply best practices to ensure the security of digital infrastructure and supply chains, in line with the 5G toolbox recommendations.

In terms of the market, the EU's cybersecurity sector has seen even more vigorous growth than its international counterparts in recent years, and yet the market is still primarily dominated by US companies. The sector is expected to grow consistently

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Landscape 2022", 3 November 2022.

in the years ahead. However, cybersecurity companies in the EU face multiple challenges when trying to grow, scale up and expand their businesses. More specifically, the cybersecurity sector in the EU is characterised by the following:

- The European market is fragmented, representing multiple and different regional and national markets rather than one single integrated market. This results in companies focusing mainly on their regional markets and customers and not expanding, thus hampering their growth potential.
- Lower levels of public spending compared to non-EU peers like the US or Israel. However, the current Multiannual Financial Framework (MFF) 2021-27 allocates significantly more resources to cybersecurity than the previous one (namely through the new Digital Europe Programme, the Horizon Europe Programme and the Recovery and Resilience Facility).
- Different cultural approaches: American investors tend to have a more risk-taking mentality and invest in cybersecurity even without fully understanding the sector, whereas European investors tend to invest only if they adequately know the sector they are investing in. Since cybersecurity is a young and technical industry, few investors invest in it.

This results in fewer and smaller specialised investment funds: VC funds in Europe are, on average, three times smaller than in the US. This reduces not only the number of companies that can be supported with equity financing but also limits the type of companies that can access this type of financing.

The EIB finances security investments in the digital domain, mainly consisting of components of relatively large digitalisation projects and programmes to strengthen the resilience of critical infrastructures and IT systems (telecom, energy, transport, financial and healthcare) against cyber-attacks, as well as other sectors making increasing use of digital, such as manufacturing, financial and healthcare. Investments comprise not only the development of cybersecurity technologies but also the purchase of cybersecurity equipment and external services.

Alternatively, the EIB supports projects dedicated to developing technologies relevant to cybersecurity, often promoted by smaller companies. Those providers can be active in various technologies, such as biometric data capture, advanced encryption and data privacy, artificial intelligence and machine learning, fraud detection and prevention, and blockchain, thus enabling trust in transactions. Under its Strategic European Security Initiative (SESI) commitment, the Bank financed cybersecurity projects to over €250 million, split between more than 30 projects. The EIF is also actively investing in funds that support cybersecurity technologies: approximately €60 million have been invested in two specialised funds, and some generalist VC funds supported by the European Investment Fund (EIF) also invest also in the cybersecurity domain.

Semiconductor Chips as the Key Input for Digitalisation

Semiconductors are the vital components that enable the digital transformation of life and society and are a strategic link in any industrial chain. Due to the enabling effect of digital technologies in the decarbonisation of the economy, semiconductors will also help to shape the green transition. Moreover, a large share of the value created by the industry goes directly to consumers, who can continually get devices and systems that are smaller, more powerful and richer in features. The semiconductor industry is a truly global market, with typical semiconductor companies being multinational enterprises with production units worldwide. For European policymakers, it is worrying that Europe has seen a steady erosion of its worldwide share of chip production, which now stands at 8% of global output.

On 15 September 2021, during the EU's annual "State of the Union" speech, European Commission President Ursula von der Leyen announced the intention to pass a European Chips Act[13] to "create a state-of-the-art European chip ecosystem, including production that ensures our security of supply [in light of the recent global chip shortage] and will develop new markets for ground-breaking European tech", a matter not only of competitiveness but also of technological sovereignty. The new European Chips Act is in line with the recent closer focus of EU policies on semiconductors, such as the objective of the 2021 Digital Compass to increase production of cutting-edge and sustainable semiconductors in Europe, including processors, to at least 20% of world production in value by 2030. In April 2023, the Council and the European Parliament reached a provisional political agreement on the regulation to strengthen Europe's semiconductor ecosystem, thereby financially endorsing the Chips Act.

The Chips Act is making substantial public financing resources available. The Digital Europe Programme has set a new semiconductor target, which will support capacity-building in the chip-sector, and the Horizon Europe research framework has assigned a total of €3.3 billion of funding for the "Chips for Europe Initiative", which is expected to mobilise a further €43 billion in public and private investments. The financing solution was found within the limits of the existing inter-institutional agreement on the Multiannual Financial Framework and comes on top of resources already allocated to similar objectives within the MFF and through the digital strand of the Recovery and Resilience Facility.

The EIB has traditionally supported the semiconductor industry, which it considers strategic for the EU. As a contribution to the EU's strategic autonomy and its Digital Agenda, the EIB stands ready to support the sector even further. The semiconductor sector typically features high capital intensity, high risks and technical and managerial complexity, as well as longer timeframes in securing return on investment.

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[13] European Commission, "European Chips Act".

The EIB contributes to accelerating investments in capital-intensive testing, pilot and advanced production capabilities to reduce the Union's dependency on chips.

Conclusion

Europe's digital sovereignty and global competitiveness depend on a strong digital sector and widespread digitalisation of the economy. Policy support for the digital transition is well justified by empirical research suggesting that digitalisation is an important enabler of innovation, international competitiveness and productivity growth. However, there is evidence that digitalisation-enabled innovation is associated with market failures that hamper private investment to levels below what would be socially optimal. This becomes particularly relevant in situations of international trade and policy relations disruption. To ensure that digital infrastructure and services are resilient to shocks, it is of the utmost importance that Europe maintains a significant presence in state-of-the-art activities in the digital sector. Considering the recognised importance of digitalisation (alongside R&D) as an enabler of innovation and productivity growth, the EU's relatively low level of investment in ICT compared with other leading economies is an ongoing cause for concern and requires policy action. Policymakers are aware of this and are taking decisive action. As the policy bank of the European Union, the EIB's lending activities for the digital sector fully support the European Commission's policy priorities inside and outside the European Union. The Bank signs finance contracts worth more than €2.5 billion annually for digital connectivity projects. This makes the EIB the financial institution with the largest capacity worldwide to intervene in financing digital projects.

5. Infrastructure: The Next German Challenge?

Thomas Puls

Closed bridges, outdated railway control centres, missing high-voltage power lines between north and south, as well as dead zones in the mobile network. In recent years, bad news about the German infrastructure has been piling up. Especially in western Germany, many infrastructures are aging rapidly. In the late 1960s and 1970s, infrastructure in the western federal states was massively expanded. This is especially true of the *Autobahn* network, which forms the backbone of the transport infrastructure. But electricity and communication networks were also brought up to an exemplary standard for the time. Afterwards, investments in infrastructure in the west of the republic were significantly reduced, while strain on the existing networks continued to increase. After the turn of the millennium, investments in infrastructure were cut nationwide. For about a decade and a half, Germany lived off its substance, especially in the area of transport infrastructure, and struggled to adapt electricity and communication networks to the demands of decentralised energy generation and mobile data use. In fact, policymakers have begun to respond to these challenges. Since around 2015, the budgets for infrastructure investments have been increasing again and new positions are also being created for the engineers needed for implementation. Unfortunately, it has also become apparent that the problems now go far beyond a lack of funds from public budgets. German planning and approval procedures are proving to be particularly obstructive. These approval procedures have largely mutated into a right to prevent construction. The situation is exacerbated by a clear shortage of skilled workers. This extends from the planning and approving authorities to the construction industry and the agencies in charge of grid operation.

Infrastructure has thus become a major challenge for Germany and the former locational advantage is increasingly perceived as a problem by companies and the population. To illustrate the magnitude of the challenge, this chapter will first show how much the perception of infrastructure in Germany has changed in just one decade. The situation will then be discussed using the example of transport infrastructure and the factors that are currently massively hindering the overcoming of existing challenges will be presented.

How Is the State of German Infrastructure Perceived Today?

The perception of Germany's infrastructure – and especially that of transport infrastructure – has changed significantly since the turn of the millennium. For decades, the German public and domestic companies perceived infrastructure as a strength of Germany as a business location. This assessment has changed quite markedly over the last decade, with various data sets signalling that the assessment of Germany's infrastructure at home is now significantly worse than it is abroad.

The international perspective is reflected in the latest edition of the World Bank's Logistic Performance Index.[1] Here, German infrastructure achieved the fourth-best score worldwide. This is undoubtedly a very positive assessment, but also significantly worse than in previous editions of the index, in which Germany was ranked first in the infrastructure sub-indicator.

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[1] World Bank, *Logistic Performance Index (LPI) – Global Ranking 2023*, May 2023.

It should also be noted that this rather positive international assessment was received with some surprise in Germany because the domestic perception of infrastructure is significantly worse and is increasingly deteriorating. This is documented by a series of surveys conducted by the German Economic Institute in the years 2013, 2018, and 2022. The rotation was based on legislative periods at federal level. Approximately 1,800 companies in Germany took part in the current survey.[2] Even though these surveys cannot be regarded as a panel survey due to the different groups of participants, the results reveal clear and quite worrying trends in the assessment of German infrastructure by companies operating in Germany.

In all three survey rounds, respondents were asked whether their current business operations were regularly impaired by infrastructure deficiencies. The response options were "No impairment", "Slight impairment" and "Significant impairment". As can be seen in Figure 5.1, the survey results have changed significantly over the three rounds of questioning. The proportion of respondents who were not affected at all fell from 41.2% to 20.7%, i.e. halved in only 9 years. This contrasts with a drastic increase in the cohort of significantly impaired companies. In 2013, only 11% of responding companies used this response option. In 2022, the share was already over 27%. In both cases, there is a stable trend across all survey rounds, although the deterioration in results has accelerated in recent years. This finding is in line with developments observed in the area of transport infrastructure in particular. Examples of this are the numerous disruptions in rail freight traffic during the last 18 months and the closure of the *Rahmede Autobahn* bridge due to acute danger of collapse.

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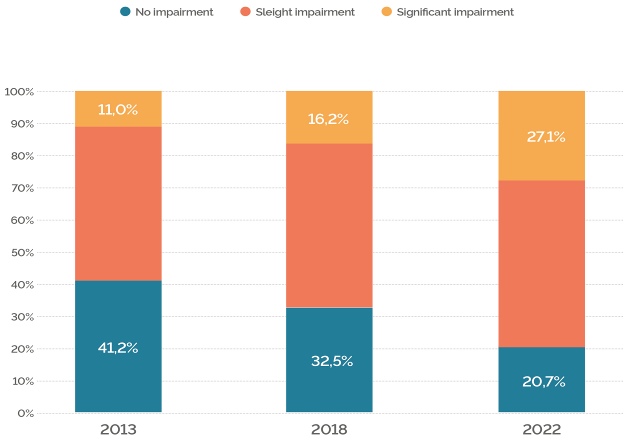
[2] T. Puls and E. Schmitz, "Wie stark beeinträchtigen Infrastrukturprobleme die Unternehmen in Deutschland?", *IW-Trends*, vol. 49, no. 4, 2022, pp. 3-21.

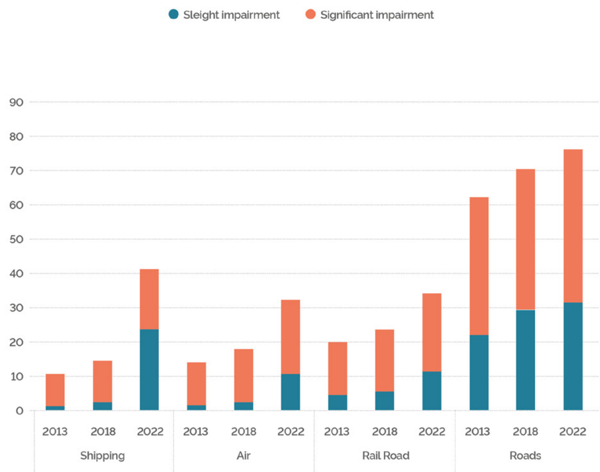
Fig. 5.1 - German infrastructure is increasingly perceived as a problem



Source:
Puls/Schmitz, 2022

In a downstream question, those companies that described themselves as slightly or significantly impaired were asked to specify which sub-areas of the infrastructure were responsible for their problems. Multiple answers were possible so that a hierarchy of impairments can be derived from the downstream question. The results concerning transport infrastructure are summarised in Figure 5.2.

Fig. 5.2 - Increasing problems with the transport infrastructure



Source:
Puls/Schmitz, 2022

Road infrastructure took the top spot. In 2013, 64% of the companies generally affected by infrastructure deficiencies located at least part of their problems in this area. By 2022, this figure had risen to 78%. It is noteworthy here that the share of those significantly affected has risen much more sharply than the share of those slightly affected. The same finding applies to the assessment of rail transport. Here too, the data show a continuous deterioration, although it should be noted that the proportion of companies surveyed that rely on rail infrastructure in their business operations is significantly smaller than the proportion that uses road. All in all, the data show a clear shift in the assessment of infrastructure in Germany, and measured against the fact that infrastructure is a rather inert variable, the changes in less than a decade are worrying. Germany is undoubtedly facing a challenge here.

Trends in German Infrastructure

How could this visible deterioration in the perception of Germany's transport infrastructure have come about? As with any major problem, several unpleasant trends come together. These include, for example:

- the age of existing transport infrastructure;
- a volume of traffic far above what the infrastructure was planned for;
- neglected investments after the turn of the millennium.

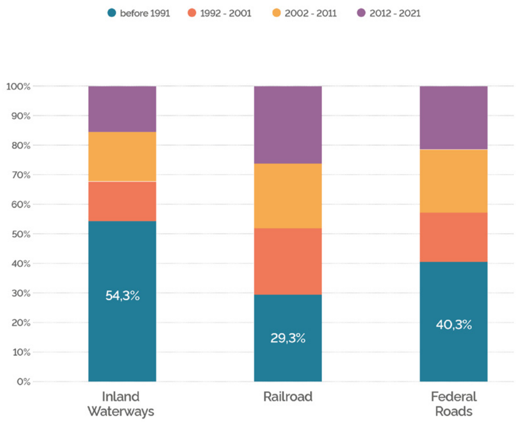
If one looks at the age structure of existing transport infrastructure in Germany based on the years of investment, it becomes apparent that considerable parts of the existing networks were built before reunification in 1990. This applies in particular to the inland waterway network, where quite a few engineering structures actually date back to the pre-war period. But also in the case of federal roads, more than 40% of the capital stock dates from before 1990.[3]

The situation is exacerbated by the fact that the newer sections of the network are heavily concentrated in the territory of the former GDR, while older sections dominate in the west. Thus, about half of the total bridge deck area on federal roads was built between 1960 and 1985 in the old federal states.[4] These bridges are now at an age where, even under favourable conditions, basic renovation would be due. However, the conditions are anything but favourable.

[3] Bundesministerium für Digitales und Verkehr (BMDV), "Verkehr in Zahlen", 2023, p. 37.

[4] Bundesanstalt für Straßenwesen (BASt), *Brückenstatistik*, May 2023.

FIG. 5.3 - THE AGE STRUCTURE OF TRANSPORT INFRASTRUCTURE IN GERMANY

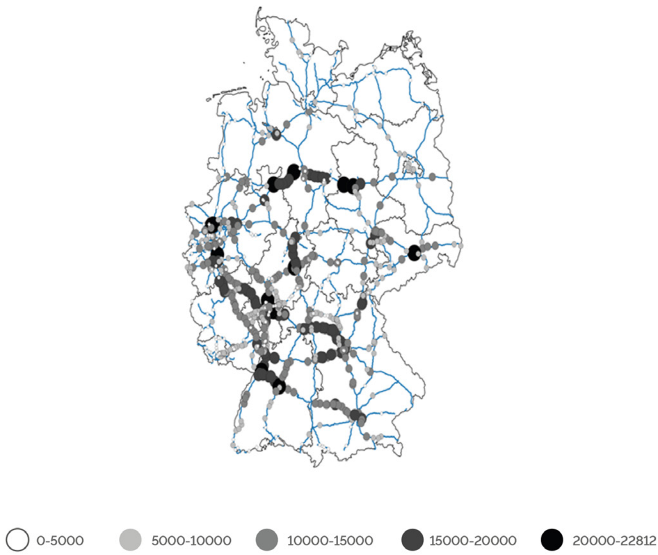


Source:
BMVD, 2023

Thus, the volume of traffic has developed far more dynamically than was imaginable when the west German transport routes were planned. The fall of the Iron Curtain has moved Germany from the periphery to the heart of the European economic area, and with the creation of the Single Market, the federal state of North Rhine-Westphalia in particular has become a European logistics hub through which a large part of Europe's seaport hinterland traffic passes. This has led to an unforeseen increase in strain on West German transport networks, which can be illustrated by lorry traffic. At the height of bridge construction in the late 1960s, about 3,500 trucks per day were counted on a German *Autobahn*; in 2021, more than 8,300 trucks per day were counted.[5] However, this national average is far exceeded on the main freight routes and these almost all converge in North Rhine-Westphalia or, more specifically, at Europe's largest inland port in Duisburg, as can be seen in Figure 5.4.

[5] BMDV (2023), p. 109,

Fig. 5.4[6] - All roads lead to Duisburg. Number of trucks per day on German motorways



Source: BASt, 2019

To make matters worse, in 1986 the permissible total weight of trucks was also increased to 40 tons while it stood at 28 tons in the early 60s. Traffic routes were not designed for this strain and the consequences are becoming particularly visible in the form of bridges in urgent need of renovation, the number of which is growing rapidly. Currently, the Federal Ministry of Transport speaks of 4,600 bridges in need of remedial action, most of which are located on the routes highlighted in Figure 5.4. The situation is no different on the corresponding rail

[6] Bundesanstalt für Straßenwesen (BASt), *Automatische Zählstellen 2019*, May 2023.

connections. These routes are highly congested and in urgent need of remedial actions.

These trends have been foreseeable for a long time. Nevertheless, investments in federal transport routes tended to be scaled down after the turn of the millennium. The federal government's spending priorities lay in other fields. With the closure of the *Leverkusen* Bridge to trucks in 2012, however, the failures became obvious for the first time. As a result, the budgets for investments in federal transport routes were increased again. From 2015 onwards, even significantly more funds were made available. The increase between 2014 and 2020 was almost 50%.[7] But this redirection came rather late on the one hand and was largely negated by accompanying circumstances on the other. Two factors proved to be particularly obstructive. Firstly, construction prices also rose dynamically, so that most of the budget increases could not take effect in the form of additional construction work. For example, prices for bridge construction in August 2022 were approximately 51% higher than in 2015. Secondly, it proved difficult to spend the budget funds provided in a targeted manner. There was a lack of ready-to-build projects, which in turn was primarily due to two bottleneck factors: the agonisingly lengthy planning and approval processes and the closely related lack of qualified personnel. These are the two major challenges that Germany must face in order to mitigate an infrastructure crisis.

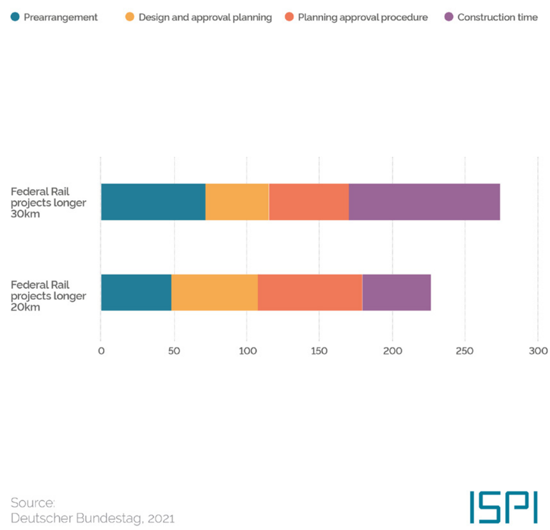
Major Challenges

Available investment funds are an undeniable bottleneck factor in tackling the infrastructure problems in Germany. They must be continuously increased for the foreseeable future. More money, however, is only a necessary but by no means sufficient condition for dealing with the existing problems. Rather, the current situation also requires that the underlying planning and approval processes be radically revised.

[7] Puls and Schmitz (2022).

The fundamental need for reform in existing German planning, approval, and public procurement law can be illustrated quite impressively by the project durations that are common today. Due to manifold rights of appeal and the resulting hedging tendency among project supervisors, the construction of new transport infrastructure in Germany often takes several decades, if it progresses at all. At the federal level, project durations are available for the period from 2009 to 2020, as shown in Figure 5.5. However, it should be noted that these periods are given without possible delays due to actions before the courts.

Fig. 5.5 - New construction of transport infrastructure stalls



According to the pictured information from the Federal Ministry of Transport, the construction of a new federal railway line took an average of about 23 years from the start of preliminary planning to inauguration, of which slightly more than 14 years had to be estimated for the administrative lead time.[8] For the construction of a new *Autobahn*, the administration even needed 15 years for planning and approval. However, according to the ministry, only one evaluable project was completed in the period indicated, so that no average could be formed. In fact, new motorway construction in Germany has largely come to a standstill for years and the network of interurban roads has even shrunk compared to 2010.[9] It was therefore all the more significant that the current federal government set itself the goal of halving the duration of planning and approval procedures in Germany as part of its coalition agreement. Initial progress has also been made through legal adjustments to the procedures for railways and waterways. What is irritating, however, is an ongoing dispute between the government parties as to whether planning should also be accelerated for road projects. Given the available data, this debate is not comprehensible from the author's point of view.

This observable standstill has a lot to do with overly complex procedures, but that is not the only bottleneck. The situation is aggravated by the lack of capacity to process the projects within the responsible authorities. This, in turn, is also due to the lack of engineers in the public service. Their positions were successively reduced during the period of shrinking investment after the year 2000. This was mostly done by not filling posts when an engineer retired. This has resulted in two serious consequences that are now becoming painfully apparent. For example, older engineers predominate among the responsible authorities, and more and more of them are now retiring. On the other hand, there is a lack of engineers with 10 to 15 years of experience who should be leading and driving projects now. For some years now, the public sector has been trying to rebuild its workforce, but in doing so it is confronted with a virtually cleared labour market, as can be seen from the labour market data in Figure 5.6.

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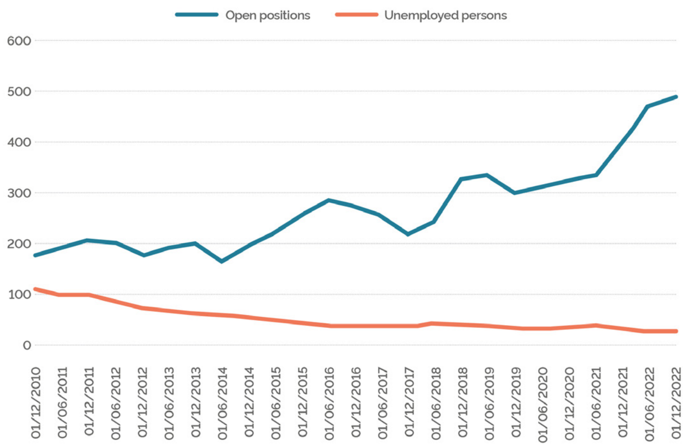
[8] Deutscher Bundestag, Drucksache 19/27459, Berlin, 10 March 2021.

[9] BMDV (2023), p. 109.

Fig. 5.6 - Desperately sought: planners for transport infrastructure and facilities



Source:
IW Fachkräftedatenbank, 2023, www.kofa.de

This shows a constantly growing gap between vacancies for engineers for the planning of transport routes and facilities on the one hand and unemployed people with this career aspiration on the other. It is no longer even theoretically possible to fill the vacancies. This is a circumstance that does not get any better by switching to a less specialised upper group of civil engineers.

Since the public sector's remuneration structure makes it ill-suited to compete with industry for these highly sought-after specialists, many positions in the public authorities currently remain vacant. Thus, it seems very unlikely that existing capacities for planning and approving transport routes can be noticeably expanded in the foreseeable future. Instead, there is much to suggest a further shortage due to retirement. This challenge will remain formative for the future.

Conclusion

The further development of infrastructure is one of the greatest challenges for Germany in the future. After a decade and a half of neglect, Germany has had to realise that a considerable backlog of investments has accumulated in the area of infrastructure. For some years now, attempts have been made to turn the situation around, but new problems have arisen in the process. The decisive factor will be whether the necessary capacities can be made available in the authorities responsible for planning and approval. Here, the shortcomings are already clearly noticeable. There is a lack of brains, which can hardly be recruited on the labour market. The situation is further aggravated by extremely complicated and lengthy procedures that tie up scarce resources unduly. To meet the challenge ahead, Germany needs to make progress in three areas, with tangible success in all three:

1. provide continuously increasing budgets;
2. simplify procedures in such a way that standard, European procedure times can be achieved;
3. improve the recruitment of engineers for the public service.

6. Energy: The Key Enabler for France's Resilience

Marc-Antoine Eyl-Mazzega

France is a country of 67.7 million inhabitants and emits 418 million tonnes of CO2 per year. Until 2022, deep decarbonisation was still a distant political issue as the country benefited from one of Europe's lowest-greenhouse gas emitting electricity sectors, thanks to a share of roughly 75% of nuclear power generation, and to 5% of hydro. The country was a net energy exporter, notably to Germany and Italy. Apart from delays in the construction of a new reactor at the Flamanville Nuclear Power Plant, everything was working perfectly. . President Macron was elected in 2017 with energy and climate playing no role, and his Prime Minister, Edouard Philippe, recognised after leaving office that he had become aware of energy and climate challenges very late. The only notable change, which took place in autumn 2021, was the decision to build new nuclear reactors and to give a new industrial perspective to this technology, in addition to seeking to prolong the existing fleet. The deployment of renewable energy sources was slow and below targets at European Union level, electricity demand was flat, and prices for consumers and industry were in the lower European range. Electric mobility was picking up, still largely driven by commercial fleet orders, and although battery cell gigafactories were finally being developed, as car makers became more aware the strategic importance of batteries, France lagged behind Germany, or even Poland and Hungary, in terms of industrial projects. Lastly, France also embraced hydrogen, but the strategy was targeted and narrow: as the country prioritised electrification, hydrogen uses is still limited to hard to abate sectors and where consumers are near production facilities.

Everything changed in 2022 when France experienced multiple simultaneous crises: a hydro crisis with low water availability in reservoirs, a nuclear generation crisis with 27 out of 56 reactors stopped, in addition to the gas crisis with Russia, and last but not least, limitations in summer for the operations of nuclear plants due to water temperatures in rivers. France stopped electricity exports and managed to secure its supplies as a result of mild weather, large imports from Germany and, to a lesser extent, renewables. The country paid a heavy price for having insufficient gas-fired power generation capacity, despite benefiting from large, well filled gas storage facilities, and for having insufficient renewable capacity, notably in the form of offshore wind – the first wind-farm was commissioned a few months ago. Beyond Russia's aggression, the crises were amplified by severe pressure on supply chains (such as the semi-conductor shortage hitting the car industry) and geo-economic tensions with OECD competitors and China. This then culminated in the Inflation Reduction Act, which was badly received in Paris because its surprise enactment in August 2022 put an immediate stop to several major clean-tech investment projects that had been under discussion, and because other EU Member States had been very wary of France's strategic autonomy agenda until then.

This chapter focuses on the current energy shake-up which has started in France, and will first look into France's current energy production field, decarbonisation strategy and to the resilience of infrastructures, then it will focus on what changes and developments are likely to occur in the wake of the polycrisis.

France Has Strong Energy Assets, But Systemic Challenges Hinder Their Efficacy

On paper, France has everything needed to succeed in decarbonisation, including a robust energy system: a large electrification rate of total energy consuming (25% of end uses), 56 nuclear reactors, large hydro reservoirs and pumped-storage plants, diversified gas imports, large gas storage facilities, two maritime façades, three LNG (Liquefied Natural Gas) import terminals, electricity interconnections with all neighbours (although both gas and electricity interconnection capacities with Spain are very low), and good potential for renewables. In the face of the polycrisis, France's gas sector has proven very resilient and adaptive: LNG imports have doubled, a floating FSRU (Floating Storage and Regasification Unit) has been ordered and will become operational in Le Havre, and France transferred 150 TWh of gas to its neighbours in 2022, which is significant and the equivalent of about 1/3 of its own demand. This was made possible through existing infrastructure, in particular through technical upgrading to allow gas to flow from West to East, besides from East to West. LNG terminals were given the possibility to operate at maximal technical capacity with some environmental limits temporarily lifted. This marked a new positioning for the French gas industry which had faced several setbacks in past years: the refusal to support a Spain-France gas interconnector, a refusal for Engie to sign a long-term contract with a US shale gas supplier, a lack of interest for large, European and international hydrogen infrastructures, or strong limitations to the roll-out of biomethane production with a modest target of 7.6 TWh set for 2030, which is already about to be met.

In electricity, France has discovered the harsh reality of being dependent on a very high share of nuclear generation and having invested too little in renewables, mainly due to political and social opposition, and to the fact that low-carbon electricity was not really needed, nor demanded. Parliamentary debates have clashed over the need to regain "energy independence" just when the country actually survived thanks to interconnections with neighbours. EDF (Électricité de France) Group was forced to make massive losses (with a debt totalling €65 billion) in guaranteeing regulated tariffs to the population, and had to sell 120 TWh in 2022 to competitors at €42 per MWh price (with some variations) even if its own total generation was largely diminished. EDF is now being fully nationalised. A noteworthy development in France is the focus on seeking to expand demand-side flexibility tools, with tenders opened for gigawatt scale interruptibility contracts of large industrial users.

The crises have shed light on what was used to be France's biggest asset, its huge nuclear power generation fleet, and which could now become a systemic challenge. EDF used to produce well over 400 TWh of electricity, this number then decreased in the past years falling to 280 TWh in 2022. While the company maintains it will produce about 330 TWh in 2023, the fact is that production levels will never go back to >400 TWh. The bulk of reactors will soon reach the 40-year threshold, and will need to have their service-life extended. Yet rules are not established by the nuclear safety authority on how this would happen. This means there is a major uncertainty over the future availability of nuclear power in France, and that in any case, the ageing fleet will require massive modernisation investments (*grand carénage*), estimated at €1 billion per reactor, not to mention the newbuilds, with industrial plans for a minimum of six (three pairs of two reactors, which will be rationalised EPR (European Pressurized Reactor) models called EPR-2, not yet built) and up to 14 large reactors. The large reactors will most probably be complemented with small modular reactors, with France possibly becoming a global leader in the deployment of large and effective industrial programme of dozens of SMRs (Small Modular Reactor) in France with a French-made supply chain. This would also entail a robust deployment capability in other markets. Beyond the generation capacity issues, the crises have also brought attention to the transmission and distribution grid challenges: France's grid was built in the 1950s and 1980s and will also need massive modernisation. In fact, by 2050, France will have to replace almost all its generation and transmission infrastructures, in a context where electricity demand is expected to increase by 30% to well over 700 TWh. As the government plans to boost the decarbonisation of the transport segment, the ageing and underinvested rail infrastructure is also coming in the spotlight.

The Crisis Has Been Used to Promote an Industrial Revival

Following the crisis, the policy focus has shifted towards addressing some of the systemic challenges and risks the country is facing, and to incorporate all the value chain aspects that have been neglected for a long time.

- Critical raw materials: the government has supported the creation of Ofremi, the French observatory of critical minerals for industrial value chains, which aims to monitor and assess vulnerabilities of supply chains in the field of defence, energy and technological industries. Ofremi gathers leading public and private research and institutional expertise and is aimed at working in close association with the government and respective industries. It will also be backed up by a public-private investment fund that may take stakes in several segments of critical value chains. France is also pushing for local mining developments, notably of lithium, and preparing the ground for social acceptance of these industries, alongside recycling and refining.
- France has adjusted its hydrogen strategy, with President Macron supporting a Spain-France offshore hydrogen interconnector between Barcelona and Marseilles. It also stood up against against the attempts in Brussels to exclude nuclear-based hydrogen from EU legislation. The reason is clear: France will hardly

have enough renewables to meet electrification needs, so current EU legislation proposals driven by Germany will make it impossible for France to produce enough green hydrogen.

- The French government has not opposed Engie's second attempt at signing up to a small new long-term gas contract with a US LNG supplier.
- A law on accelerating the deployment of renewable energy sources was adopted in March 2023 and promulgated after intense debates.
- RTE, the French electricity transmission system operator, is preparing an unprecedented investment plan, probably consisting in tripling annual grid investments and tools to boost system resilience, digitalisation and storage systems.
- A law on accelerating the construction of nuclear power plants and infrastructure is also being passed through Parliament, with the main aim of reducing permitting time and making it possible to start building works on selected sites for non-core nuclear infrastructure, while waiting for for last permits to be issued. At the same time, work is ongoing to finance this massive industrial expansion.
- The government is also working on helping to decarbonise the 50 highest-emitting industrial sites in the country by providing case-by-case solutions.
- The government is also expected to expand its support for biomethane producers: production costs dropped below natural gas import costs in 2022, and yet the best spots have already been taken so that grid connection costs can increase while production costs see only limited potential for decrease. All in all, there can be significantly higher production, at least 10% of total current demand by 2030.
- The government is keen to continue attracting new clean-tech investments into the country, notably in the

field of battery cells, recycling of raw materials, solar, wind and hydrogen, and to provide support for IPCEI (Important Project of Common European Interest). On clean road mobility, it is expected to push for smaller cars and batteries in legislation to foster the raw material and environmental sustainability of the deployment of EVs.

- All in all, the French government has also largely used the France Relance 2030 programme to boost funding to sectors and projects, with €54 billion available over a 5-year period. Participation in European IPCEI projects has also been supported.

These are significant steps, but not sufficient ones. France will have to undertake major strategic planning ahead of a series of key legislative milestones in 2024, notably the need to update the country's multi-year energy plan (*Programmation pluriannuelle de l'énergie*) and already this year, the EU national climate and energy plan.

Many Systemic Challenges Still Need to Be Overcome

First and foremost, most political elites still take a pick-and-choose approach to renewable energy sources, generally opposing onshore wind (not really embracing offshore wind) and currently seeing a limited role for solar, beyond the low-hanging fruit. As such, the law on accelerating renewables has many shortcomings and has largely been described as a missed opportunity. Elements which could ease the infrastructure footprint of projects, such as developing PV (Photovoltaic) on agricultural land or on forestland close to networks, have been banned.

Secondly, the plans do not yet give a boost to offshore wind, although increasing efforts have been made in this field. France has not succeeded so far in boosting floating offshore wind, which will be key. Moreover, France's renewable ambitions will face systemic obstacles: the bulk of power electronics needed will have to be imported as domestic and European manufacturing is insufficient. Costs have been increasing, alongside the dependence on China. There is a lack of skilled workforce, ships and cable laying vessels, and ports have to be expanded and transformed. France will need to boost offshore wind deployment and let foreign players in, while avoiding a cost race to the bottom where the winner is the lowest bidder, at the expense of local content promotion and resilience in value chains. Moreover, decentralised demand will pick up, which also comes with systemic challenges.

As for nuclear, it remains to be seen if France will have the capabilities to conduct three battles at the same time: nuclear expansion works, newbuilds of large reactors in France and the UK, and the SMRs. Beyond the engineering expertise and the manpower challenge, financing these projects will be very challenging, especially with limitations to state aid when borrowing costs of a newbuild plant can represent over 50% of its total construction costs. Competition with US developers will heat up, yet the market is so big that there should be room for everyone.

For the transmission and distribution grids, challenges are immense too, stemming from the need to have sufficient copper, and to improve recycling, to finding and training sufficient project managers, and to expand the grid charging infrastructure. France will need massive additional flexibility tools on the generation side, notably for longer term storage, and there is little that can realistically be done without gas-fired power plants, except seeking to maximise the pumped storage potential, and to modernise existing hydro reservoirs. Connecting the new solar PV installations will require a massive development of local distribution grids, which is costly and comes with acceptance challenges. There are some recently commissioned cross-regional interconnections, such as with Ireland or the UK, and more are planned with Spain, Ireland

and the UK. A problem is that with inflation, projects are all facing costs increases in the range of 20% to 30%.

Another challenge will be to meet the growing demand for electricity from large energy-intensive industries and their additional hydrogen requirements. Industries will seek to sign up to corporate PPAs (Power Purchase Agreements), not only with renewable projects, but also with nuclear and hydro ones, which is why the permitting battle is essential. Yet the bulk of France's political elites have not yet understood how strategic renewable energy sources are, and that they are not necessarily and solely problems for the grids, being the latter still too expensive and ineffective. These industries will need massive additional electricity in their facilities, and some of them could actually also contribute to the flexibility of the electricity system by designing flexible equipment and installing batteries and solar generation capacity at their facilities.. CCS (Carbon Capture and Storage) is now also being accepted as a solution in a case by case approach.

Finally, France is lacking a wider cross-European view on the future of decarbonisation and resilience infrastructures, notably including North Africa, Ukraine, the Black Sea, Turkey and most importantly, the North Sea. Attention has just started to be paid to the new electricity cables planned to link up the two sides of the Mediterranean. There is no industrial plan for producing all the sustainable aviation fuels that will be needed in the coming years, and which will most likely have to be imported. Efforts to source raw materials are too limited, too slow, probably too late, and insufficiently integrated in a bilateral and European context. Last but not least, transport infrastructure is still conceived and developed as in the older days: more highways and soil artificialisation, and plans for expanding the rail freight transport from 11% of current total freight to 17% are facing systemic obstacles so that only little progress can be expected.

To conclude, France obviously faces many similar challenges to those faced by other European Member States. The difference is perhaps that it must accelerate sharply and faces a major risk for its electricity system. France's strategic autonomy agenda has focused attention on the fact that the energy and digital transformations must happen based on European technologies and in mastering key elements of the value chains to ensure resilience, jobs and cohesion, even if it comes at a slightly higher, immediate upfront cost. Now it is the time to coordinate more actions towards this goal at EU level, and to resolutely implement it.

7. Resilience and Growth in the Italian Road System: The Case of the ASPI Motorways Network

Ennio Cascetta, Flavia Scisciot

The Italian Transport System and the Present and Future Role of Motorways

In spite of the recent and welcome developments of Italy's High Speed Railway lines and major projects on both alpine railway tunnels and urban metro networks, the country's transport system is strongly dependent on the road subsystem, as recently stated by the "Moveo" report published by the Italian Ministry of Infrastructure and Transport. Across the national network as a whole and excluding short trips, road mobility accounts for 73% of travel, compared to 13% for railway. As far as freight transport is concerned, road's share rises to almost 88%, while railway falls to little more than 3%.[1]

[1] Analysis conducted on medium to long trips in terms of trips per kilometer and tonnes per kilometer. Analysis conducted on medium to long trips in terms of trips per kilometer and tonnes per kilometer.

TAB. 7.1- MODAL SPLIT FOR EXTRA-ZONAL TRAVEL AND TRAVEL*KM

Transport Mode	Modal split travel (%)	Modal split travel*km (%)
Train	10,07%	17,31%
Airplane	0,14%	4,11%
Other (bus, car, bike, by walk, etc.)	89,18%	73,22%
Not defined*	0,61%	5,37%
Total	100%	100%

Source: Elaboration by FS Research Centre on Vodafone data
Mobilità e logistica sostenibili: analisi e indirizzi strategici per il futuro (MOVEO, 2022)

ISPI

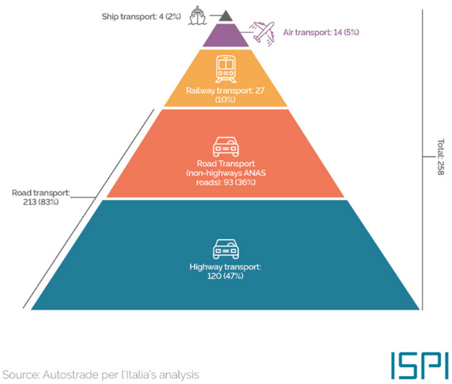
In 2022, Autostrade per l'Italia studied the modal split on the national transport network (SNIT) in the wake of the Covid pandemic. Analyses indicate that passenger mobility demand reached 260 billion passengers per km, 83% of which was travel by road (47% on highways and 36% on other roads managed by ANAS), 10% by rail, 5% by air and 2% by sea.

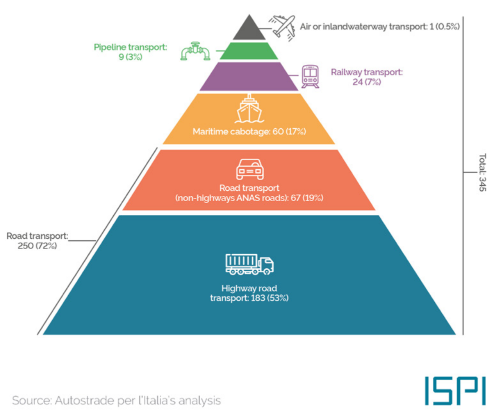
It is worth noting that, although the pandemic crisis hugely impacted public transport, highway traffic of passengers on both regular and tourist buses is estimated to amount to 8 billion passengers * km, which is comparable to the number of passengers * km that use high-speed rail services on a yearly basis.

Similarly, out of a total of 345 billion tonnes per km, 72% of freight transport was sent by road (53% of which on highways and 19% on other roads managed by ANAS), 17% by maritime cabotage, 7% by rail, 3% by pipeline, and less than 1% by air or inland waterways.

This is not a purely Italian phenomenon: in fact, road transport percentages as estimated by Autostrade per l'Italia for the Italian SNIT network show the same situation as identified by the European Commission across the EU as a whole.

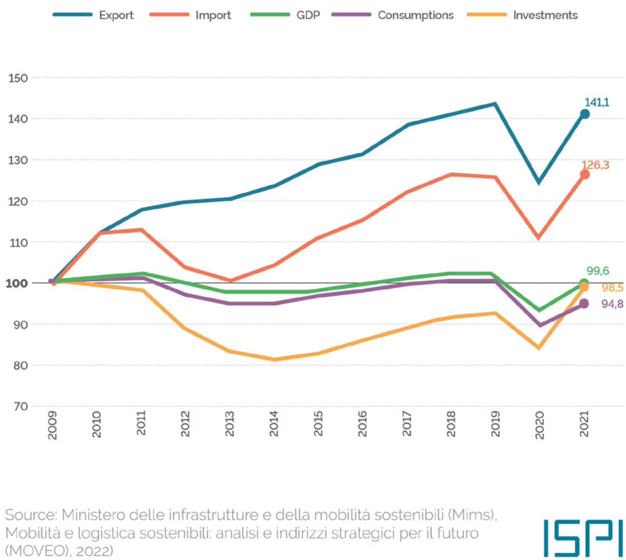
Fig. 7.1 – Passenger and freight mobility pyramids on national network (SNIT) 2021





Last decade's never-completely-overcome economic crisis started a deep transformation of the Italian economy and mobility[2] habits/needs both for passengers and freight. Trend analysis for national trade in goods and services between 2009 and 2021, recalled also in Ministry of Infrastructure and Transport's MOVEO 2022 document, shows a significant boost to internationalisation of the national economy, against a marked contraction of internal macroeconomic fundamentals.

Fig. 7.2 – Trend for 2009-19 Italian macroeconomic variables (values for 2009 = index 100)

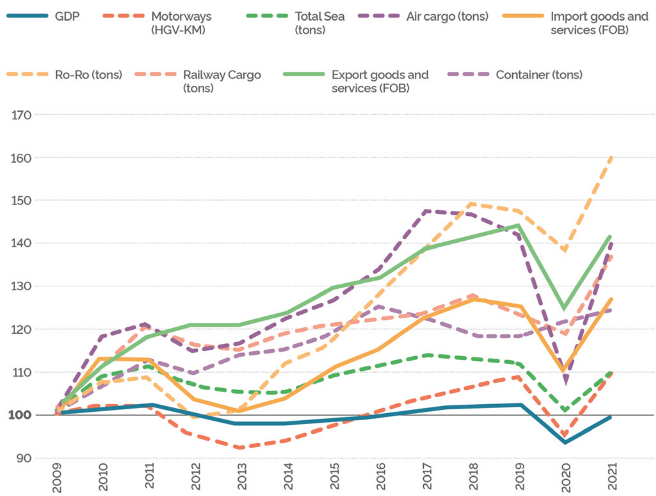


In particular, strong import and export growth caused a significant rise in freight transport, with a much greater increase than GDP, highlighting a clear decoupling between economic and freight transport development, which affected

[2] E. Cascetta, I. Henke, and M. Di Bartolomeo, "La settima rivoluzione dei trasporti. Le innovazioni in corso e i possibili scenari futuri", Ingegneria Ferroviaria 2021.

all transport modes, to differing degrees. Decoupling can also be found during the pandemic crisis, when the drop in demand for freight transport in some market segments was very small (e.g. -4% for railway cargo), or even ran counter to the trend in GDP (e.g. +2.7% of containerised tonnes handled in Italian ports). A similar trend has been reported for passenger mobility.

FIG. 7.3 – TREND FOR 2009-19 ITALIAN TRANSPORT VARIABLES (VALUES FOR 2009 = INDEX 100)



Source: Ministero delle infrastrutture e della mobilità sostenibili (Mims), Mobilità e logistica sostenibili: analisi e indirizzi strategici per il futuro (MOVEO), 2022

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Recent economic and geopolitical events on a global scale have profoundly influenced the evolution of Italy's economic and social scenarios. As pointed out in the abovementioned MIT's analysis, the global Covid-19 pandemic caused a contraction in GDP of 9% compared to the values of 2019. The partial recovery in 2021 resulted in a 6.6% increase in the wealth produced compared to the previous year, for a total amount of 1,677.5 billion euros. At present, following the energy crisis that started in 2021 and the Ukrainian conflict of 2022, GDP growth for 2022 settled at 3.9% (source ISTAT, November 2022), with values similar to those observed before the pandemic.

At this point in time, it is particularly difficult to anticipate the evolution of the Italian transport system[3], as for most othercountries. However, all forecasting exercises show that the role of the motorway system is going to remain central in Italy.

An example is provided by the Transport Cluster's study[4] "*PATHs to 2030: Possibili traiettorie del trasporto su strada per il raggiungimento degli obiettivi del pacchetto climatico EU Fit for 55*" aimed at reconstructing road mobility demand for passengers and freight in 2019, as well as estimating possible business trend "as usual" scenarios for 2030. Within the study two scenarios were defined, one related to the minimum demand growth for road transport (maximum decarbonisation) and the other related to the maximum (minimum decarbonisation), based on reasonable assumptions on trends, current policy developments and their potential evolutions, socio-economic trends and the automotive market development, and what they might produce in terms of variation in road mobility demand (for passengers and freight).

The definition of the two scenarios was based on the "ASI" paradigm:

- Avoid: actions aimed at demand containment and making demand more efficient;
- Shift: policies to promote public transport over individual transport;
- Improve: policies that affect the results that can be achieved through technological upgrading of the sector.

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[3] E. Cascetta, A. Cartenì, V. Marzano, and I. Henke, "A cognitive and participative decision-making model for transportation planning under different uncertainty levels", *Elsevier*, vol. 116, February 2022, pp. 386-98,.

[4] Association of public and private entities recognised by MIUR as a reference for the transport systems and mobility sector. Association of public and private entities recognised by MIUR as a reference for the transport systems and mobility sector.

Results of the study show that in 2030 road mobility demand will vary between -9.1% and +5.1% compared to 2019 when referred to, respectively, a traffic reduction scenario ("MAX" for emission reduction) and a traffic growth scenario ("MIN"). In both scenarios, the ranges of light and heavy vehicles, 2030 versus 2019, are different from each other. In fact, light vehicles may vary between -11.3% and +1.9%, and heavy vehicles between +1.1% and 19.8%, depending on how effective the programmed policies of "avoid", "shift" and "improve" prove to be.

Resilience of the Motorway System

Road infrastructures support increasingly complex global supply chains, and any disruption can spread with ripple effects: reductions in service levels, due to natural events (extreme weather events, natural disasters, etc.) and/or human intervention (i.e. cyber attacks, accidents), can have significant social and economic impacts, given the interdependence of networked systems3. Transport infrastructure managers and operators have a mandate to minimise this risk. It is, therefore, necessary to increase the level of resilience offered, through highly efficient management and operation of networks throughout their life cycle, where resilience is defined as "*the ability of a system exposed to hazards to resist, absorb, accommodate, adapt, transform and recover from the consequences of an event in a timely and efficient manner*." Resilience is a property that characterises both the individual element (e.g., a bridge, a tunnel) and the individual section (e.g., the A1 Milan-Bologna), as well as the entire network (highway, road, etc.), progressively increasing the complexity of the system. The concept of resilience applied to a transport network is closely related to that of vulnerability[5] and

[5] A. Reggiani, P. Nijkamp, and D. Lanzi, "Transport resilience and vulnerability: the role of connectivity", vol. 109, *Elsevier*, 2015.

beyond: a widely cited approach is that of Bruneau,[6] referred to as the 4R,[7] developed to measure resilience to natural disasters:

- Robustness, which for a structure, in accordance with Eurocode 1 Part 1-7, means the ability to withstand events such as fire, explosion, impact or consequences of human error without being damaged disproportionately to the root cause. Thus, it means the ability to withstand a level of stress or demand while continuing to provide an adequate level of functionality.
- Redundancy, which can be achieved by alternative routes or alternative modes of transport.
- Resourcefulness, where being prepared with the right personnel, equipment and materials in the right place at the right time is crucial to ensuring resilience.
- Rapidity, where to reduce loss-of-function time, it is a significant advantage to have teams trained in emergency response.

Resilience Needs for Existing Infrastructures: Priorities and Regeneration Maintenance

The resilience of the overall system, as well as the motorway sub-system, depends on a number of factors, both external and internal to the system itself. These include economic development and its implications on traffic levels, the impact on infrastructure of weather modifications caused by climate change, the maintenance status of infrastructure built more than 50 years ago, as well as disruptive technological changes under way.

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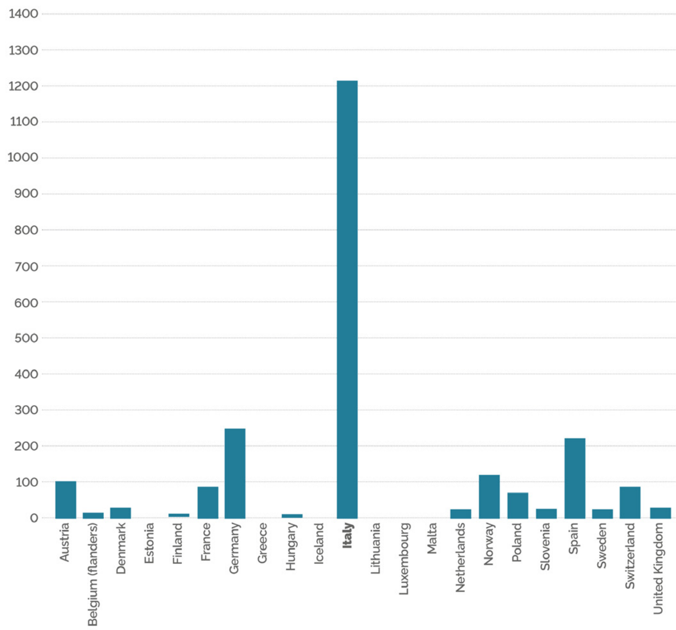
[6] M. Bruneau et al., "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities", *Sage Journal*, 2003, DOI: 10.1193/1.1623497.

[7] Based on these 4R elements, H. Furuta, K. Ishibashi, and K. Nakatsu ("Resilient Restoration Scheduling on Road Network", 13th International Conference on Applications of Statistics and Probability in Civil Engineering, ICASP13 Seoul, South Korea, 26-30 May 2019) proposed an index to quantitatively assess the resilience of a road network.

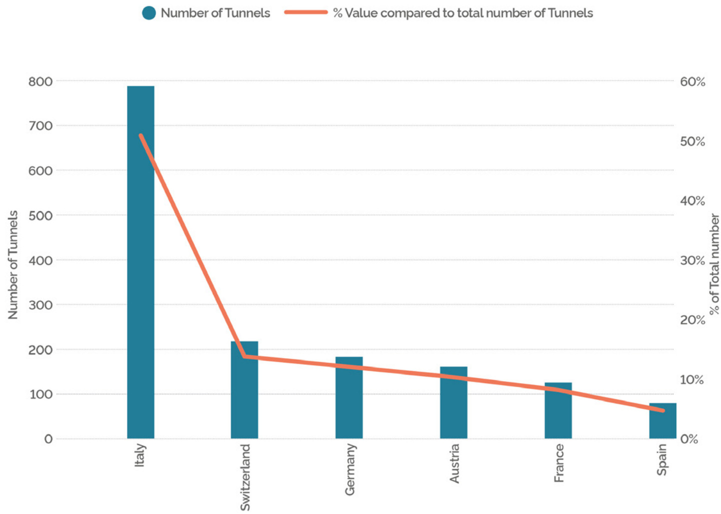
The Italian motorway system has a number of peculiarities compared with all other European systems: it is the most complex in Europe in terms of geography and orography, it has an average of 14% of bridges and viaducts per kilometre of road, against a European average of 2.6%, in addition to having 50% of the continent's tunnels, and the geological and morphological features of the territory it crosses make it particularly susceptible to landslides (2/3 of the landslides surveyed in Europe fall in Italy).

Fig. 7.4 - Total length of bridges at the European level (Highways - TEN-T Network)



Source: 2021 Pan European Road Network Performance Report, CEDR Working Group

Fig. 7.5 - Number of tunnels in Europe
and percentage of total

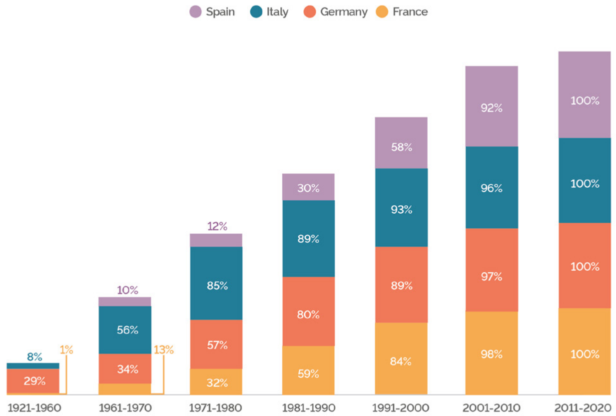


Source: Autostrade per l'Italia's analysis

Italy's highways are also much older than those of all European countries (in Italy more than 50% of the network was built before 1970 compared to 34% in Germany, 13% in France and 10% in Spain).

In the European context, Italian highways are the most used and useful, with an average daily volume of 40,000 vehicles travelling each kilometre of the network compared to 30,000 in France (25% less) and 20,000 in Spain (50% less). Trucks account for a quarter of the total vehicle volumes in Italy, equating to about 10,000 units, versus 4,000 in France and 2,000 in Germany.

FIG. 7.6 - PERIOD OF CONSTRUCTION OF EUROPEAN HIGHWAYS



Source: Autostrade per l'Italia's analysis

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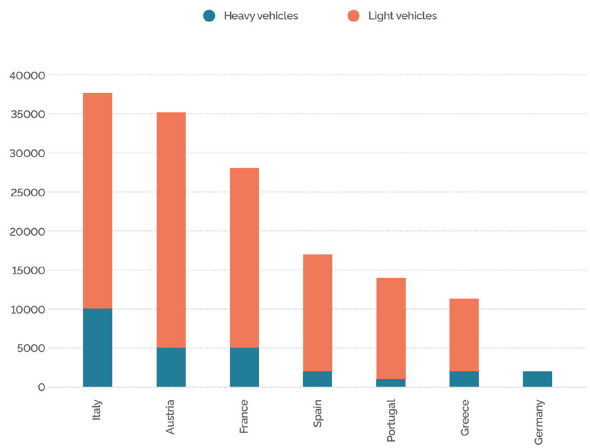
FIG. 7.7 - AVERAGE ANNUAL DAILY TRAFFIC 2021



Source: ASECAP 2021

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Autostrade per l'Italia conducted a study that highlights how, compared to the international picture, Italy's highway infrastructure has more aspects that require attention. As well as having an inherent "structural vulnerability" that is higher than the average in other countries, the Italian network presents a very differentiated gradient of "transport strategicity" offering overall a varied picture of complex situations concentrated in specific areas of the territory.

The vulnerability of the country's highway network was mapped in order to provide a measure of the need for infrastructure modernisation.

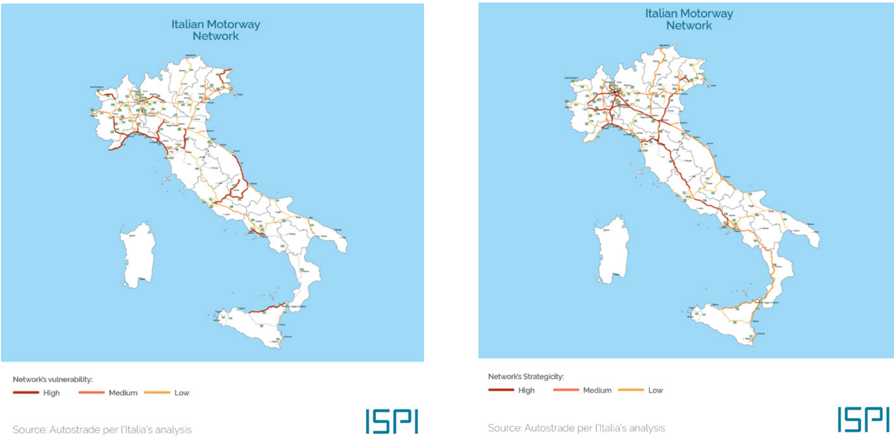
Vulnerability was estimated based on:

- age of first opening of the highway section as a measure of the state of preservation and the incidence of specific time-dated construction technologies (e.g., post-tensioned cable pre-stressing and no waterproofing in the tunnel);
- incidence per km of viaducts and tunnels, as a measure of the complexities of network management and modernisation activities; seismicity;
- orography as a potential accelerator of degradation (e.g., as a result of snow and chloride exposure).

This analysis is particularly significant when compared with the transport strategicity index, i.e. how crucial given section of highway is within the overall network and the potential impact generated by roadworks on it, estimated on the basis of:

- daily average traffic accessibility, expressed in terms of density of interchanges;
- anthropogenic sphere (e.g., access routes into metropolitan areas);
- connectivity (e.g., spatial connections in contexts where infrastructure plays a predominant role in mobility and development).

Fig. 7.8 - Structural vulnerability and transport strategicity

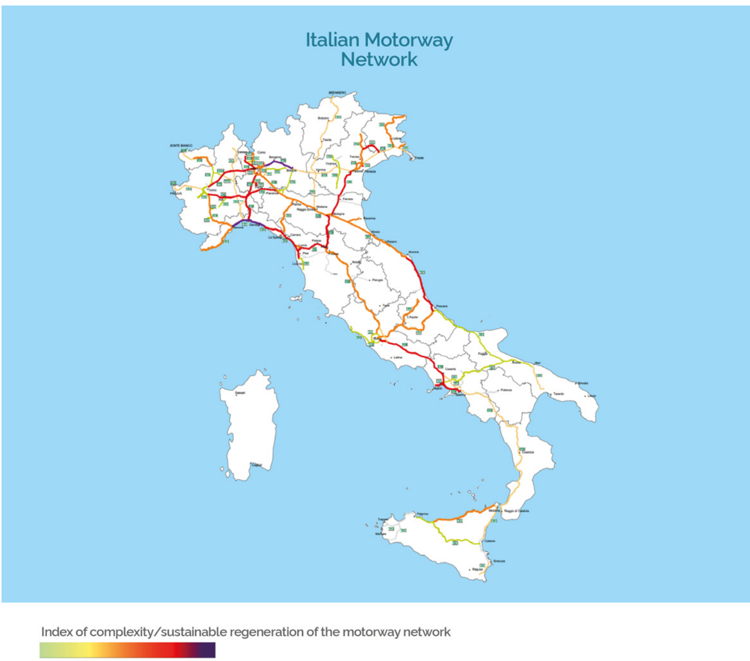


Source: Autostrade per l'Italia's analysis

The two aspects of infrastructure vulnerability and transport strategicity were then evaluated in an integrated way in order to arrive at an integrated index of the "complexity/sustainable regeneration" of individual highways. The index valuation shows considerable differences between concessions and routes, which identifies clear priorities and implies highly differentiated intervention efforts (maintenance, modernisation, and upgrading) and roadway impacts depending on the management complexity of each specific concession (and ultimately also in terms of the appropriate grantor-concessionaire governance to preserve the health and safety status of the assets).The index valuation, depicted in Figure 7.9, shows significant heterogeneity between concessions and sections, which identifies clear priorities and implies highly differentiated intervention efforts (maintenance, modernisation, and upgrading) and roadway impacts depending on the management complexity of each specific concession (and ultimately also in terms of grantor-concessionaire governance appropriate to preserve the health and safety status of assets).

The results obtained are of particular interest, especially for the ASPI network, where the indices for certain sections, such as the Ligurian node, are particularly critical. These sections are in fact conditioned by peculiar and limited geometric characteristics of the routes in operation and by the absence of infrastructural axes that could provide alternative routes for highway traffic during disruptive events, such as the presence of construction sites.

Fig. 7.9 – Index of complexity/sustainable regeneration



Source: Autostrade per l'Italia's analysis

The collapse of the Morandi bridge in Genoa raised an alert on the vulnerability of the whole system. In fact, this tragic event has imposed on the country and the scientific community the need for a profound revision of regulations to define clear rules for the global safety assessment of existing works and the related evaluation of operating conditions. Following the issuance by the Italian Superior Council of Public Works of the "Guidelines for risk classification and management, safety assessment and monitoring of existing bridges"[8] and of the "Guidelines for the classification and risk management, safety assessment and monitoring of existing tunnels"[9] the management model of the worksboth in terms of surveillance and in-depth investigations aimed at determining their state of conservation, has undergone a substantial evolution also in terms of inspection methods and frequencies.

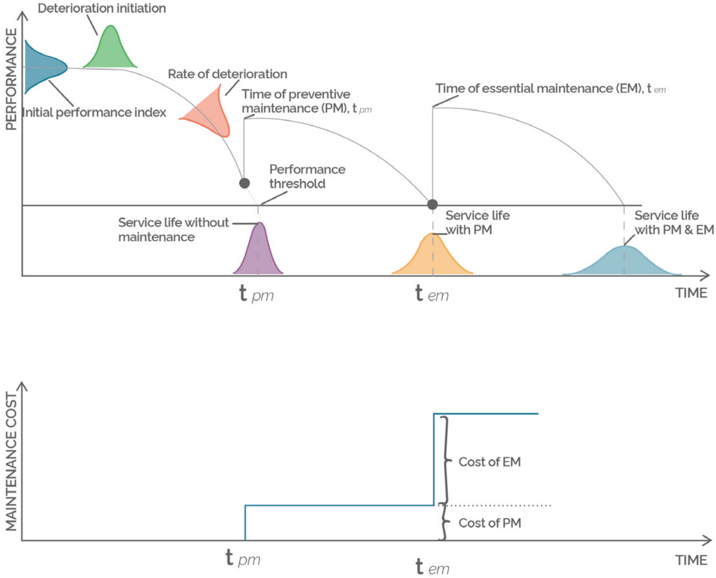
We have entered the implementation phase of regenerative maintenance (Essential Maintenance, EM) interventions. These interventions increase the reliability of the works, adjusting their expected performance, both in terms of useful life on assets that are generally very dated, and in terms of complying with current regulations, which have evolved from those underlying the original project; all this at a higher cost than Preventive Maintenance (PM) interventions. This approach, applicable to all the structural parts of the highway body, is now codified in the recently enacted national regulations for the management of existing infrastructure assets, implying an awareness and a radical transformation of the investment strategy with the need to direct the available financial resources at national level to

[8] Guidelines for risk classification and management, safety assessment and monitoring of existing bridges (hereinafter Bridge GLs) issued by the Higher Council of Public Works, approved by Ministerial Decree No. 578 of 17/12/2020 and subsequently updated by Ministerial Decree No. 204 of 01/07/2022.

[9] Guidelines for risk classification and management, safety assessment and monitoring of existing tunnels (hereinafter Tunnel GLs) issued by the Higher Council of Public Works and approved by Ministerial Decree No. 247 of 01/08/2022.

re-establish the expected performance and reliability of the existing structures. The effects of regenerative interventions on the probabilistic trend of a structure's reliability, which is subject to deterioration over time, and the related costs are depicted in Figure 7.10.[10]

FIG. 7.10 - EFFECTS OF REGENERATIVE INTERVENTIONS ON THE PROBABILISTIC TREND OF RELIABILITY OF A STRUCTURE AS A FUNCTION OF TIME



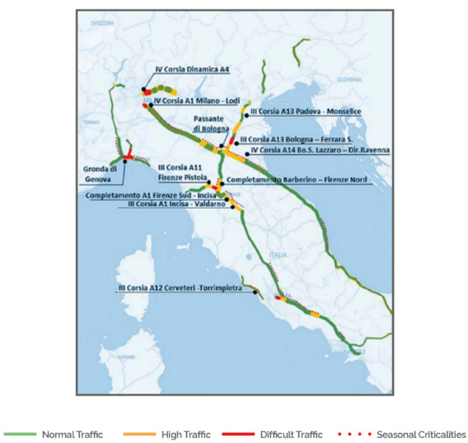
Source: D.M. Frangopol, Y. Dong and S. Sabatino, Bridge life-cycle performance and cost: analysis, prediction, optimisation and decision-making, The Hong Kong Polytechnic University, 2017

[10] D.M. Frangopol, Y. Dong, and S. Sabatino, "Bridge life-cycle performance and cost: analysis, prediction, optimisation and decision-making", *Structure and Infrastructure Engineering*, 2017, DOI: 10.1080/15732479.2016.1267772.

Network Resilience: Investing in New Infrastructures

The need to intervene on existing infrastructure to increase its resilience is not sufficient to ensure that of the highway network as a whole, i.e. the ability to provide adequate service in the event of events that reduce, or, *in extremis*, cancel the service capacity of an individual section. Network resilience therefore depends on the availability of remaining capacity on the individual section and/or the highway network as a whole. When this residual capacity is very low or zero, it is necessary to upgrade the network. Figure 7.11 locates the main upgrades planned by Autostrade per l'Italia and shows an analysis of network performance during an average weekday peak hour. The level of congestion is measured by the traffic flow/maximum outflow capacity ratio and the corresponding Level of Service (colours), while traffic intensity is expressed in terms of annual average daily volumes (gauges). Sections characterised by particularly intense seasonal flows have been highlighted with red hatching.

FIG. 7.11 – MAIN AUTOSTRADE PER L'ITALIA NETWORK UPGRADES IN RELATION TO TRAFFIC CHARACTERISTICS



Source: Autostrade per l'Italia's analysis

It is believed that the positive effects of such a major upgrading plan will be felt system-wide, not only in the highway area, but also along the second-tier roads that will be relieved of some of the traffic due to the increased highway capacity. In order to assess in greater detail the level of saturation, and consequently the priorities for intervention, of the sections on which planning activities for upgrading initiatives (carriageway widenings and road variants) are under way, Autostrade per l'Italia carried out in-depth analyses of traffic characteristics (peak frequencies, seasonality, etc.). The traffic data were related to the capacity of each highway section, which is a function of the geometric characteristics of the route (number of lanes, steep gradients, bends, etc.).

In this analysis, a careful assessment was then made of the specific long-term regenerative maintenance needs, regardless of the upgrades, of the roadworks that would be required, and the resulting reduction in capacity.

In fact, reasoning about what the priorities for upgrading intervention are only by assessing service levels under ordinary conditions is no longer enough. In fact, it must be considered that routes, regardless of enlargements, also need, in a long-term scenario, regenerative maintenance of existing assets, and intervening in advance with upgrades could provide an opportunity to optimise the construction sites required for the two purposes while limiting traffic impacts. The analysis made it possible to make a summary assessment of the performance of the routes under consideration under different scenarios (ordinary traffic scenario, summer scenario, scenario with traffic growth, scenario with roadway reduction or roadway closure and interchange). A comparison between saturation levels and levels of service considered "threshold limit" was also performed.

In relation to the different scenarios, the number of times traffic exceeds the "saturation threshold limit", called the "capacitive fragility index", was highlighted. The capacitive fragility index for the i-th section is calculated as follows:

IFC = (F/Cs)/S.L.S. MIN

where:

IFC = capacitive fragility index

F = flow in equivalent vehicles in the peak hour

Cs = Capacity of the section in vehicle equivalents per hour in scenario s (ordinary circulation or with regenerative maintenance sites)

S.L.S. MIN = MINimum Saturation Limit Threshold. Minimum value of the flow-to-capacity ratio of service level C.

The results of the saturation analysis were given in the current state and highlight the capacitive fragility index in a long-term hypothetical scenario of full deployment of regenerative maintenance sites, which would not currently be possible to implement without brownfield initiatives (enlargement) and greenfield initiatives (for instance Genoa Bypass). For each route, the configuration of the construction site and the resulting capacity limitation depends on the type of work required on the assets.

The analyses described have shown unequivocally that in many cases, in the absence of upgrades, service levels would decline significantly both during the summer periods and even more so in the presence of regenerative maintenance worksites. This situation is even more evident in the scenario of growth in traffic demand. For example on the Ligurian network, where there is already a systematic overshoot of the desirable saturation levels, the new Genoa Bypass is necessary to give an alternative to the urban highway. The new Genoa Bypass will serve to improve the levels of service in ordinary conditions but also to allow, in the long-term, a full deployment of regenerative maintenance on the existing network.

However, the measures used do not fully account for the effects on the highway system and the areas served in the absence of the upgrades. Levels of "capacitive fragility" greater than 2/3 indicate that the affected highway is no longer able to meet traffic demand and thus allow people and businesses to move and produce, causing a real transport "breakdown" in the system. This can cause both individuals and companies to choose alternative options, with very serious impacts on the economic fabric of the local supply chain. In fact, these are impacts capable of transforming the land-use of an area, reducing production and relocating the economy to other production contexts, such as:

- Loss of competitiveness of ports and logistics nodes, to the point of reduction/loss of ship traffic that might prompt shipowners to choose other more accessible Italian or EU ports of call;
- Economic losses for industrial activities;
- Losses of opportunities for the tourism economy of territories (e.g., reduced GDP), negative impacts on consumption patterns and trade (e.g., reduced travel and increased e-commerce purchases);
- Extra costs for commuters and road transport users (e.g., increased travel time);
- Changes in mobility behaviour (e.g., choosing other, more accessible destinations).

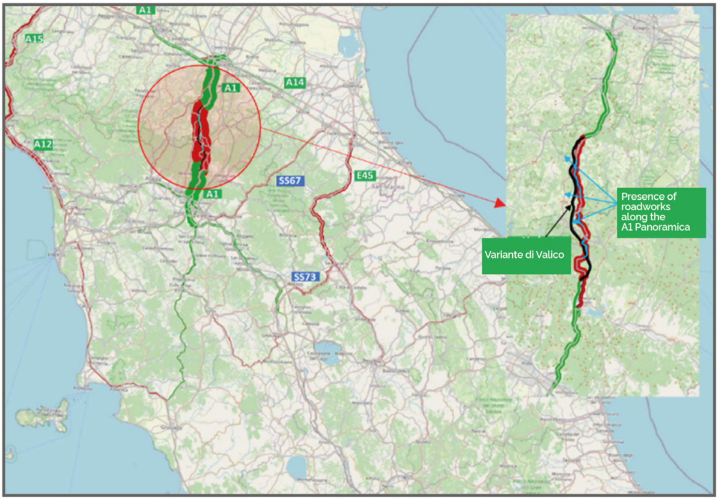
In order to try to better explain what a "system breakdown" might mean in terms of long-term network disruption due to high saturation or accidental events, another analysis was conducted that shows how the resilience of the Italian road network should be considered as a whole (roads and highways) through an assessment of possible "alternative routes" (and their quality) to reach each possible destination. This is because only the presence of viable alternatives would make it possible to adequately "absorb" the impacts caused by unforeseen events and/or maintenance works (e.g. roadway narrowing, detours, disruption of road sections).

To provide examples that clarify the above concepts, some representative scenarios were developed with the help of nationwide traffic simulation models. One of these concerns the section between Bologna and Florence where the two alternatives of the A1 Panoramica and the Variante di Valico have been in place since 2015. The objective of the simulations is to measure, by means of transport indicators, the resilience of the network, in the current configuration (Panoramica and Variante di Valico in operation) and in a hypothetical condition in which the Variante di Valico is not viable.

Figure 7.12 shows in red the routes that would see increases in traffic in the absence of the Variante di Valico (in addition to the A1 Panoramica, the A15 Parma-La Spezia, the E45 north of Arezzo to Cesena, and the SS67 Tosco Romagnola) and in green the routes that would lose traffic (the A1 between Arezzo and Bologna and the A14 and A1 adduction sections to Bologna). The closure of the Variante, together with maintenance works on the A1 Panoramica involving the closure of one carriageway and the diversion of flows onto the opposite carriageway with traffic reduced to one lane in each direction, would produce inevitable longer alternative route choices and more hours spent in traffic. The model leads to an estimate of about 2 years lost each day (by all vehicles) and more than 150 million euros per year lost by the community for the additional time spent in traffic alone.

In the case presented, the simulations refer to standard weather and traffic conditions for an average weekday. Obviously, adverse weather events (such as precipitation, snow, etc.) or accidents would make the picture even more complex, with impacts resulting in a sharp reduction in network resilience and "system breakdown". The flooding in Emilia-Romagna in May 2023 is the most prominent example. It follows an important reflection on the role played by second-tier roads and in particular those adduction roads to the highway system. In fact, it is precisely such roadways that make the network resilient and enable it to respond to temporary service disruptions on the first-tier network. In conclusion, the management and maintenance of the second-tier and highway feeder roadways is also a central element in a systemic approach to improving network resilience.

Fig. 7.12 – Flow diagram showing difference between scenario without Variante di Valico and scenario with Variante di Valico in the event of roadworks along the A1 Panoramica



Daily vehicles

Decrease Increase

Source: Autostrade per l'Italia's analysis

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Conclusion

The chapter addresses the resilience needs of the 3000 km long motorway network managed by ASPI (Autostrade per l'Italia), a "life-line" infrastructural system for Italy. The analysis suggests that the current, and possibly future, climate of "deep uncertainty" characterising base economic, technological and meteorological key variables will not substantially change the central role of the motorway system in Italy. This system, however, has some problems in terms of its resilience, i.e. its capacity to overcome unexpected problems. We distinguish the resilience analysis with respect to existing and new infrastructure.

For existing infrastructure, the most pressing resilience needs derive from the overlapping of several factors: construction age and the need for re-generative maintenance, levels of traffic intensity and levels of territorial risks (hydrogeological and seismic).

Resilience needs for network expansion derive from the level of spare capacity on individual links. Spare capacity helps absorb the traffic impact of accidents and much needed maintenance works. From this respect a capacity fragility index was elaborated to prioritise sections with higher capacity extension needs. A different analysis was carried out to prioritise the new highway sections that are needed to provide alternative routes in the event of link "failures". Examples show that the existing highway network has very different levels of network resilience in different areas. The role played by second-tier roads and in particular those feeder roads to the highway system is also important. Ultimately, the operation and maintenance of highways must be analysed in relation to upgrading and regenerative maintenance needs with a long-term systemic view, always considering the proper functionality of the transport system as a whole, in which networks of different levels must cooperate.

8. Infrastructure and the New Geography of Value Chains in the MENA Region

Mariarosa Lunati, Alin Horj

This chapter will be published in the final version of the Report.

9. Between Europe and Africa, the Role of Morocco as a "Gateway" for Global Trade

Aldo Liga

In recent years, the resilience of global value chains (GVCs) has become increasingly central to the debate on the future of industrial policies in European Union countries. The outbreak of the Covid-19 pandemic and the Russian invasion of Ukraine have significantly contributed to shaping this debate. Member states have begun to look at opportunities for shortening and regionalising value chains through near-shoring practices in "friendly" neighbouring countries of great interest, focusing the spotlight on southern and eastern neighbours. In this context, Morocco appears extremely promising not only for its geographical proximity (it lies only some 14 km from Europe at its closest point) but for its political stability, the monarchy's support for steady industrial development, and the existence of advanced infrastructure plans.

The country's strategic potential is not only interesting in a North-South perspective. Morocco is also of the greatest significance as a "gateway to Africa" for global trade. Rabat has made relations with sub-Saharan countries a key element of its foreign policy, as it is through its "African depth" that Morocco "breathes and shines".[1]

[1] Ministry of Foreign Affairs of Marocco, "M. Nasser Bourita Préside La Cérémonie De Célébration De La Journée De L'Afrique", 25 May 2023.

In order to understand the role of Morocco as a "gateway" to global trade, for both European and African countries, it is therefore useful to examine the country's position in global value chains, international trade, maritime traffic and energy routes, and to consider the political and economic challenges along the road towards greater economic integration into globalisation processes.

The Role of Morocco in Global Value Chains

Over the thirteen years between 2005 and 2018, Morocco's rate of participation in GVCs rose by 7.6% to around 46.7% (a similar rate to that of countries like Mexico, Romania and Russia, and ahead of Turkey, Brazil and India).[2] The integration of Morocco's economy into GVCs faces significant challenges, but also offers important prospects for industrial development, employment opportunities and, more generally, for the resilience of the country's socio-economic fabric. The automotive, aeronautical and phosphate industries are among the best integrated sectors.

With a production capacity of over 700,000 vehicles a year, the automotive industry is the leading sector for Moroccan exports.[3] The country is Africa's leading automotive manufacturer and the second largest supplier to the European Union. The automotive sector created more than 220,000 jobs between 2014 and 2021.[4]

The sector relies on more than 250 international and national suppliers and has developed around the Renault Group's Tangier

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[2] Royaume du Maroc, Ministère de l'Economie et des Finances , Direction des Etudes et des Prévisions Financières, H. Mrani Alaoui, "Positionnement du Maroc dans les chaînes de valeur mondiales", DEPF Policy Brief, no. 28 January 2022.

[3] A. Amachraa and B. Quelin, *Morocco Emergence in Global Value Chains: Four exemplary industries*, Policy Paper, Policy Center for the New South, 20 April 2022.

[4] A. Amachraa, *Driving the Dream: Morocco's Rise in the Global Automotive Industry*, Policy Paper, Policy Center for the New South, 17 May 2023.

plant and that of Stellantis in Kenitra. Local players are poorly represented and mainly active in tier 3-4 and as subcontractors.

Nevertheless, there are signs of a transition in the Moroccan car industry towards a better positioning within more advanced and complex value chains. The latest investments also show that the sector's development trajectory is gradually aligning with the energy transition policies implemented by Rabat in recent years. The country aims to become a leading manufacturer of electric vehicles, and a series of signed agreements seem to support this ambition.[5] For instance, in the last few years, the Stellantis Group's Morocco Technical Center (MTC) has contributed to the development of two new electric vehicles. STMicroelectronics group, which has been active in Morocco for over 20 years, is also involved in supporting this new specialisation. The group's Bouskoura plant has already inaugurated a new electronic chip production line to supply the American manufacturer **Tesla.**[6] Finally, at the end of May, the government announced the signing of a memorandum of understanding with the Chinese battery cell manufacturer Gotion High-Tech to establish the country's first **gigafactory**.[7] This intervenes in a broader context of announced international investments on the exploitation of the country's resources of critical raw materials for the electric vehicle industry.[8]

Aeronautics is another emerging sector in Morocco's integration into GVCs. Many international groups, including EADS, Boeing, Bombardier Aerospace and Safran have relocated manufacturing processes to Morocco. Over 140 aeronautical companies are now operating in the country, employing around

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[5] N. Mzaghrani, "Industrie des voitures électriques au Maroc : Ryad Mezzour fait le point", *Le Matin.ma*, 4 October 2022.

[6] M. Sauers, "Morocco to Begin Manufacturing Electronics for Tesla Automobiles", *Morocco World News*, 29 June 2021.

[7] A. Irwin-Hunt, "Gotion explores Africa's first gigafactory in Morocco", FDI Intelligence, 9 June 2023.

[8] E. Sambène, "Comment le Maroc est en train de devenir un hub mondial de la fabrication des batteries électriques", *le360*, 14 Aprile 2023.

20,000 people. 2022 saw the sector's exports growing by **34.4%** compared to the previous year.[9]

Moving on to phosphates, an essential ingredient for the production of fertilisers, around 70% of the world's known reserves are located in Morocco. Last year, partly thanks to price increases triggered by the conflict in Ukraine, the country saw a 43% increase in the value of its phosphate exports, to a total of $11 billion. Morocco's *Office Chérifien des Phosphates* (OCP) is a world leader in the phosphates sector and is a key instrument of Morocco's Africa policy, thanks to its factories and subsidiaries in 16 African countries. In the medium term, the country aims to improve the sustainability of the fertilizer value chain by using green ammonia.

While the country has made considerable progress in the development of integrated value chains in the automotive and phosphate industries, two other essential export sectors, agri-food and textiles, show signs of vulnerability. The agriculture sector risks being affected by the long-term consequences of climate change and water shortage, as well as by dependence on a limited number of export markets (Moroccan fruits and vegetables are exported mainly to France and Spain). The vulnerability of the textile sector is exacerbated by dependence on single international investors, with the Spanish Inditex group being the dominant player.[10]

The Prospect of New Africa-Europe Energy Corridors

The role of Morocco in the rethinking of supply chains on a regional scale, and in the promotion of near-shoring requires a broad network of sustainable infrastructures. New industrial activities and trade corridors need to be coupled with investments

[9] https://www.oc.gov.ma/sites/default/files/2023-02/IEE%2520D%25C3%25A9cembre%25202022.pdf

[10] Amachraa and Quelin (2022).

in sustainable energy infrastructures: new energy interconnections need to convey electricity from renewable energy sources (solar, wind, or hydro) or green hydrogen (produced using renewable electricity to split water). Sustainable energy is an urgent priority for both the North and the South of the Mediterranean basin due to the more and more evident impact of climate change on the whole region. In the last two years Morocco has been hit by the most severe drought in decades.

The country is an ideal candidate to produce sustainable electricity and green hydrogen, for both domestic use and exports to Europe. Several feasibility studies and projects have been announced in this respect. Although at this stage they have not materialised, the country aims at playing a role in the building of a green-energy backbone between the two continents. Even today, the only existent transcontinental infrastructure consists of two transmission cables connecting Spain to Morocco.

Last year, at COP27 in Sharm-El-Sheik, Morocco signed a memorandum of understanding with France, Germany, Portugal, and Spain to support the integration of green electricity markets. Morocco and Spain are planning the building of a third power interconnector between the two countries, besides a new interconnection between Morocco and Portugal, considered as "key" by the Portuguese government. Another important project is the Xlinks Morocco-UK Power Project, candidate to be the world's longest undersea electric cable. Its feasibility, though, both in technological and economic terms, has not been proved yet.

A Logistic Platform and Trans-Shipment Hub Between the Mediterranean and the Atlantic Ocean

The growing integration of Morocco into GVCs has also been supported by the development of the country's ports. Over the last fifteen years, Morocco has emerged as a key player in Mediterranean logistics and trans-shipment. Since its opening in 2007, the port of Tanger MED has been expanded and now boasts the highest container capacity in the entire Mediterranean basin (over 7 million TEUs per annum). The port now ranks number four in *the World Bank's Global Ranking of Container Ports* for 2022.[11] Thanks to rail links with the Renault plant in Tangier and the Stellantis factory in Kenitra, Tanger MED has been a key driver for the development of the Moroccan automotive industry. The port hosts a free zone and is connected to a network of 180 ports and 70 countries worldwide, including 18 African states. For this reason, it is one of the symbols of Morocco's Africa policy.

The success of Tanger MED has led to plans to build new commercial ports on the country's Mediterranean and Atlantic coasts. These include Nador West Med, which is expected to be completed by the end of 2024. This port's activities will focus on three main areas: container trans-shipment, storage and the processing of bulk goods and energy products. Nador West Med is expected to handle over 25 million tons of hydrocarbons.[12] The authorities hope that Nador will emerge as a supply base for oil tankers transiting the Mediterranean and European national fuel distributors. The opportunities for growth and development which stem from this project will also help to alleviate the tense socio-political conditions and harsh economic situation in *Oriental*, the region where Nador is located. One of the poorest of the entire country, *Oriental* has often seen protests, riots, and subsequent crackdowns by the Moroccan authorities.[13]

In the case of Dakhla Atlantique too, the construction of new port infrastructure acquires great political significance: Dakhla is one of the largest cities in the Western Sahara region, a former Spanish colony and a territory considered "non-self-governing"

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[11] World Bank, *The Container Port Performance Index 2022: A Comparable Assessment of Performance Based on Vessel Time in Port*, Working Paper, OKR Open Knowledge Repository BETA, 18 May 2023.

[12] El Mehdi Berrada, "Maroc : Nador West Med, futur carrefour pétrolier?", *JeuneAfrique*, 16 March 2021.

[13] H. Morayef, "Morocco: Protesters, activists and journalists detained over Rif protests must be released", Amnesty International, 28 November 2017.

by the United Nations. Rabat considers Western Sahara to be an integral part of Morocco and the keystone of its foreign policy, "the prism through which Morocco looks at the world", the "clear and simple criterion by which it measures the sincerity of friendships and the effectiveness of partnerships".[14] The construction of infrastructure in the *provinces du Sud* and their economic development are therefore part of a strategy to "Moroccanise" the region. The new port will have a section dedicated to fishing, the region's main economic activity. It will also be connected to the Tiznit-Dakhla highway, already 80% complete, and therefore to the national transport system.

Morocco plans to position itself as a key actor in African portuality. The public operator Marsa Maroc aims at expanding its presence in Africa, both by obtaining port concession contracts and by participating in large-scale projects on the continent.

In the context of expanding trans-shipment capacity, the *Conseil Economique, Social et Environnemental* recently recommended the creation of a national shipping company for the transport of goods.[15] Morocco is almost entirely dependent on international operators for its maritime traffic, so, in a context of rapidly rising transport costs, a national fleet could contribute to significant economies for imports and exports.

Obstacles to Moroccan Ambitions

Over the last twenty years, Morocco has made dramatic progress in terms of participation in GVCs, infrastructure development and in the development of portuality and trans-shipment capacity. However, structural problems persist, and they could thwart the country's ambitions.

[14] Á. Escalonilla, "Mohamed VI: 'El expediente del Sáhara es el prisma con el que Marruecos mira al mundo'", *Atalayar*, 21 August 2022.

[15] A. Sylla, "Najib Cherfaoui: 'Le Maroc est largement en mesure de lancer une compagnie maritime nationale de fret'", *Challenge*, 24 November 2022.

Morocco's participation in GVCs is still characterised by low added value, and this deters the further development of integrated industrial activities. The country is currently positioned "upstream" in most GVCs, importing foreign goods to produce its own exports but struggling to establish itself in higher added value segments and to improve the involvement of local industries.

Another critical issue stems from a low-skilled workforce, a lack of innovation capacity and low investments in research and development. The newly announced national strategy for industrial development seems to indicate a will to address some of these issues.[16] In addition, the recent launch of the country's first national car manufacturer and recent developments in the electric vehicle industry may, perhaps, be signs of a transition towards more advanced and complex value chains.

The need to make Morocco's industry more sustainable in the short term will probably be another obstacle to the industrial development of the country. Although Morocco is undeniably the "North African leader" in energy transition, Europe's forthcoming implementation of the Carbon Border Adjustment Mechanism (EU CBAM), which imposes import tariffs on carbon-intensive products like fertilizers, could have a serious impact on Moroccan industry, which is largely dependent on exports to European countries.

It is still unclear when and if green electricity and hydrogen will start to flow from the country to Europe, as it depends on technological developments, the economic competitiveness of the new infrastructures, and the implementation of a green transition that, in Morocco, is advanced but still not sufficient to satisfy both domestic demand and export needs. At the moment, the prospects for a future "green-energy backbone" in the country have to coexist with the real consequences of the war in Ukraine for energy markets and geopolitical

[16] S. Naoumi, "Une nouvelle stratégie industrielle nationale en gestation", *Le Matin.ma*, 9 May 2023.

tensions with neighbouring countries. In November 2021 Algeria decided to stop gas flows through the Maghreb-Europe pipeline, in the broader context of diplomatic strains between the two countries. Deprived of Algerian gas, Morocco has relaunched the exploration of its own hydrocarbon resources, as well as a project to construct a new gas pipeline with Nigeria and new regasification terminals on the country's coasts. In order to guarantee the supply of natural gas in the short term and the operativity of its combined cycle power plants, Rabat has signed an agreement with Madrid for the use of Spanish regasification plants and the import of liquefied natural gas (LNG) by reversing the flow of gas in the Maghreb-Europe Gas Pipeline.

Despite the opportunities offered by trans-shipment and international trade, the goal of emerging as a gateway to the African continent risks being hampered by poor road connections with neighbouring countries. This infrastructure gap could frustrate the country's ambition to become a continental hub and interface between the European Union and the Africa continent. The trans-Maghreb motorway axis, intended to connect the Tunisian, Algerian and Moroccan road systems, has never been completed, and the almost 30-year closure of the border between Morocco and Algeria makes it impossible to transport goods by road.[17] To the south, the Trans-Saharan axis between Tangier and Dakar suffers from a number of interruptions and bottlenecks.[18]

According to some estimates, Moroccan trade with Sub-Saharan African countries accounted for only €5.8 billion in 2022,[19] a relatively limited value. The Ivory Coast is the

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[17] OECD Library, "Infrastructure", in *Intégration régionale dans l'Union pour la Méditerranée. Rapport d'étape*, 28 May 2021.

[18] N. Mareï and O. Ninot, "Entre Afrique du Nord et de l'Ouest, les relations transsahariennes à un moment charnière", *Bulletin de l'Association de Géographes Francais*, vol. 95, no. 2, 2018, pp. 239-58.

[19] "Maroc-Afrique : les échanges commerciaux dépassent 65 MMDH à fin 2022 (Mezzour)", *Le matin.ma*, 31 January 2023.

17th destination for Moroccan exports, Senegal the 19th and Mauritania the 25th. If considered, the country's application to join the Economic Community of West African States (ECOWAS), submitted over five years ago, could prove a driving force for trade with the region. Unfortunately, membership is still on hold as a consequence of tensions over Western Sahara.

Despite these obstacles to increasing the added value of Moroccan industrial output and to better integrating the country's infrastructures with those of neighbouring nations, there is no doubt that Morocco has already established itself as an essential player in the development of integrated Mediterranean value chains, as a credible actor in energy transition, and as a gateway for trade between the European Union and African countries. Initiatives like the *Green Partnership on Energy, Climate and the Environment*, signed by Morocco and the EU last October, and the massive infrastructure investments planned by the *Global Gateway* or imagined in the context of the Spain-Portugal-Morocco joint bid to host the 2030 World Cup[20] can only strengthen this prospect.

[20] E. Sembène, "Why Morocco is teaming up with Spain and Portugal to bid for the 2030 World Cup", *Le Monde*, 12 April 2023.

10. US Resilient Infrastructure: The Key Tool for Industrial Leadership?

Michael Bennon

The United States is currently undergoing a period of massive change in its economy, which is being spearheaded by three major pieces of federal infrastructure and industrial policy legislation: the Infrastructure Investment and Jobs Act (IIJA), the Creating Helpful Incentives to Produce Semiconductors (CHIPS) Act, and the Inflation Reduction Act (IRA). In their totality, these three pieces of legislation will invest trillions of dollars in infrastructure rehabilitation, high-tech manufacturing and supply chain resiliency and the energy transition.

This recent legislation is not simply investing more, however. The legislation also represents significant changes in how the US invests. The CHIPS and IRA mark an American turn towards vertical industrial policy, and directly managed state investment and subsidy programmes, which would have seemed foreign in the United States a decade ago. Similarly, the IIJA includes significant changes to the ways that the federal government invests in infrastructure and the types of projects that it invests in.

In this brief chapter, I review these changes in the "how" of US industrial policy and federal investment, and discuss two of the challenges that the US government faces as it attempts to orchestrate major changes to its economy. The first challenge relates to the infrastructure and other fixed investments in the legislation. While the US has significantly increased investment, it has not changed or otherwise addressed preexisting environmental and social regulations designed to slow or otherwise constrain growth and dynamism. These regulations are now constraining federal investments in clean energy and resiliency in the same way that they previously constrained investments in other sectors. As a result, "permitting reform" has become a topic of political urgency, but the Biden Administration has yet to make significant changes to speed up investment.

The second set of challenges facing the US transition stem from unique aspects of American governance and the United States' unique role in the global economy, which differs significantly from many other nations that rely on state-led direct investments and industrial policy for growth. The United States is new to the world of industrial policy, and lacks the clear metrics and controls that other nations have used to prevent goal proliferation or rent seeking, and to adjudicate conflicts between various development goals and interest groups. It is also a divided democracy with checks and balances that tend to pull investment policies in multiple directions. Absent these institutions to direct state-led investments and subsidies, the US risks taking a haphazard approach to delivering its key industrial policy initiatives.

The Legislation

At more than $2 trillion in direct federal spending, the Biden Administration's combined industrial policy legislation in the IIJA, IRA and CHIPS Act represent a massive investment programme. More importantly, however, the legislation makes important, potentially precedent-setting changes in how the US government invests, by investing in new sectors, investing through new, more direct channels, and by creating new programmes to supplement private investment.

The IIJA made significant changes to US federal infrastructure spending by adjusting the balance of federal funding between sectors and working more directly with cities and local public sponsors. The majority of the federal funding in the IIJA remains formula funding programmes through state governments, much of which is allocated towards road infrastructure.[1] However, the legislation also includes unprecedented allocations to transit infrastructure and other sectors, including $55 billion to water infrastructure, $65 billion to broadband and digital infrastructure, and $8 billion to regional rail infrastructure outside of the already massive allocation that the legislation makes to Amtrak.[2] In the renewable energy and climate mitigation sectors the changes are far more substantial. The IRA alone is estimated to catalyse more than $1.7 trillion into the climate and renewables industries, and renewable energy is expected to attract 78% more investment per year than it would have otherwise.[3]

The United States' industrial policy legislation also changed the way that the federal government invests to include more discretionary grant programmes, or programmes that work directly with cities and local public sponsors, rather than allocating capital through the states. For instance, the IIJA and the IRA include 18 new programmes and billions in funding for cities that focus on community design and transportation impacts.[4] Prior discretionary grant programmes were expanded while other completely new programmes were created, such as the connecting communities programme or the new, $848 million resilience grant programme to protect transportation infrastructure from the impacts of climate change. While the

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[1] A. Tomer, K. Caroline, and J.W. Kane, "The Start of America's Infrastructure Decade: How Macroeconomic Factors May Shape Local Strategies", Brookings Institution, 1 February 2023.

[2] D. Hampton, "Amtrak CEO Outlines Plans for Spending $66 Billion from Infrastructure Funding," *NBC News*, 8 November 2021.

[3] R. Meyer, "A Huge, Uncharted Experiment on the U.S. Economy Is About to Begin", *The New York Times*, 12 February 2023.

[4] A. Tomer, "Will the Infrastructure Law and Inflation Reduction Act Transform American Transportation? It's Complicated", Brookings Institution, 1 November 2022.

majority of the transportation and other funding is still being allocated through state programmes, the direct investment initiative in the IIJA and the IRA mark an important shift towards an investment programme more directly allocated and managed by the federal government.

The IRA and the CHIPS act also expand the number of industrial policy tools that the federal government will use to support select industries, and both pieces of legislation are also focused on relocating or retaining manufacturing jobs and facilities in the United States. This is also a marked shift. For instance, the EV tax credits passed in the IRA are only available for vehicles manufactured domestically. Likewise, the CHIPS Act includes $60 billion in subsidies across a number of programmes, including tax credits, grants and government loan programmes, but only for domestic manufacturing facilities.[5] The industrial policy subsidies used are also in some cases more directly linked to policy outcomes, including metrics as specific as a $3 tax credit per kilogram of green hydrogen.[6] Between the IIJA, IRA and CHIPS Act, the United States has aggregated an industrial policy programme of direct investments, private sector subsidies and loan programmes that is truly unprecedented in scale or administration.

Conflicting Priorities

As the United States navigates its transition into a more state-led economic development model, it faces challenges in two key areas. The first can be found in the legacy policies and regulations to protect against environmental and social harms by controlling growth. The second is a lack of the institutions that other state-led economies use to direct investment, prioritise among public goods and prevent rent seeking.

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[5] D. Kamin and R. Kysar, "The Perils of the New Industrial Policy", *Foreign Affairs*, 18 April 2023.

[6] "America's Government Is Spending Lavishly to Revive Manufacturing", *The Economist*, 2 February 2023.

To grow or not to grow

Many US environmental regulations were designed during the 1960s and 1970s, in an area of dynamic growth and change, and one with very high levels of capital investment in both public works and the private sector. Significant environmental and social impacts of that growth and development were a key contributor to the creation of those regulations.[7]

The most important of these new regulatory policies was the National Environmental Protection Act of 1970 (NEPA), which would act as a precedent and template for a wide range of similar regulations at the state and regulatory level after it became law.[8] NEPA has evolved to limit the environmental and social impacts of federal infrastructure investments and other actions in three general ways. First, administratively, it required agencies to complete a detailed environmental study for any action that would have significant environmental impacts prior to undertaking it. Second, it included a democratic process through which agencies were required to present the results of their studies to the public, before accepting and responding to public comments on the proposed project. Finally, it created a judicial private right of action through which citizens or stakeholder groups could challenge an environmental study in court, and potentially block the investment until problems with the environmental study were remedied.

While NEPA application was limited to federal infrastructure projects and the other major actions of federal agencies, NEPA's basic regulatory formula was replicated in many US state environmental laws or even local planning regulations. Other regulations to protect habitat, species or historic buildings were also structured similarly. In the manufacturing sector, the financial liabilities that manufacturers faced from

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[7] D. Bear, "The National Environmental Policy Act: Its Origins and Evolutions", *Natural Resources & Environment*, vol. 10, no. 2, 1995, pp. 69-73.

[8] D.R. Mandelker, *NEPA Law and Litigation*, 2nd Edition, Clark Boardman Callaghan, 2018.

environmental impacts were also increased through regulations, with enforcement via environmental lawsuits and agency action.[9]

These regulations were broadly successful in improving US environmental outcomes and in many cases reducing the social impacts of large infrastructure or industrial development projects. During the same period, however, the time to develop large federal infrastructure projects in the United States increased significantly, and US manufacturing also declined precipitously as a share of the economy. Today, the median time to complete a federal environmental study for a renewable generation or transmission project is 3.5 years with projects taking 9 years or more in some cases. Other federal permitting actions can take just as long or longer.[10] The longer term decline in US manufacturing employment accelerated after a change in trade policy eliminated the potential for tariff increases in Chinese imports after the turn of the century.[11]

While this network of policies has been successful at regulating growth and development in the United States, it presents some clear challenges for the new industrial policy development model as well. American development regulations were naturally designed to prioritise local environmental and social impacts, whereas mitigating and adapting to climate change will require significant investments in renewable generation, transmission lines and other infrastructure investments. Reinvesting in high-tech and renewable manufacturing will likewise face the same headwinds today that those industries faced before the federal subsidies in the CHIPS act and the IRA were put in place.

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[9] R. Ryan, "Adequate Agency Action: How Procedural Trends in Environmental Citizen Suit Litigation Prompt a Reconsideration of Deference and Presumptions of Diligence", *Ecology Law Quarterly*, vol. 44, 2017, pp. 445-68.

[10] R. Sud, S. Patnaik, and R. Glicksman, "How To Reform Federal Permitting To Accelerate Clean Energy Infrastructure", Brookings Institution, February 2023.

[11] J.R. Pierce and P.K. Schott, "The Surprisingly Swift Decline of U.S. Manufacturing Employment", *National Bureau of Economic Research*, NBER Working Paper, no. 18655, December 2012.

In other words, the same constraints on dynamism and change that were designed to prevent their attendant environmental and social impacts are now also constraining the US government's new development agenda of investing in infrastructure, establishing a more resilient manufacturing supply chain and hastening the transition to renewable energy.

Congress and the Biden Administration have struggled to navigate this impasse since passing their landmark legislation. Congress included minor reforms to the permitting process in the One Federal Decision (OFD) policy that was in the IIJA.[12] More recently, the US debt ceiling negotiation produced some minor permitting reforms to NEPA and attempted to set stricter timelines for federal environmental permits.[13] However, the Biden Administration has also reversed guidance from the prior Trump Administration to clarify the legal requirements of environmental studies under NEPA.[14]

The United States is embarking on a reformation of its economy that will require massive capital investments in infrastructure and manufacturing, yet it is not a developing economy that is able to make capital investments quickly. All forms of infrastructure development or industrial investment create environmental or social externalities, to one degree or another. The United States has developed a wide range of laws and policies to mitigate those impacts by constraining development. Those very same policies will also impede the federal government's new development initiatives in infrastructure renewal, the energy transition and resilient manufacturing supply chains.

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[12] A. Winkler and O. Minott, "IIJA Provisions to Accelerate Clean Infrastructure Permitting and Environmental Review | Bipartisan Policy Center", *Bipartisan Policy Center* (blog), n.d.

[13] M. Catanzaro, "Permitting Reform in the Debt Ceiling Bill: A First Step, with More to Come", 7 June 2023.

[14] D. Grandoni and A. Phillips, "Biden Restores Climate Safeguards in Key Environmental Law, Reversing Trump", *Washington Post*, 19 April 2022.

Directing Investment

The second set of challenges that the United States faces in directing its economic transition relates to its governance and unique role in the global economy, which will make industrial policy and direct investment programmes in the United States less resistant to problems common to industrial policy programmes globally – notably goal proliferation and rent seeking. The United States lacks some of the governance mechanisms and performance indicators that other nations with large state-led industrial policy or direct investment programmes take advantage of. It will need to account for these disadvantages as it sets out on implementing its industrial policy programmes in the coming years.

The first problem that the US faces in this regard is a simple matter of governance. The United States does not have an authoritarian or single-party system of governance which can exert significant unilateral control over an investment initiative. It is instead a divided liberal democracy with many checks, balances, interest groups and stakeholders. Major investment programmes run the risk of getting pulled in multiple directions as a result, which can inhibit them from achieving their primary goals. Examples abound already in the major US legislation. In the runup to the IIJA's passing, elected leaders came up with a wide range of justifications for why various sectors and investments counted as "infrastructure".[15] Similarly, after the IIJA became law the Biden Administration issued guidance to states that appeared to direct them to not invest federal funding in projects that would add lane-miles to existing highways. The guidance drew criticism from congressional Republicans before it was eventually withdrawn. The potential for goal proliferation in industrial policy programmes is perhaps even greater. When the US commerce department released its

[15] E. Boehm, "Everything Is Infrastructure Now", *Reason.Com* (blog), 5 September 2021.

guidance for private companies interested in receiving federal subsidies under the CHIPS Act, the requirements addressed a very wide range of other public policy objectives that had little to do with semiconductor manufacturing, including requirements as wide ranging as providing on-site childcare for any construction workers building the federally supported manufacturing facilities.

The United States is also not a developing economy with an export-led growth model, and this also poses challenges for its industrial policy initiatives in particular. Export promotion is not only an end goal of many industrial policy initiatives, but it also provides a useful metric for programmes to reduce rent seeking and allocate subsidies more efficiently. Many industrial policy initiatives in Asia, for instance, require subsidised manufacturers to successfully increase exports in order to continue receiving or receive higher subsidies.[16] The subsidy programmes put in place in the United States more closely resemble import substitution policies, which have a long history and a nuanced track record.[17]

This challenge is largely limited to the execution of the United States' new industrial policy programmes, but in the future the same issue would apply to whether the US creates additional programmes in additional industries. Historically, US interventions more commonly took the form of countervailing duties or tariffs, which were justified based on a subsidy or other trade distortion on the part of a trading partner. If America's new industrial policy programmes are instead justified based on strategic competition, new economic development priorities, or the simple fact that "others are doing it",[18] then there is not a clear

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[16] For country level case studies see J. Page and F. Tarp, *The Practice of Industrial Policy: Government-Business Coordination in Africa and East Asia*, Oxford, Oxford University Press, 2017.

[17] For a review of import substitution practices in the global south through the 1980's, see H.J. Bruton, "A Reconsideration of Import Substitution", *Journal of Economic Literature*, vol. 36, no. 2, 1998, pp. 903-36.

[18] J. Harris and J. Sullivan, "America Needs a New Economic Philosophy. Foreign

limit on the potential scope of similar policies going forward. This is likely part of the reason that many allies and trading partners of the United States have expressed significant concerns of their own in response to recent US industrial policy initiatives.[19]

Conclusion

America's turn towards industrial policy and state-led direct investment is an effort to further transition its national economy into one that is less carbon-intensive, more resilient with respect to global supply chains and more competitive in high tech and renewable energy manufacturing. It can already boast many achievements. Just one year into the IIJA, billions in federal funding have been deployed for roads, transit, bridge repair, airports and water infrastructure projects.[20] Similarly, capital investment in US manufacturing investment is skyrocketing even as production levelled off after a post-pandemic boost.[21] There are even indications that the industrial policy initiatives in the IRA have succeeded in making renewable energy products manufactured in the United States globally competitive on price.

However, the US faces challenges and inherent conflicts between its new industrial policies and its current regulations and governance. In the end, the United States' new industrial policy initiatives will be judged not by the amount of federal funding they are able to invest, or even on the private capital they are able to catalyse. They will be judged on whether those investments actually achieve their objectives of broad economic growth, supply chains that are more resilient to geopolitical conflict, a more competitive high tech and renewable manufacturing sector and a greener economy.

Policy Experts Can Help", *Foreign Policy*, 7 February 2020.

[19] Kamin and Kysar (2023).

[20] Ibid.

[21] L. DePillis, "After Pandemic Rebound, U.S. Manufacturing Droops", *The New York Times*, 2 May 2023.

11. China's Quest for High-Quality Infrastructure and Growth

Victor De Decker

A decade ago, President Xi Jinping announced the Belt and Road Initiative. Promising large infrastructure projects, the initiative was welcomed by vastly underinvested countries all over the world. Also on the home front, Chinese state-owned enterprises and banks were eager to participate. In recent years, however, China has been facing an increasingly hostile environment. The BRI itself has become the subject of criticism due to construction defects and a mounting debt burden.

In this chapter, the main drivers and changing dynamics of the BRI are touched upon. Changing trends are forcing China to focus increasingly on quality, rather than quantity in its development policy. This is the case for China's domestic industrial policies, as well as for its foreign investment policy through the BRI.

History

Since the inception of the People's Republic of China (PRC), infrastructure development has played a pivotal role in China's domestic and foreign policy. Throughout the history of the PRC, infrastructure development has taken different proportions, shapes and roles. After a brief period of domestic reconstruction, the Chinese Communist Party (CCP) formulated its first Five Year plans (1953-57 and 1958-62).

These plans entailed a Soviet-style approach to development, targeting GDP growth through a high rate of investment. As part of its early foreign policy in the 1960s, the PRC already instrumentalised infrastructure investments through in-kind grants[1] to distressed African nations, of which the Tanzania-Zambia Railway is an example. To the PRC, this policy was a means to actively break out of its diplomatic isolation.

After the Cultural Revolution, the CCP embarked on a programme of Opening Up in 1978. The country was still vastly underinvested and lacked basic infrastructure, logistics, and manufacturing capacity. In order to fill this funding gap, Chinese authorities encouraged domestic savings, which provided the state-led and state-owned policy-banks with ample resources which could be allocated to fuel a new high-investment-led growth regime. This development finance model, together with a closed-off financial system and inflows from foreign capital, together with ample infrastructure investment opportunities, resulted into a rapid increase in productivity and steady high growth rates.[2] Besides carefully targeting domestic capital, foreign capital in the form of foreign direct investment (FDI) was welcomed as well from the 1990s onwards. This trend was strengthened by China's WTO accession in 2001.[3] From virtually zero in 1979, FDI net inflows soon accounted for 6.2% of GDP.[4] A significant proportion of this capital was channelled to infrastructure development. Between 1992 and 2011, China ploughed 8.5% of its GDP into infrastructure, far exceeding any other country or region. The largest share of this spending went on the construction of roads, power, rail, and

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[1] In-kind grands = a grant based on the provision of facilities that does not include the provision of cash funds to the applicant.

[2] M. Pettis, "Can China's Long-Term Growth Rate Exceed 2–3 Percent?", Carnegie Endowment for International Peace, 6 April 2023.

[3] World Trade Organization (WTO), "NEWS - WTO Ministerial Conference approves China's accession", Press 252, 10 November 2001

[4] World Bank, "Foreign direct investment, net inflows (% of GDP)", China [Dataset].

water infrastructure.[5] Another important impetus for increased infrastructure investment was the twin crises China faced in 2008: on the one hand the Global Financial Crisis (GFC) was harming China's exports, while at the same time China's heartland was hit by a devastating earthquake, causing 70,000 casualties and rendering millions of people homeless.[6]

These crises urged central authorities to implement a vast stimulus package, using both fiscal and monetary policies to maintain growth and restore infrastructure in the affected provinces. A significant portion of the fiscal package, totalling $586 billion (RMB4 trillion) over 27 months, was earmarked for large-scale infrastructure investments. According to figures provided by the National Development and Reform Commission (NDRC), RMB280 billion ($41 billion) was allocated for housing projects; RMB370 billion ($54 billion) for improving infrastructure in rural areas, and RMB180 billion ($26 billion) for building highways, railroads, and the power grid. On top of this, an additional RMB1 trillion ($146.5 billion) was allocated to the areas worst-hit by the earthquakes.[7]

Key in this post-GFC infrastructure push was the introduction and vast expansion of China's high-speed rail (HSR) network. In the first decade following the GFC, China consecutively constructed and put into operation over 25,000 km of dedicated HSR lines. This not only improved transport connections for average Chinese citizens, but also provided the Chinese economy with considerable experience in planning, constructing, and operating HSR infrastructure, as well as developing a localised ecosystem for HSR technology. All of this was done at a significantly lower cost than for similar HSR projects in Western countries. With an approximate rate of $17-21 million per km, the PRC only paid two-thirds of what other

[5] *Chinese infrastructure: The big picture*, McKinsey & Company, 1 June 2013.

[6] C. Sorace, "China's Vision for Developing Sichuan's Post-Earthquake Countryside: Turning Unruly Peasants into Grateful Urban Citizens", *The China Quarterly*, vol. 218, 2014, pp. 404-27.

[7] "NDRC reveals details of stimulus package", *China Daily*, 27 November 2008.

countries had to pay. This can, to a large extent, be explained by a high degree of standardisation in design and procedures.[8] Still, this initial rail infrastructure was of poor quality. Testament to this was the dramatic Wenzhou bullet train crash in 2011, which was attributed to "design flaws".[9] In the 2010-11 WEF Global Competitiveness Report, China's quality of overall infrastructure ranked only in 72nd place globally.[10]

While the Stimulus Package was effective in fostering a strong rebound of the Chinese economy, achieving a double-digit annual growth rate in 2010 (10.6% GDP growth), the overall trend ever since has been one of declining annual growth rates.[11] This trend instigated fears that the PRC could be facing the "middle-income trap" (MIT).[12] The MIT phenomenon happens when a rising economy attains a certain level of development, income rises and so the country loses its competitive edge. If an economy is more export-based, it is more prone to the MIT.[13] As the Chinese economy is highly dependent on an industry-led, labour-intensive export sector, it is feared that China could be an easy prey for the MIT in the coming decade.

In parallel to this relative decline in annual GDP growth rates, the strong reliance on investments burdened the Chinese economy with mounting debt. Especially since the GFC, China's corporate and household debt has risen sharply.[14,15]

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[8] M.B. Lawrence, R. Bullock, and Z. Liu, "China's High-Speed Rail Development", World Bank Groups, 2019.

[9] "China bullet train crash 'caused by design flaws'", *BBC News*, 28 December 2011.

[10] World Economic Forum (WEF), *The Global Competitiveness Report 2010-2011*, 2010, p. 129.

[11] Worldbank, "GDP growth (annual %)" – China. [Dataset].

[12] L. Glawe and H. Wagner, *The People's Republic of China in the Middle-Income Trap?,* ADBI Working Paper Series, no. 749, ADB Institute, 2017.

[13] M. Vivarelli, "The middle income trap: a way out based on technological and structural change", *Econ Change Restruct*, vol. 49, 2016, pp. 159-93.

[14] "China's debt problem", *Reuters*, 17 September 2014.

[15] "China's Debt-to-GDP Ratio Rises to Record 279.7% on Credit Boom", Bloomberg.com, 8 May 2023.

Underlying this rising debt-to-GDP ratio is a marked slowdown in growth in output per worker since the GFC.[16] This trilemma – lower growth, higher corporate debt, and lower productivity – indicated that the PRC could not simply spend its way out of stagnation, but that it needed a new paradigm for growth.

BRI 1.0

This new paradigm for growth was partly offered by the announcement of the Belt & Road Initiative in 2013. Henceforth, China's growth strategy would be more outward-looking.

The BRI can be perceived as a continuation of existing foreign policy initiatives, notably the Going Out Strategy, in which the Chinese government supported Chinese state-owned enterprises to expand internationally,[17] and an already increasing Outward Foreign Direct Investments (OFDI) rate. The BRI intensified these ongoing dynamics and specifically targeted foreign infrastructure development.

Moreover, the BRI was also a way to avert a collapse of China's domestic investment-led growth model by remoulding it into an internationalised investment-led growth model. State-owned banks and enterprises were redeemed from hard trade-offs regarding their overcapacity and high corporate debt while their market broadened.

The initial name – "One Belt One Road (OBOR)" – was derived from the overland "Silk Road Economic Belt" (SREB) and the "21st Century Maritime Silk Road" (MSR), concepts which Xi Jinping introduced in Kazakhstan and Indonesia. At the centre of this initiative were a host of infrastructural projects with the purpose of interlinking all the countries and cities of the Eurasian continent. The Silk Road Economic Belt involved

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[16] L. Brandt et al., *China's Productivity Slowdown and Future Growth Potential*, Policy Research Working Paper 9298, World Bank Group, June 2020.

[17] "China's 'going out' strategy", *The Economist*, 7 August 2009.

the establishment of a continental economic and trade corridor extending the entirety of Eurasia and Africa. The Maritime Silk Road, on the other hand, promoted the development of ports and maritime trading hubs across the world.

The SREB had six pivotal infrastructure project corridors linking Chinese provinces to neighbouring countries and regions: the China-Pakistan Economic Corridor (CPEC), the China-Mongolia-Russia Economic Corridor (CMEC), the New Eurasian Land Bridge Economic Corridor (NELBEC), the China-Central Asia-Western Asia Economic Corridor (CCAWAEC), the China-Indochina Peninsula Corridor (CIPC) and the China-Bangladesh-India Economic Corridor (CBIEC). The MSR on the other hand was aimed at port development projects along the Ancient Silk Road. This way China's major ports could be even better integrated into international shipping routes.

Initially the BRI was unveiled by the Chinese government as an infrastructure project, putting in place a secure and efficient network of land, sea and air passages, lifting connectivity to a higher level.[18]

Though of significance at the launch of the BRI, the geographic scope along the above-mentioned "corridors" has become less straightforward. Over the past decade the list of "BRI countries" has evolved into a patchwork of around 150 nations spanning the world. The commitment of these countries to the BRI varies widely and is often defined vaguely by the signature of Memoranda of Understanding, which imply no binding commitments on either side (neither for the PRC nor for the signatory country).[19] It is also important to note that, despite its more elaborate global branding than the "Going Out" strategy, the BRI did not significantly alter the sectoral or geographic composition of China's overseas development

[18] English.gov.cn, The State Council, The People's Republic of China, "Initiative offers road map for peace, prosperity". 30 March 2015.

[19] Profiles - Belt and Road Portal, https://eng.yidaiyilu.gov.cn/info/iList.jsp?cat_id=10076

financing programmes.[20] China's trade and investment relations with "BRI countries" had already started to intensify well before the announcement of the initiative.[21]

Nonetheless, at the time of the announcement, emerging and developing economies were in dire need of infrastructure development and, with an investment gap of $452 billion per year,[22] were eager to accept any increase in infrastructure investments. For China, on the other hand, this was a way of averting the trilemma of low GDP growth, lower levels of production and high corporate debt. China's internal investment-oriented development model could be externalised to foreign markets where seemingly low-stake, high-yield, and productive infrastructure investment opportunities were plentiful.

The BRI took off with great speed, as over the first five years, the number of "mega-projects" – financed with loans worth more than $500 million – approved each year tripled.[23]

Chinese industrial and financial players – facing high financial debt and industrial overcapacity, especially since the GFC – eagerly tapped into the externally faced growth-potential of BRI.[24] They have since played a pivotal role within the BRI; Chinese SOEs have contracted about half of BRI projects by number and nearly three quarters by value.[25] In this view, the

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[20] A.A Malik et al., *Banking on the Belt and Road: Insights from a new global dataset of 13,427 Chinese development projects*, AIDDATA (Executive Summary), AIDDATA, September 2021.

[21] M. Ruta et al., "Belt and Road Economics: Opportunities and Risks of Transport Corridors", World Bank Group, 18 June 2019.

[22] F. Ruiz-Nuñez and Z. Wei, *Infrastructure Investment Demands in Emerging Markets and Developing Economies*, Policy Research Working Paper 7414, World Bank Group, September 2015.

[23] A.A Malik et al. (2021).

[24] D. Zhang and J. Yin, "China's Belt and Road Initiative, from the inside looking out", *The Interpreter*, Lowy Institute, 2 July 2019.

[25] Z. Xinwei, "Zhen Xinwei: It is of great significance for central enterprises to participate in the construction of the 'Belt and Road' with high quality", Belt and Road Portal, yidaiyilu.gov, 22 March 2019.

domestic component should not be understated either. Chinese provinces too play a key role in the BRI. For example, local authorities conveniently leveraged the BRI narrative to revive faltering or previously deemed unsustainable infrastructure projects and locally owned SOEs on the home front, as was the case in Hubei and Hunan Province.[26]

BRI 1.0 and Made in China 2025

China's outward-looking BRI cannot be seen separately from its domestic industrial policies and economic ambitions.

In 2015, the China State Council announced its "Made in China 2025" industrial policy masterplan as part of the 13th Five Year Plan (2016-20). Unsatisfied with a lower-end role within global value chains, this plan was intended to make China a dominant high-tech powerhouse in ten high-end sectors.[27] By becoming a tech leader itself, China aspired to achieve a 70% self-sufficiency in the identified sectors.

The intention of MIC2025 was thus three-fold: to create high-value growth, to escape the middle income trap that haunted other emerging markets, and to become less dependent on external market forces.

The BRI expanded the market for Chinese high-end products used in transport and energy infrastructure, which were highlighted in MIC2025. Eventually, this increased usage was projected to further (regional) standards for Chinese IT, machinery, and high-speed rail. The expansion of the Chinese

[26] M. Ye, "Fragmentation and Mobilization: Domestic Politics of the Belt and Road in China", *Journal of Contemporary China*, vol. 28, no. 119, 2019, pp. 696-711.

[27] State Council of the People's Republic of China. "'Made in China 2025' plan issued", Press release, 19 May 2015. Ten sectors: 1. New Information Technology; 2. High-end numerically controlled machine tools and robots; 3. Aerospace equipment; 4. Ocean engineering equipment and high-end vessels; 5. High-end rail transportation equipment; 6. Energy-saving cars and new energy cars; 7. Electrical equipment; 8. Farming machines; 9. New materials, such as polymers; 10. Bio-medicine and high-end medical equipment.

HSR network stands front and centre of the BRI. Particularly in Southeast Asia Chinese companies have been using High Speed Rail (HSR) and Higher Speed Rail (HrSR) technology and rail-building experience in BRI-investments in the Jakarta-Bandung Line[28] and the China Lao Railroad.[29]

On the supply side, the Chinese government started to integrate BRI countries into Chinese supply chains. Moreover, there was an active push for the migration of whole production facilities to foreign countries. This view has been reflected by a rare speech by Jin Qi, the Chairman of the Silk Road Fund. In 2016 she said that China sits in the middle of the global production chain and could help countries at an early stage of development to industrialise. She further noted that "China possesses high-quality industrial production capacity, technology, ample supply of funds and 30 years of development experience. […] [Chinese capital can] help facilitate international production cooperation and reorganise the global production chain".[30]

As it became clear that the MIC2025 benchmarks would not be reached by 2025[31] and Chinese plans for tech dominance and self-sufficiency were increasingly met with American and European backlash, Chinese officials started to soften the MIC2025 discourse by 2018. Ever since this date, officials have either downplayed or ignored the plan wholeheartedly.[32]

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[28] S. Strangio, "Indonesian High-Speed Railway to Begin Operations in August: Minister", *The Diplomat*, 11 April 2023.

[29] *Xinhua*, 4 December 2021. Strictly speaking, with a top-speed of 160 km/h, the China-Lao Railway qualifies as "higher speed rail", but not as "high speed rail", which handles speeds by 200 km/h and above.

[30] P. Cai, *Understanding China's Belt and Road Initiative*, Lowy Institute, 2017.

[31] J. Wübbeke, M. Meissner, M.J. Zenglein, J. Ives, and B. Conrad, "MADE IN CHINA 2025. The making of a high-tech superpower and consequences for industrial countries", MERICS Papers on China no. 2, *MERICS*, December 2016; S. Writer, "'Made in China' chip drive falls far short of 70% self-sufficiency", *Nikkei Asia*, 12 October 2021.

[32] M. Martina, K. Yao, and Y. Chen, "Exclusive: Facing U.S. blowback, Beijing softens 'Made in China 2025' message. U.S.", *Reuters*, 25 June 2018.

BRI 2.0

The initial years of the BRI were marked by low interest rates, declining energy prices, a China-friendly global trade environment and a still booming domestic Chinese economy. The Covid-19 pandemic, rising interest rates, intensified geopolitical tensions, elevated energy prices, and the Russian invasion of Ukraine have made the current environment much less auspicious. As a significant amount of BRI-projects have stalled, billions of dollars, mostly provided by Chinese policy-banks, have turned into mountains of debt for low and middle income countries, with 42 nations currently having levels of public debt exposure to China in excess of 10% of GDP.[33]

Covid-19 impacted China's global investment drive. In 2020 China's global outward FDI plummeted 72% from the average of the previous five years. In BRI-countries, the impact was less strong, but still amounted to a 62% decline.[34] Development finance to BRI-countries has dropped simultaneously.[35] Countries that are highly dependent on Chinese lending to finance their infrastructure needs are thus left vulnerable. Next to financial setbacks, one decade after its inception, the BRI is being increasingly criticised for its low construction quality. Over the past years there have been numerous reports from BRI projects in Pakistan, Uganda, and Ecuador, indicating cracks in Chinese built and financed hydroelectric plants.[36] It is estimated that 35% of China's overseas infrastructure projects have faced major issues, ranging from corruption scandals, labour violations, environmental hazards and public pushback.[37] To

[33] The editorial board, "China's emerging Belt and Road debt crisis", *Financial Times*, 27 July 2022; Malik et al. (2021).

[34] A. Garcia-Herrero and E. Freymann, "A new kind of Belt and Road Initiative after the pandemic", Bruegel Blog, 23 June 2022.

[35] R. Ray and B.A. Simmons, "Tracking China's Overseas Development Finance", Global Development Policy Center, 7 December 2020.

[36] R. Dube and G. Steinhauser, "China's Global Mega-Projects Are Falling Apart", *The Wall Street Journal*, 20 January 2023.

[37] Garcia-Herrero and Freymann (2022).

make matters worse, in 2021, it was estimated that 42 Low and Middle Income Countries (LMICs) had debt exposure to China exceeding one tenth of their annual GDP.[38]

An overall deteriorating environment as well as financial and construction setbacks turned the global narrative against the BRI and instigated China to rethink the Initiative. Something had to change in order to keep the BRI alive.

In 2019, Xi Jinping formulated a fundamental reorientation at the Belt & Road Forum.[39] He iterated this vision by a metaphor: to transform BRI from a "*xieyi*" (freehand painting with broad brushstrokes) to a more refined "*gongbi*" (meticulous painting style with fine brushstrokes). This "*gongbi*" approach would imply project prioritisation and result-oriented implementation.[40,41]

In this vein, "BRI 2.0" is reoriented towards more nimble priorities and benchmarks, as well as towards "high-quality development".[42] Important to note here is that official guidelines have been emphasising "high quality development" ever since. Nonetheless, guidelines on specific schemes and processes for achieving these "high-quality" benchmarks remain largely absent.[43]

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[38] K. Walsh, K. Solomon, S. Zhang, T.-B. Elston, and S. Goodman, *Banking on the Belt and Road: Insights from a new global dataset of 13,427 Chinese development projects*, AIDDATA (Executive Summary), AIDDATA.

[39] C.H. Wong and J.T. Areddy, "China's Xi Vows New Direction for 'Belt and Road' After Criticism", *The Wall Street Journal*, 26 April 2019.

[40] K. Zhu, R. Shi, and R.J. Lempert, "Recalibrating the Belt and Road Initiative amidst deep uncertainties", *Journal of Mega Infrastructure & Sustainable Development*, vol. 2, no. 1, 2020, pp. 47-68.

[41] Remarks by H.E. Xi Jinping President of the People's Republic of China At the Press Conference of The Second Belt and Road Forum for International Cooperation, The Second Belt and Road Forum for International Cooperation, 24 April 2019.

[42] Foreign Ministry of the People's Republic of China, High-Quality Belt and Road Cooperation: Partnership on Connectivity Report on the Findings and Recommendations from the Meetings of the Advisory Council of the Belt and Road Forum for International Cooperation in 2019 and 2020, 2021.

[43] Zhu, Shi, and Lempert (2020).

While BRI 1.0 focused on mega-projects along corridors spanning entire sub-continents, the current BRI 2.0 focuses on development through collaborative agreement along the lines of specified areas. Four key sectoral "Silk Roads" were iterated:

- The Health Silk Road: supporting mutual efforts to combat Covid-19; enhancing the availability, accessibility and affordability of vaccines, medicines and medical supplies; establishing bilateral, regional and international mechanisms for health cooperation; investing in sound and resilient health infrastructure.
- The Green Silk Road: promoting green and sustainable development through "Green Investment Principles".
- The Digital Silk Road: promoting international collaboration on cloud computing, big data, IoT, and AI.
- The Clean Silk Road: addressing corruption along BRI cooperation.

While high party officials like Wang Yi still laud the progress made in hard connectivity (i.e. infrastructure development), as a part of the BRI,[44] emphasis has shifted increasingly towards soft connectivity and collaboration efforts.[45]

Also important to note is that BRI 2.0 has a considerably lower price tag. In 2020, megaprojects fell to their lowest year-to-year level since the announcement of BRI, with individual investments seldom exceeding $1 billion.[46]

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[44] "China to push high-quality Belt and Road cooperation with participating economies: foreign minister", *Global Times*, 7 March 2022.

[45] Foreign Ministry of the People's Republic of China, High-Quality Belt and Road Cooperation: Partnership on Connectivity Report on the Findings and Recommendations from the Meetings of the Advisory Council of the Belt and Road Forum for International Cooperation in 2019 and 2020…, cit.

[46] B. Tanjangco, Y. Cao, R. Nadin, O. Borodyna, L. Calabrese, and Y. Chen, *Pulse 2: China navigates its Covid-19 recovery – outward investment appetite and implications for developing countries*, ODI Economic Pulse Series: China's outward investment and Covid-19: emerging trends for developing countries, Overseas Development Institute (ODI), February 2021.

From the side of emerging markets, which are primarily targeted by the BRI, infrastructure investment is, however, still seen as an important prerequisite for economic development. As the BRI evolves into a smaller-scale project around finding collaborative synergies, it remains to be seen whether BRI 2.0 can reverse the chronic dearth of infrastructure investments in these countries.

BRI 2.0 and the Dual Circulation Strategy

While MIC2025 branding faded, the core economic ambitions of China remained unchanged: to move up supply chains and become increasingly self-reliant. The Party needed a new strategy, more sophisticated, feasible, and with a clear vision of the current state of globalisation. In April 2020, Xi Jinping launched the Dual Circulation Strategy (DCS). Similar to MIC2025, DCS emphasises indigenous innovation and self-reliance. It is an overarching plan for managing global integration, explicitly reorienting the Chinese growth model from exports and domestic investments towards innovation and domestic consumption.[47]

As its aim is to internalise globalisation, self-reliance within the DCS does not imply autarky, but rather a dynamic management of its economic development – at home and abroad.[48] Four core objectives can be distilled from the DCS:

1. Boosting domestic consumption relative to external demand as a driver of economic growth;
2. Positioning China as a high value-added manufacturing powerhouse;
3. Attaining higher levels of self-sufficiency in key areas;
4. Ensuring access to critical inputs by diversifying supply chains.[49]

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[47] A.L. Brown, J. Gunter, and M.J. Zenglein, "Course correction: China's shifting approach to economic globalization", *MERICS*, 19 October 2021.

[48] Ibid.

[49] B. Hart, *Will the Dual Circulation Strategy Enable China to Compete in a Post-Pandemic*

In the current conjuncture, these goals point to inherent paradoxes in the domestic and international ambitions of China in global value chains. Firstly, China wants to reorient its growth model away from export and investment as the twin driving forces of its economy, moving up the ladder of global supply chains. This way, self-reliance can be enhanced and better-paid jobs provided for its growing middle-class, which will therefore see its consumption power increased.

Also the rising tensions between China and the West are hampering China's growth. As China's economy still relies on American and European technology, know-how and capital, the looming threat of a de-coupling between the West and China poses serious problems for the DCS in the near future. While BRI countries can indeed offer commodities, low-end manufacturing and trade partners, they are no substitute for the indispensable role of Western economies in China's growth model.

A global health crisis, China's ambiguous stance towards the war in Ukraine, decoupling, sanctions and technological containment efforts by the US government are making international firms think twice about investing in China.[50] Contrary to what the DCS is aiming for, exports towards the US and the EU, have also been on the rise again, resulting in a rather familiar high trade surplus[51] – as opposed to the intended reorientation towards consumption.

When it comes to ensuring access to critical inputs by diversifying supply chains (goal 4), BRI countries can indeed play an important role in the upstream value chain (lower-end manufacturing) and in providing a reliable supply of raw materials for the DCS. It remains to be seen whether these countries, already facing considerable debts, will be willing to act as mere commodity and low-end supply partners of China.

World?, ChinaPower Project, 19 April 2022.

[50] A. Lee, "Ukraine war, 1 year on: are China's supply chains headed toward upheaval, or can it stem the tide?", *South China Morning Post*, 24 February 2023.

[51] World Bank, "Net trade in goods and services (BoP, current US$)" - China [Dataset].

Facing these discrepancies and challenges, high party officials have been advocating a more mutually reinforcing relationship between the BRI and the DCS. Vice-Premier Han Zheng called for a better alignment between the BRI and the DCS "where domestic and overseas markets reinforce each other".[52] Without explicitly mentioning either the DCS or BRI, in March 2023, President Xi Jinping again pledged to speed up efforts for high-quality development and achieving self-reliance. Further in his speech, President Xi mentioned that "China should ultimately rely on scientific and technological innovation" for growth.[53]

Conclusion

In trying to offset its internal economic discrepancies, China burst onto the scene with a massive plan for development, projecting its domestic growth model to the world. Less than a decade later, however, China came to the realisation that it was fighting the same demons abroad as it was at home from the onset: debt, overcapacity, low productivity, and setbacks due to low construction quality.

To a certain extent, high-ranked officials have already come to the same conclusion, as they have recently started to publicly advocate for higher quality development, and better coordination between the goals and practices of the BRI and DCS, indicating unease with the current conjuncture.

Pledges of high-quality development alone will not be sufficient to address the issues at hand. Rather, setting clear and coherent commitments towards quality criteria, standards and benchmarking should be the objective in the near term to develop a sustainable pathway towards growth – domestically as

[52] State Council of the People's Republic of China, Vice-premier stresses high-quality development of Belt and Road Initiative, February 2022.

[53] "Xi stresses high-quality development in China's modernization endeavor", *Xinhua*, 6 March 2023.

well as internationally. It will be tough to achieve high-quality growth while being increasingly side-lined from Western technology, hence a "thaw" in geopolitical tension would be more than welcome for the Chinese side as well.

In any case, the ball is in Zhongnanhai's court to implement a "new reform and opening up". If these profound policy changes are not made, all the calls made for a BRI 2.0 and DCS will ring hollow. If this day comes, it will bring an unavoidable reckoning for a large proportion of the Chinese SOE and policy-bank landscape, who will not be able to have their cake and eat it anymore. However, one should remember that economic reform is no dinner party.

12. The Resilience and Safety of Japan's Infrastructural Assets

Corrado Molteni

In 2024, sixty years will have passed since the successful organisation of the Tokyo Olympics. In view of that event, marking the rebirth of the country from the ashes of WWII, the Japanese government embarked on a large, unprecedented programme of investment in infrastructure, from the Shinkansen or New Trunk Line, the world's first high-speed railway connecting Tokyo to Osaka, to the dense network of urban motorways crisscrossing the overcrowded central districts of Japan's capital. At that time, these infrastructures, completed punctually and without any major drawback, were a true marvel of engineering, the result of a national project supported by public and private entities.

Since then, the country has continued developing a wide and finely connected system of nationwide motorways, high-speed railways and high-quality telecommunications and electricity grids. Japan is also endowed with excellent gas, water and sewage facilities, including large water reservoirs like the Metropolitan Area Outer Underground Discharge Channel in Kasukabe City, 30 km north of Tokyo. This is the world's largest underground flood diversion facility, designed to protect the capital from torrential rains during the typhoon season and from the increasing threat of climate-change related flooding. Built deep below ground level, this huge water tank is 177 meters long, 78 meters wide, 25 meters high and supported by more than 50 reinforced concrete pillars: a statement of Japan's technological prowess and engineering.

However, in recent years there are growing signs that the existing facilities are becoming obsolete and in need of additional and more costly maintenance to assure the same, excellent level of security and efficiency guaranteed so far. Moreover, Japan's infrastructural endowment must be upgraded to make it more sustainable and environment friendly in view of achieving carbon neutrality by the year 2050, a goal announced by the Japanese government in October 2020. But to achieve these goals Japan must overcome several challenges. There is the issue of serious fiscal constraints in a country burdened, at central and local government levels, by a large and growing public debt. Not to mention the problem of a shrinking supply, in rapidly ageing Japan, of qualified engineers and professionals devoted to maintenance and repair activities. And competition for both financial and human resources is going to become even tougher in the year ahead. Nevertheless, the challenges are being addressed by both the private sector and the government, which has adopted a set of policy initiatives aimed at overcoming the problem. But before discussing the policy measures, let us take a closer look at the current reality of infrastructure facilities in Japan.

Japan, the Infrastructure Kingdom

Over the years, Japan has devoted a large amount of its national resources to the development of infrastructural facilities. And it continues to do so, even in recent years. Indeed, according to the Ministry of Finance (MoF), in fiscal year 2020, public works accounted for 6,857 billion yen or 6.7% of the total expenditure of the general account budget, a level slightly higher, in absolute terms, than that of fiscal year 1990. Moreover, as a percentage of GDP, over the last ten years, public works in Japan have accounted for about 3%, a higher level than other advanced countries according to the Organisation for Economic Co-operation and Development (OECD) statistics.[1]

The importance and the weight of public works in the Japanese economy can also be seen by the large number of individuals employed by the construction industry. According to data published by the Statistics Bureau of Japan, in 2022 the construction sector employed 4.79 million persons or about 7% of the total number of employed. This is a very large number, although it has been declining substantially over the last twenty years. In fact, in 2002 more than six million persons or almost 10% of the total were employed in the construction industry. The declining trend is expected to accelerate in the years ahead, as the labour force is on a downward trend and young people are more reluctant to look for a job in construction. This tendency has serious negative implications for the sustainability and resilience of the sector.

But let us now examine in some detail the current situation of major public infrastructures, focusing on railways and roads. As for railways, these are divided between conventional ones, running on a narrow gauge, cheaper to build and well suited for the country's mountainous terrain, and the Shinkansen lines limited to passenger transport and running on a standard gauge (the two systems are completely separate and cannot be integrated).

In recent years numerous local conventional lines have been closed as the population in rural areas has declined and the number of passengers has diminished accordingly. However, the country still boasts a dense railroad network with a total length of about 27,000 km, devoted mainly to passenger transport.

On the other hand, the Shinkansen lines have been gradually but constantly extended since the first was inaugurated in 1964. Today, with the latest addition, the Shinkansen network has

[1] The only exception was France that, during the period from 2006 to 2012, recorded a percentage slightly higher than the one for Japan (Japan: Cabinet Office "National Accounting", fiscal year basis; other Countries: OECD "National Accounts", calendar year basis).

reached almost 3,500 km in length and further extension of the existing lines is already under way or in the planning stage. Moreover, a completely new line using Maglev technology is currently under construction and is scheduled to connect Tokyo to Nagoya in 2027 and to be extended to Osaka in 2045.

The Shinkansen, a very successful undertaking, has an impressive record in terms of safety and efficiency: it is an incredible achievement in a country always under the threat of massive earthquakes and other natural disasters. The early earthquake detection system has proved very effective as it detects tremors at an early stage and immediately halts the trains. In fact, in the 61 years since its start, the Shinkansen has never registered an accident with passenger fatalities. Punctuality is another strong selling point of this transport system that the Japanese government is eager to export to other Asian countries and to the United States. According to the Japanese Ministry of Land, Infrastructure and Transport (MLIT), the average delay time per trip is within one minute, even including weather related delays. And, lastly, the environmental footprint of the Shinkansen is less than that of any other transport system and is being constantly improved with the adoption of more advanced materials and systems.

Turning to the road system, Japan has a total of about 355,000 km of roads, including 9,050 km of "national expressways/motorways", under the jurisdiction of the Ministry but managed by private companies in charge of development, operation and toll collection. There are also about 60,000 km of "national highways", developed and serviced by the Ministry or the prefectures, as well as a very dense network of prefectural and municipal roads.

This complex network is the main supporting structure for freight transport, carrying more than half of the total tonnage carried in one year. In this segment the railway system is a dwarf, delivering only about 5% of total freight, while the rest is transported by waterways. The road system is thus the key mode of transport, essential for the functioning of the Japanese economy. To ensure its smooth operation, a complex, costly system of road maintenance has been developed over the years, accounting for a yearly budget that is rapidly swelling.[2] However, this already sizable budget is likely to grow further in the years ahead as the percentage of infrastructure facilities that are becoming old and obsolete is increasing at an accelerating pace.

In the section devoted to the obsolescence of social capital in the 2021 White Paper issued by MLIT,[3] it is estimated that the percentage of road bridges more than 50 years old will be around 63% in 2033, while it was a mere 25% in 2018. As for tunnels, it will reach about 42% in 2033 against 20% in 2018. Similar percentages are estimated for other critical public infrastructures, including those for regulating the flow of rivers, an essential asset protecting the life and the properties of the population in typhoon battered Japan.

The Issues Related to Ageing Infrastructures

As can be inferred from the above data, in Japan there is a widespread concern about the obsolescence of infrastructures that were constructed in the high-growth period of the Japanese economy and will soon be more than 50 years old. Moreover, several accidents in recent years have played a role of catalyst, drawing media attention and public opinion to the problem. In particular, the collapse in December 2012 of the ceiling of the Sasago tunnel on an expressway leading to Tokyo – an accident that caused the death of nine persons – shocked road administrators and made them aware of the need to carry out systematic and more frequent inspections. The government too intervened. In 2013 it amended the Road Law

[2] "Road Statistics of Japan", in *Statistics*, Chapter 4, 2020.

[3] Ministry of Land, Infrastructure, Transport and Tourism, "Section 2 Increased Disaster Risk and Aging Infrastructure", in *White Paper on Land, Infrastructure, Transport and Tourism 2021*.

and in 2014 a Ministerial Ordinance made it compulsory for road administrators to conduct close visual inspections on a regular basis. Bridges too came under strict scrutiny as a large percentage of them is ageing and deteriorating.

A report issued in September 2021 by the Japan Society of Civil Engineers provides a detailed analysis of the state of the art of Japan's infrastructures.[4] The survey classified the health of the country's infrastructures by assigning a grade from A for facilities in sound condition to E for those posing a danger to users. The overall evaluation was positive for the railways with a B (good) grade for bridges, tunnels and tracks, accompanied by a horizontal arrow, implying that "the current state of the management system is likely to be maintained". On the other hand, a bleak picture emerges from the assessment of the condition of roads. Bridge and road pavement are assigned grade C (requiring attention) as "degradation is progressing in a significant number of facilities" with a downward arrow meaning that the situation is likely to get worse. Furthermore, in the case of road tunnels the assigned grade was D (requiring vigilance), as degradation is apparent in most of the facilities and their repair or strengthening is deemed necessary. Negative grades have been assigned also to river structures (D), waterwork pipe facilities (C), mooring and protective facilities for harbours (C). All these critical grades are also associated with a worrying downward sign. Only dams and sewage pipe systems have gained a B grade.

The main reasons for the health of infrastructures trending downwards are insufficient budget and inadequate maintenance systems by local governments. To overcome these problems, the central government has devised various schemes to provide financial and technical support. It is also promoting the adoption of innovative, labour-saving methods of inspection and maintenance. One of them is known as the "Infradoctor"

[4] *Japan's Infrastructure Grades 2020 & Introduction of Maintenance Technologies*, Japan Society of Civil Engineers, 2021.

(infrastructural doctor), an innovative system, providing support for road maintenance through GIS (Geographical Information System) and 3D point cloud data. Private construction firms are also pouring investment into new technologies that can save cost and reduce dependency on human activities.

However, these policies are finding a major obstacle in the acute shortage of human resources in general and particularly at the local level. As the population decreases, and there are no signs that the trend will be soon reversed, the cost of maintenance and replacement of public infrastructure stocks per capita will certainly increase. And the number of toll-paying users is also projected to decrease making the solution even harder to find.

Conclusion

When considering the state of its infrastructures, Japan is at a critical juncture and will have to envisage innovative solutions, not excluding the opening of the country to foreign labour and specialists. A few steps in this direction have been taken but the measures adopted so far are on a limited scale and the public is still reluctant to endorse a policy fostering immigration. However, this is an issue that cannot be left unanswered and strong political leadership is needed.

All this notwithstanding, Japan is still at the forefront in the development, construction and operation of high-quality, well-functioning and reliable infrastructures. And it is also a major exporter of its technology to advanced and emerging counties, a key element of its foreign economic policy since 2010, when the government adopted the first infrastructure strategy. In recent years, as part of this policy, it has been competing fiercely with China in the markets of South and Southeast Asia. Japan has been emphasising the high quality and reliability of its technology versus China's competitive edge in terms of costs and financial support. The results have not always been in Japan's favour, however, with Indonesia, for example, choosing China as partner for building its first high-speed railway line.

On the other hand, Japan has registered an important success in India, where the high-speed railway line between Mumbai and Ahmedabad will be built using Shinkansen technology.

Quality infrastructure investment is in fact the keyword of Japan's export promotion strategy. This is also clearly stated on the website of the Foreign Ministry, where we can read that "it is important to consider not only quantity but also quality of infrastructure, such as transparency, openness, economic efficiency in view of life-cycle cost, and debt sustainability to achieve 'quality growth' in developing countries".[5] In this respect, Japan is well positioned, provided it can maintain the excellent level of its technology and know-how. It is also important to avoid major accidents not only for the sake of the welfare of its citizens but also for the image of the country. To this end, systematic, accurate maintenance of its infrastructures will be crucial in the years ahead.

[5] Ministry of Foreign Affairs of Japan, Official Development Assistance (ODA). Quality Infrastructure. Quality Infrastructure Investment, 10 May 2023.

13. Cyberprotection for Critical Infrastructure Resilience: The Case of Taiwan

Valentin Weber

As the geopolitical environment becomes more volatile, conflict ought to be part of any country's cyber risk management framework.[1] How does one build resilience with conflict in mind? This article considers aspects of creating cybersecurity resilience for a time when conflict may become a reality. It does so by examining the case of Taiwan. While the Taiwanese context may have some lessons for other geopolitically volatile regions, they are not meant to be generalised.

With the integration of information technologies into critical national infrastructure (CNI) during the last decades, cybersecurity has become crucial to CNI resilience. Information technologies create more efficient ecosystems and the ability to operate technologies remotely. At the same time these opportunities create new possibilities for malicious actors to compromise the confidentiality, integrity or availability of data residing on those systems.[2] While CNI operators still actively

* The author would like to thank Maria Pericàs and Emma Laumann for their research assistance.

[1] V. Weber, [@weberv_], February 2023, *Two takeaways from day one of this year's Munich Cybersecurity Conference. @MiekeEoyang notes that conflict must be part of cyber* [Tweet], Twitter, (last retrieved on 09 May 2023).

[2] B. Genge, I. Kiss, and P. Haller, "A System Dynamics Approach for Assessing the Impact of Cyber Attacks on Critical Infrastructures", *International Journal of*

build resilience against traditional threats such as natural disasters, ageing and decay, terrorist activities, and cascading failures of systems, cyber threats have made it to the top of the list of threats to critical infrastructure.[3] With the rise of cyber threats resilience against them has also become a considerable point of concern.

Resilience is about preventing the likelihood of shocks, reducing their impact and allowing entities to recover quickly from incidents.[4] In the academic literature resilience has been examined in four contexts: techno-centric, organisational, community and urban.[5] Resilience building that focuses on technological aspects emphasises the need for security guidelines, the preparation of emergency procedures and network segmentation among other measures. Organisational resilience, for its part, deals with the social aspects. It comprises command structures within an organisation or the public outreach an organisation conducts when an incident occurs. Furthermore, community resilience is concerned with how the public reacts to crises and how CNI operations can be re-established to a level that allows societies to continue operations to a tolerable level. Lastly, urban resilience relates to the resilience of cities.

In cybersecurity terms resilience is often enhanced through a mix of social and technical measures such as redundancy (having a backup strategy), network segmentation (limiting access throughout an entity's systems), or the training of personnel (increasing the sensitivity to security guidelines).[6]

Critical Infrastructure, vol. 10, 2015, pp. 3-17;

[3] R. Osei-Kyei, V. Tam, M. Ma, and F. Mashiri, "Critical Review of the Threats Affecting the Building of Critical Infrastructure Resilience", *International Journal of Disaster Risk Reduction,* vol. 60*,* 2021.

[4] M. Bruneau, S.E Chang, R.T Eguchi, et al. "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities", *Earthquake Spectra*, vol. 19, 2003, pp. 733-52;

[5] R. Cantelmi, G. Di Gravio, and R. Patriarca, "Reviewing qualitative research approaches in the context of critical infrastructure resilience", *Environ Syst Decis*, vol 41, 2021, pp. 341-76;

[6] European Union Agency for Cybersecurity and Computer Emergency

Measures to protect power grids, pipelines or hospitals are not that different from measures taken to improve one's own cybersecurity. The 2016 attack on the Ukrainian power grid by Russia shows how crucial updating software is. A glitch in Siemens software, for which the company had issued a patch, remained unpatched in the Ukrainian power grid, thereby allowing Russian malicious actors to take advantage of it and wreak havoc.[7] Hence regular patching of systems is key to the resilience of CNI, similarly to conducting frequent software updates as an individual user. Simple steps, such as network segmentation and multifactor authentication might have avoided the Colonial Pipeline ransomware attack and saved a hefty sum for the targeted company.[8] The European Network and Information Security 2 (NIS2) Directive requires essential and important entities to implement network segmentation and multi-factor authentication.[9] In addition to this, such entities need to have secure emergency communication systems within the organisation and adopt zero-trust principles among other measures. Essential / important entities that violate these regulations can be fined at least €10 million / €7 million or a maximum of 2% / 1.4% of total worldwide annual turnover.

The remainder of the article is structured as follows. It starts by examining the resilience of Taiwan's internet infrastructure. Taiwan has increased the number of undersea

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Response Team for the EU, *Boosting Your Organisation's Cyber Resilience*, 2022.

[7] A. Greenberg, "New Clues Show How Russia's Grid Hackers Aimed for Physical Destruction" *WIRED*, 12 September 2019.

[8] D. Sanger and N. Perlroth, "Pipeline Attack Yields Urgent Lessons About U.S. Cybersecurity", *The New York Times*, 14 May 2021; S. Kelly and J. Resnick-Ault, "One Password Allowed Hackers to Disrupt Colonial Pipeline, CEO Tells Senators", *Reuters*, 9 June 2021.

[9] European Parliament and Council of the European Union, "Directive (EU) 2022/2555 of the European Parliament and of the Council of 14 December 2022 on measures for a high common level of cybersecurity across the Union, amending Regulation (EU) No 910/2014 and Directive (EU) 2018/1972, and repealing Directive (EU) 2016/1148 (NIS 2 Directive) (Text with EEA relevance)", *Official Journal of the European Union*, 27 December 2022.

cables connecting it to the world and engaged in building up backup communications channels via microwave internet and satellite technologies. The second part goes beyond the analysis of how resilient Taiwan's internet infrastructure is. It explores more in depth Chinese malicious cyber activities that have been targeting Taiwanese CNI. This part analyses Chinese threat actors, which CNI they target and the aims they pursue. The article concludes by examining how China perceives Taiwanese resilience and how this perception might feed into Chinese assessments on whether or not to invade the island-country.

Examining the Resilience of Taiwan's Internet Infrastructure

In the coming years, Taiwan's internet infrastructure will almost certainly encounter severe challenges to its operations. Some US officials noted that China might be ready to annex Taiwan by 2027.[10] Against this backdrop, the small island country has begun to make considerable efforts to increase the cybersecurity of its critical infrastructure. Taiwan has identified 8 critical national infrastructures: energy, water resources, telecommunications, transportation, banking and finance, emergency aid and hospitals, central and local governments, and high-tech parks.[11] The designated entities ought to notify Taiwanese authorities within hours of a breach. They are struck with penalties if they fail to do so.

A key challenge for Taiwan ahead of and during an invasion will be the availability of communication networks. Just like in Ukraine, daily broadcasts of Taiwanese officials' speeches will be necessary to counter Beijing's propaganda. Internet connectivity is also crucial for Taiwan so it can continue to

[10] A. Hawkins, "Taiwan foreign minister warns of conflict with China in 2027", *The Guardian*, 21 April 2023.

[11] Administration for Cyber Security, moda, *Cyber Security Defense of Critical Infrastructure*, 21 February 2023.

provide services to its citizens during periods of emergency. In the event of an invasion, China is expected to launch missiles against Taiwanese data centres. As Mieke Eoyang, US Deputy Assistant Secretary of Defence for Cyber Policy noted, data localisation could be a liability in conflict regions.[12] Ukraine has mitigated this threat by transferring its government data into the public cloud hosted across Europe. In this way Russian cruise missiles destroying data centres in Ukraine were futile, as Ukrainian citizens and officials could still access the data. The cloud has hence been a hallmark of resilience in this conflict region.[13]

In a Taiwanese context the question is: where can data be stored outside Taiwan? How would the government have access to it if its communication channels to the outside world were to be cut? Given that China will most probably induce severe energy outages and that defenders will be overwhelmed, operating government services from overseas cloud data centres – where they will continuously receive power and where cybersecurity personnel from major technology companies can aid in defending networks – might be the best option to ensure continued online government services.[14] While the Taiwanese government has undertaken efforts to migrate services to the cloud, it is unclear whether the servers are located domestically, internationally or in both locations.[15]

To maintain communications with servers both at home and abroad, Taiwan relies on the following technologies, which serve as backup communication channels if China disrupts one or the other. Those are: submarine cables, microwave internet and satellite communications.

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[12] Weber (2023).

[13] B. Smith, "Extending our vital technology support for Ukraine", *Microsoft on the Issues*, 3 November 2022.

[14] S. Freedberg, "US tech firms should wargame response if China invades Taiwan, warns NSA cybersecurity chief". *Breaking Defense*, 11 April 2023.

[15] Ministry of Digital Affairs, *Service Resilience for the Cloud Generation,* 22 February 2023.

The primary threat actor targeting these communication networks will likely be China's People's Liberation Army. It has been developing capabilities to interfere with commercial and SAR satellites (synthetic aperture radar), which could be used by US military to obtain an accurate picture over the geographic space that is Taiwan and surrounding areas. Disrupting satellite capabilities might also make it more difficult for US and allies to deploy precision-guided weapons in a regional conflict.[16] Similarly, electronic warfare units of the PLA might engage in jamming Taiwan's microwave internet and covert PLA Navy militia might sever submarine cables.[17]

Submarine cables

Taiwan has 14 submarine cables that connect it to the outside world in 8 landing stations.[18] It is connected to China through several cables, including the Taiwan Strait Express-1 (TSE-1), built by Chinese HMN Tech and the Cross-Straits Cable Network, which connect Taiwan's Kinmen Islands with the mainland. While those cables are vulnerable to disruptive activities, an increasing number of cables still means more resilience. In this vein, the Pacific Light Cable Network (PLCN) became operational in 2022, connecting Taiwan with the Philippines and the United States. Yet another one, the Apricot cable system, is set to become operational in 2024, linking Taiwan to Japan and other countries in the region.[19] One of the main threats to cables, especially close to China's coast, are fishing vessels, whose anchors or nets can sever submarine cables. While shipping vessels cutting cables can occur by accident, it could also be intentional. As China's fishing fleet is sometimes used for reconnaissance purposes and manned by militia, an

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[16] T. Copp, "DIA Warns China's Space Tech Seeks to Block U.S. Radars, Jam Munitions", *Defense One*, 12 April 2022.

[17] Z. Haver, "Unmasking China's Maritime Militia", *Radio Free Asia*, 17 May 2021.

[18] TeleGeopraphy, Submarine Cable Map.

[19] V. Weber, "Taiwan's Offensive Cyber Capabilities and Ramifications for a Taiwan-China Conflict", Council on Foreign Relations, 7 December 2022.

intentional disruption under the guise of commercial fishing is conceivable.[20]

Submersible vehicles pose a threat too. Submarines can engage in tapping activities and China's unmanned underwater vehicle HSU-001 in seabed warfare, which could manifest itself in sabotage.[21] To mitigate this threat, countries such as the United Kingdom deploy ocean surveillance ships that are designed to protect cables.[22]

The prospect of cable cuts for Taiwan became again a reality in early 2023. On 2 February, Chinese fishing vessels damaged cables leading to Taiwan's Matsu Islands.[23] A few days later, on 8 February, a Chinese cargo vessel severed a second cable. Back in 2021, the cables connecting Taiwan and its islands were impaired five times and in 2022 four times.[24] Since then, Matsu Islands inhabitants have only had limited bandwidth. To make cable cuts more difficult in the future, Taiwanese mobile operator Chunghwa Telecom is building a new undersea cable, which will be buried 1.5 meters under the seafloor (reduces the likelihood of the cable being severed by ships) and is projected to be finished by the end of 2025.[25]

Microwave internet

While submarine cables connecting the Matsu Islands to Taiwan were damaged, inhabitants were immediately reconnected to Taiwan and the world through a backup system that uses

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[20] Z. Haver, "Unmasking China's Maritime Militia", *Radio Free Asia*, 18 May 2021.

[21] F.A. Gehringer, "Undersea cables as critical infrastructure and geopolitical power tool", Konrad-Adenauer-Stiftung, no. 495, 2023, pp. 1-10;

[22] G. Allison, "Britain to build second undersea cable protection ship",*UK Defence Journal*, 3 October 2022.

[23] B. Watson, "Today's D Brief: Undersea cables cut near Taiwan; China fears Starlink; USAF budget preview; Missile test over Pacific?; And a bit more", *Defense One*, 8 March 2023.

[24] S. Shan, "Lienchiang Internet to be restored by end of April", *Taipei Times*, 17 February 2023.

[25] M. Jiang, S. Su, and L. Ko, "NCC confirms undersea cables linking Taiwan, Matsu cut by vessels", *Focus Taiwan*, 16 February 2023.

high-powered microwave radio. This system is placed outside Taipei (Yangmingshan mountain), guarded by the military, and beams the internet across 200 kilometres to Matsu.[26] While this option proves to be yet another way to uphold communications, it is very slow. The repairing of the damaged cable has also been taking months, which indicates rather low resilience against such types of attack. In addition to this, in wartime China may easily interfere with radio signals and an interference-free transmission, as is the case now, may not be possible in the future.[27]

Satellite communications

Either shortly before or during a potential invasion China will very likely interfere with satellite communications technology used by Taiwan. Such interference occurred during the first few hours of Russia's invasion of Ukraine. Russia targeted the KA-SAT Network, which the Ukrainian military relies on for its communications and is run by the California-based company Viasat.[28] While the modems used by the Ukrainian military were disrupted and had to be sent back for repair to factories, the Ukrainian forces could fall back on landlines to continue coordinating defence activities.[29] While Viasat devices were disrupted, Starlink satellite communications gear, which is also extensively deployed by the Ukrainian military, has largely continued to function unabated.[30]

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[26] H. Wu, and J. Lai, "Taiwan suspects Chinese ships cut islands' internet cables", *AP News*, 18 April 2023.

[27] J. Whitney, "RF and microwave equipment: tackling the interference problem", *Military+Aerospace Electronics*, 1 July 2019.

[28] Viasat, Inc, *KA-SAT Network cyber attack overview,* 30 March 2022.

[29] K. Zetter, "Viasat Hack "Did Not" Have Huge Impact on Ukrainian Military Communications, Official Says", *Zero Day*, 26 September 2022; J. Pearson, "Russia downed satellite internet in Ukraine -Western officials", *Reuters*, 11 May 2022.

[30] E. Howell, "Elon Musk says Russia is ramping up cyberattacks on SpaceX's Starlink systems in Ukraine", *Space.com*, 14 October 2022.

But satellite technologies come with a major caveat. They are operated by private companies, which are driven by commercial incentives. SpaceX's founder Elon Musk, for instance, warned that SpaceX could stop its Starlink services in Ukraine[31] after Ukrainian public officials voiced criticisms of his proposal regarding Ukraine-Russia negotiations.[32] In the Chinese context Elon Musk, who is also the CEO of Tesla, could have very different incentives than in a small market like Russia. Tesla has considerable exposure to the Chinese market through its Shanghai factory, which manufactured half of Tesla's global supply in 2021.[33] Musk already stated that Taiwan should be put under Chinese control as part of a special administrative zone.[34] In light of these comments, Taiwan cannot be confident that Starlink will reliably provide internet services in times of war.

Instead, for Taiwan becoming more resilient might mean relying on a variety of providers of satellite communications technologies, as well as developing domestic capabilities. Having observed what happened in Ukraine, the Taiwanese government will now spend $18 million to set up 700 satellite receivers across the island and overseas to uphold critical communications in emergency situations.[35] This plan is called the "Communication Network Digital Resilience Reinforcement with Response or Wartime Application Emerging Technology Plan" and should ensure continued communication in times of war.[36]

In the medium term, the Taiwanese government aims to spin off a project of the Taiwan Space Agency (TASA) that covers low earth orbit satellites. The aim is to retain a minority stake in this

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[31] A. Hern, "Elon Musk's SpaceX says it can no longer fund Starlink internet in Ukraine", *The Guardian*, 14 October 2022.

[32] "Elon Musk draws backlash from Ukrainian officials with unsolicited 'peace' plan", *CBS News Bay Area*, 3 October 2022.

[33] H. Davidson, "Taiwan politicians dismiss Elon Musk's 'ill-informed and belittling' China comments", *The Guardian*, 10 October 2022.

[34] Ibid.

[35] "Taiwan seeks satellite solutions after undersea cables cut", *RFI*, 13 April 2023.

[36] K. Everington, "Taiwan building backup satellite internet network amid risk of Chinese attack", *Taiwan News*, 14 September 2022.

company, which could provide communication services in times of conflict.[37] Taiwan's digital minister said that their "primary concern… is facilitating the societal resilience, to make sure for example that journalists can send videos to…international viewers even during a large-scale disaster".[38]

Assessing China's Cyber Challenge to Taiwanese Critical National Infrastructure

Having examined the state of Taiwan's internet infrastructure, this article now broadens its analysis to other parts of Taiwan's CNI. While it is difficult to say whether Taiwan's cybersecurity practices have *prevented* shocks induced by Chinese cyber operations, it is in some instances more feasible to assess whether a cyber operation's impact has been *reduced* or to assess how quickly Taiwan *recovered* from incidents. Those are all indicators of resilience. The article examines 9 major cyber events that targeted Taiwan's critical infrastructure in the past 5 years. While this is a non-comprehensive list of cyber activities that targeted Taiwan in this span, it does provide a glimpse of who the Chinese actors focusing on Taiwan are, what infrastructure sectors they target, which aims they pursue and how successful they were in their endeavours.

While the main threat actor challenging the internet connectivity of Taiwan appears to be the PLA, cyber operations against Taiwanese CNI are extensively carried out by various groups that operate on behalf of China's Ministry of State Security (MSS), which is tasked with foreign intelligence gathering. The groups that have targeted Taiwan in the past years (APT10 and threat actors clustering around the Winnti Group) will likely also be active during an invasion as they are familiar with exploiting Taiwanese networks.

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[37] K. Hille, "Taiwan plans domestic satellite champion to resist any China attack", *Financial Times*, 6 January 2023.

[38] Hille (2023).

In the various cyber activities laid out below, the major aims of China's efforts can be defined as follows. China is seeking to undermine Taiwan's industrial competitiveness through widespread cyber-industrial espionage targeting its world-leading semiconductor and computer industry, as well as crucial research organisations, which serve as incubators for technology startups. While in many countries economic losses due to Chinese espionage are painful, for Taiwan it is a matter of survival. If the Taiwanese industry becomes less competitive and economic growth suffers, the support for independence within the population may wane. China has long argued that unification would be beneficial to the Taiwanese economy.

Second, China has been widely targeting Taiwanese government entities to gain politically sensitive information. This could be used to incriminate government officials in future disinformation campaigns or serve the gathering of information to broaden its cyber operations against even more politically sensitive targets. It might also help China to better gauge Taiwan's readiness to fight.

One crucial goal of China's cyber activities has been to sow fear and distrust in Taiwan's economic and political institutions among Taiwanese citizens. The attacks on the energy, financial and government sectors serve this purpose. It appears as if Chinese communist leaders want Taiwanese citizens to experience negative repercussions for their independently minded political leaders, as was the case during the ColdLock ransomware attack, where China used cyber operations to cause economic damages a few weeks before the Taiwanese presidential inauguration. Similarly, it was alleged that Chinese patriotic hackers defaced Taiwanese websites and made them inaccessible during Nancy Pelosi's (Speaker of the US House of Representatives) visit to the island-country.

Another goal of China might be to maintain persistent access to Taiwanese networks. This would allow it to maintain strategic optionality.[39] In other words, in the Barium and Antlion cases detailed below, China may have been preparing the ground for the day that it may need access to selected organisations, e.g. in the event of an invasion. This access would give it options for disrupting those networks at a time of its choosing or to continue gathering intelligence through them.

The following lines give an overview of the 9 cyber incidents on which the above analysis is built.

Stealing intellectual property

Chimera – Chimera is a threat group that has been targeting Taiwan's semiconductor industry with the aim of stealing intellectual property, including source code and software development kits in 2018 and 2019.[40] The semiconductor companies were based in the Hsinchu Science Park in the northwest of Taiwan, which qualifies as a critical infrastructure. Then in April 2020, a highly sophisticated threat group targeted Taiwanese government agencies. While the attribution to Chimera was not made, due to insufficient evidence, several techniques of this threat group resembled those of Chimera, leading to the conclusion that Chinese threat groups share tools and malware.[41]

TAG-22 – In 2021 this threat group targeted the Industrial Technology Research Institute in Taiwan, which has been key in incubating major chips companies such as TSMC or UMC.[42] The main aim might have been to exfiltrate vital data to make Chinese companies more competitive.

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[39] Weber (2023).

[40] *CyCraft*, "Craft for Resilience", n.d..

[41] "Taiwan Government Targeted by Multiple Cyberattacks in April 2020", *CyCraft*, 14 October 2020.

[42] Industrial Technology Research Institute, "ITRI Overview"; Inskit Group, "Chinese State-Sponsored Activity Group TAG-22 Targets Nepal, the Philippines, and Taiwan Using Winnti and Other Tooling", 8 July 2021.

Gaining long-term access to politically sensitive data

BlackTech – In another cyber espionage operation that started in 2018 and continued up until 2020, BlackTech, a threat group linked to the Chinese government, aimed to compromise several Taiwanese government agencies using Taidoor malwar. It also staged a supply chain attack targeting Taiwanese technology companies that contracted with the government.[43] The aim of the operation seems to have been the exfiltration of sensitive data out of government agencies. Separately, BlackTech may have been also behind the targeting of government agencies using the Waterbear malware in April 2020, potentially with similar motives.[44]

Earth Preta – This threat activity group is interesting as it aims to gain a long-term foothold in government networks across the world including in Taiwan. Such activity relating to Taiwan was discovered in 2022 and may have served as an exercise to gather documents and data that could propel future cyber intrusions.[45]

Economic and political disruption

Winnti[46] – At the beginning of May 2020 a ColdLock[47] ransomware attack struck CPC Corporation (Taiwan Chinese

[43] Y. Lee, "Taiwan says China behind cyberattacks on government agencies, emails", *Reuters*, 19 August 2020.

[44] *CyCraft* (2020); V- Su, A. Hsieh, and D. Chiu "Waterbear Returns, Uses API Hooking to Evade Security", *Trend Micro*, 11 December 2019.

[45] N. Dai, V. Su, S. Lu, "Earth Preta Spear-Phishing Governments Worldwide", *Trend Micro*, 18 November 2022.

[46] The Winnti Group, Barium or Threat Activity Group 22 (TAG-22) are threat labels that point to a threat cluster of private contractors working on behalf of the Chinese Ministry of State Security; The U.S. Department of Justice, Seven International Cyber Defendants, Including "Apt41" Actors, Charged In Connection With Computer Intrusion Campaigns Against More Than 100 Victims Globally, 16 September 2020; Inskit Group (2021).

[47] David, "Targeted Ransomware Attacks in Taiwan", *Cyberint*, 14 May 2020; "China-Linked Threat Group Targets Taiwan Critical Infrastructure, Smokescreen Ransomware", *CyCraft*, 2 June 2021.

Petroleum),[48] which is a major state-owned importer of oil products and liquefied natural gas to Taiwan.[49] Alongside it, 10 other Taiwanese companies were targeted, including the country's largest telecommunications company, Chunghwa Telecom, as well as Formosa Petrochemical Corp and Powertech Technology Inc.[50] Winnti group[51], a Chinese threat actor, was identified as the attacker. The operation did not affect energy delivery directly, but CPC payment cards were unable to buy gas,[52] so customers had to pay by cash or credit card.[53] As such, the attack did have some effect onto the targeted networks, but it was very brief.[54] Since there was no way to decrypt the encrypted files, the supposedly financially-motivated ransomware attack was just a disguise for other nefarious and more political motives pursued by Chinese state-led threat groups.[55] The fact that the attack took place weeks before Taiwan's presidential inauguration points to the motive of exerting fear onto the Taiwanese population if it pursues supporting candidates that support a more independent Taiwan, e.g. Tsai Ing-Wen.

APT10 – In 2021 and 2022, APT10 (medium degree of attribution confidence), a Chinese state-sponsored threat group affiliated with the Ministry of State Security (MSS) conducted several cyber operations against Taiwan's financial and securities trading industry that undermined the confidentiality and integrity of data.[56] The threat group conducted a sophisticated

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[48] Ministry of Justice Investigation Bureau, "Investigation of ransomware attacks on important domestic enterprises", n.d.

[49] S. Lyngaas, "Taiwan's state-owned energy company suffers ransomware attack", *Cyberscoop*, 5 May 2020.

[50] "Bureau names ransomware culprits", *Taipei Times*, 17 May 2020; *CyCraft* (2021).

[51] Ministry of Justice Investigation Bureau, n.d.

[52] S. Lyngaas, "Taiwan suggests China's Winnti group is behind ransomware attack on state oil company", *Cyberscoop*, 18 May 2020.

[53] *CyCraft* (2021).

[54] Ibid.

[55] Ibid.

[56] "China Implicated in Prolonged Supply Chain Attack Targeting Taiwan

supply chain attack exploiting a zero-day vulnerability in financial software, which gave the group access to several Taiwanese security traders.[57] The attacks resulted in manipulated stock prices and thereby in a loss of confidence in financial markets and Taiwan as a safe place for investments. Two securities traders had to suspend their online trading, which caused additional financial losses.[58]

Patriotic hackers – During Nancy Pelosi's visit to Taiwan in 2022, it is alleged that patriotic hackers conducted Distributed Denial of Service (DDoS) attacks against the Taiwanese presidential office, the Ministry of Defence and the Ministry of Foreign Affairs as well as Taiwan Taoyuan International Airport, where Pelosi's plane arrived.[59] At the same time hacked TV screens at public grocery stores were flooded with anti-American messages.[60] The primary aim of these activities was to sow fear and confusion within the population. But the attacks remained underwhelming. The airport's website was unstable for only three hours, for instance. This resilience was also due to security precautions that critical entities in Taiwan had taken prior to the incident.[61]

Broader espionage campaigns

Antlion – Antlion has been one of the most persistent Chinese threat groups targeting Taiwan. It managed to maintain illicit access to financial institutions for over 18 months, giving it ample time to identify valuable information on those networks.[62]

Financial Sector", *Cycraft*, 22 February 2022.

[57] Ibid.

[58] "Smokescreen Supply Chain Attack Targets Taiwan Financial Sector, A Deeper Look", *CyCraft*, 1 March 2022.

[59] M. Miller, "Taiwan presidential office website hit by cyberattack ahead of Pelosi visit", *Politico*, 8 February 2022.

[60] S. Wu, "From 7-11s to train stations, cyber attacks plague Taiwan over Pelosi visit", *Reuters*, 4 August 2022.

[61] S. Shan, "Record number of cyberattacks reported", *Taipei Times*, 5 August 2022.

[62] Symantec, "Antlion: Chinese APT Uses Custom Backdoor to Target Financial

Barium – In 2019, a supply chain attack against ASUS systems, a major Taiwanese computer company, came to light. The attackers inserted a backdoor into the ASUS Live Update Utility, affecting masses of people, but the attackers limited the payload execution to around 600 victims. It is still unknown who the victims were.[63]

Tab. 13.1 - Selected high-level cyber incidents targeting Taiwan during the past five years (2018-23)

Chinese-based entities targeting CNI	Government entity	Target	Goal of cyber activities
Chimera (2018-2019)	/	Semiconductor industry	Espionage (IP theft)
Barium (2019)	MSS	ASUS	Espionage
BlackTech (2018-2020)	/	Taiwanese government	Espionage
Winnti (2020)	MSS	Finance and energy	Disruption (ransomware)
TAG-22 (2021)	MSS	Major technology research organization	Espionage
APT 10 (2021-22)	MSS	Financial and securities trading sector	Disruption and espionage
Antlion (2020-22)	/	Finance	Espionage
Earth Preta (2022)	/	Government	Espionage
Patriotic hackers (2022)	/	DDoS and defacements of TV screens	Disruption

ISPI

Institutions in Taiwan", 3 February 2022.

[63] GReAT and AMR, *Operation ShadowHammer: a high-profile supply chain attack*, 23 April 2019; Kasperssky, *Operation ShadowHammer: new supply chain attack threatens hundreds of thousands of users worldwide,* 25 March 2019.

Conclusion: Chinese Perceptions of Taiwanese Resilience and Implications for a Taiwan-China Conflict

As shown above, cybersecurity has been key to maintain the resilience of Taiwan's critical infrastructure. It has helped it to identify threats and mitigate them, thereby bolstering Taipei's economic competitiveness and its ability to keep government secrets, while maintaining the Taiwanese people's confidence in their country's capacity to self-govern. But China has been constantly testing how resilient Taiwan's national critical infrastructure is. It targeted Taiwan's energy sector under the guise of criminal activity. It has deeply penetrated Taiwan's financial sector. It is likely that it cut submarine cables connecting Matsu Islands and Taiwan with the help of civilian Chinese ships.

It is unclear how China assessed these operations. If China perceives that its cyber operations and sabotage activities were effective and that Taiwan's resilience is low, it might be more inclined to launch an invasion. In contrast, if Taiwan appears to be well prepared it would make a Chinese invasion both less likely to succeed and more costly.

So, does China consider its operations a success or does it view them as having underperformed? Considering that no major long-term cyber disruption let alone destruction has occurred in Taiwan to date, it is unlikely that these publicly attributed cyber operations were considered a confidence-booster for Chinese cyber operators. Also, the disruptive cyber operations and disinformation campaigns that aim at inducing fear into Taiwan's population are unlikely to succeed. Russia has been attempting to do this unsuccessfully for years in Ukraine. And yet Ukraine remains willing to fight. However, it might be that sabotage operations such as cutting submarine cables have boosted Chinese confidence in a successful annexation of (at least parts of) Taiwan, as internet connectivity has been severely reduced in the Matsu Islands and damage reparations have been time consuming and costly for Taiwanese operators. In addition to this, the long-term and clandestine cyber operations that give China persistent access to Taiwanese networks might feed into China's confidence to be able to use this access during an invasion.

Going beyond Chinese perceptions, all the above paints a mixed picture of Taiwanese resilience. The island country has not experienced a major blow due to Chinese meddling activities, and yet its critical infrastructure remains vulnerable to Chinese attacks, especially the archipelagos of islands that are located closer to China. However, the more China is testing the ground, and the more it meddles into Taiwanese affairs, the more experienced Taiwanese defenders become. Like in Ukraine, where Russia has been engaged in disruptive cyber activities for years, such operations have only made defenders more experienced and given them ample opportunity to build resilience.

PART II
CHALLENGES

14. Future-proofing Existing Infrastructure for a Changing Climate: Resilience Building and Maintenance

Raffaele Della Croce, Savina Carluccio

Following the Covid-19 shock to economies and societies and further to the recent energy crisis caused by the Ukraine war, many countries are renewing investment in existing infrastructure as a stimulus measure. Such investments present a golden opportunity for governments to address complex and interconnected infrastructure challenges through targeted maintenance spending, while seizing the opportunity to embed resilience, adapt to climate change and prepare infrastructure for an uncertain future.

The Urgent Case for Resilient Infrastructure

Recent events have highlighted the strains on and fragility of our infrastructure. As exemplified during the Covid-19 pandemic crisis and by recent severe flooding in Germany, Belgium and Italy, infrastructure systems such as healthcare, power, water and sanitation, transport, and telecommunications are particularly vulnerable, as they are often organised into networks through which even small local shocks can propagate quickly.[1] Increasing pressure on infrastructure systems has been

[1] OECD, "Good Governance for Critical Infrastructure Resilience", *OECD Reviews of Risk Management Policies*, OECD Publishing, Paris, 2019.

compounded by fragmented governance, poor maintenance, mismanagement and chronic underinvestment, pushing many of these systems toward an increasingly uncertain future.[2] Infrastructure systems with low resilience are disrupted with greater frequency, higher intensity, on a larger scale and for longer durations than more resilient systems. The impacts of an infrastructure disruption can cascade across cities, regions and nations, causing society-wide disruption to essential services and threatening the realisation of other infrastructure-enabled outcomes.[3]

Climate change poses a number of threats to economic development and impacts on infrastructure. As governments reconsider their priorities and implement recovery plans, they face major new challenges.[4] Infrastructure investment is subject to increasing levels of complexity as it is being called upon to meet multiple, often conflicting objectives and to deliver multiple benefits both in the short and long term, in a context of increasing interconnectedness and interdependence of infrastructure systems across regional geographies, sectors and levels of government. Lifeline infrastructure systems are increasingly impacted by hazards with human-induced and natural origins.[5] Climate change poses a number of threats to economic development and impacts on infrastructure, with rising sea levels and increased risk of drought in some areas, in connection with extreme wildfires, shifting rainfall patterns and

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[2] B. Collins, "Strategic Issues: Discussion Paper", National Preparedness, December 2020.

[3] T. Dolan, "Systemic Perspectives on National Infrastructure for a Sustainable, Resilient Net Zero Future", *Frontiers in Built Environment*, vol. 7, 15 November 2021.

[4] OECD, *OECD Implementation Handbook for Quality Infrastructure Investment Supporting a Sustainable Recovery from the COVID-19 Crisis*, 2021; OECD, *Aligning short-term recovery measures with longer-term climate and environmental objectives*, G20 Italia, 2021.

[5] United Nations Office for Disaster Risk Reduction (UNDRR), "Principles for resilient infrastructure", 2022.

greater prevalence of temperature extremes[6]. Climate change is expected to exacerbate adverse impacts caused by multiple hazards and compounding threats, prompting an even greater need to strengthen infrastructure capabilities that can address known and unknown threats.

Current geopolitical tensions and the Covid-19 pandemic have added to the deep uncertainty over which infrastructure investment must take place. Uncertainty, ambiguity, volatility and complexity are inherent characteristics of the environment where infrastructure needs to exist and operate.[7] Uncertainty in projecting the future impacts of climate change, as well as the broader environmentally harmful impacts of socio-economic expansion, such as biodiversity loss and ecosystem degradation – including reaching tipping points beyond which it is difficult to predict ecosystem responses – is compounded by other pressures, such as accelerating technological change, population growth and urbanisation. The system-wide impacts caused by the Covid-19 pandemic and – more recently – ongoing geopolitical tensions have threatened the ability of infrastructure systems to sustain economic and social activity and have heightened the need to consider infrastructure resilience alongside impacts on communities at a broader level.

Spending better, adopting a lifecycle approach, leveraging Digitalisation and Nature Based Solutions. In the current

[6] Many changes in the climate system become larger in direct relation to increasing global warming. For example, every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves (very likely), and heavy precipitation (high confidence). See Intergovernmental Panel on Climate Change (IPCC), "Summary for Policymakers", in *Climate Change 2021: The Physical Science Basis*, Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, Cambridge University Press, 2021; Idem, "Summary for Policymakers", in *Climate Change 2022: Impacts, Adaptation, and Vulnerability*, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

[7] N. Bennet and J.G. Lemoine, "What VUCA Really Means for You", *Harvard Business Review*, January 2014.

context of constrained finance, ageing facilities and rising demand, optimising existing infrastructure assets upgrades the existing asset stock, making it more effective, cheaper and longer lasting. As infrastructure needs far exceed the resources available to countries, policy intervention should focus on spending current resources better and increasing the efficiency of capital spending. Improving infrastructure governance to produce better outcomes from existing assets is among the critical ways to close the global infrastructure gap. [8] Digitalisation and Nature Based Solutions (NbS) can make infrastructure assets more resilient and enable "building back better".

The Investment Case for Resilient Infrastructure

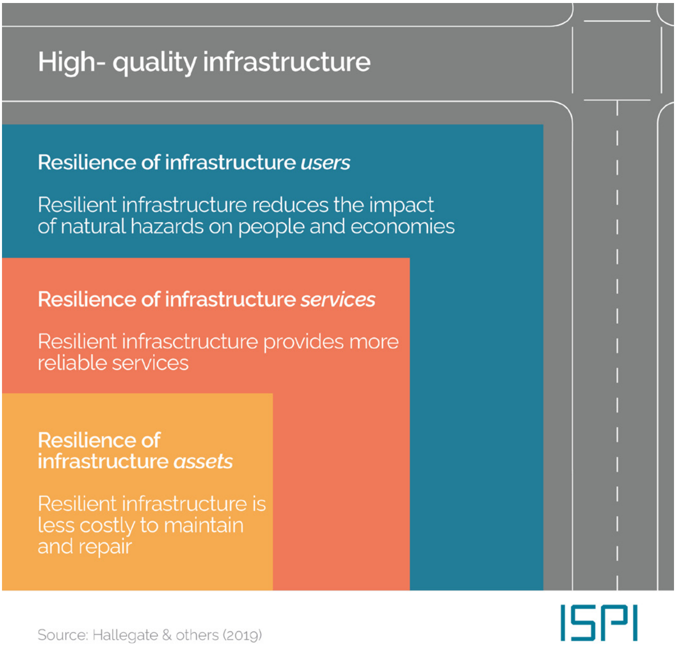
Recognising the full breadth of benefits and true value delivered by resilient infrastructure, while acknowledging the potential trade-offs against other policy drivers. Recognising the multi-dimensional qualities of resilient infrastructure (e.g., resilience of individual assets, services provided and infrastructure users) can help articulate the broader benefits delivered by the infrastructure (see Figure 14.1).

Resilience measures can generate a broad range of socio-economic and environmental co-benefits,[9] such as reducing the incidence of unsafe sanitation or providing new jobs. However, some of these co-benefits can be difficult to quantify in a way that can attract investors and the full suite of benefits can take a long time to come to fruition.

[8] OECD, "Getting Infrastructure Right: A framework for better governance", OCED Publishing, Paris, 2017; OECD, "Recommendation on the Governance of Critical Risks", 2017; J. Rozenberg and M. Fay, *Beyond the Gap: How Countries Can Afford the Infrastructure They Need while Protecting the Planet. Sustainable Infrastructure*, Washington, DC, World Bank, 2019.

[9] ICSI (2021).

Fig.14.1 - Multidimensional resilience of infrastructure and value delivered



In addition, there will often be trade-offs to be made between resilience and other policy objectives. Many of the techniques for increasing the reliability of service provision may also increase costs, for example, by adding redundancy or designing assets to account for a wider range of potential climates and adapt them to those changes through retrofitting[10]. As well as

[10] Additional costs for adapting infrastructure (new construction or rehabilitation) depends on the risk, type of asset, and location. For example, increasing a road's resilience to flooding by improving the drainage system only costs a few percent more, while increasing the level of a railway line may increase costs by up to 50%, *Overview of Engineering Options for Increasing Infrastructure Resilience. Project Report*, Miyamoto and World Bank, 2019; C. Evans et al., "Maintaining Resilient Infrastructure Systems", T20 Policy Brief, Italy, 2021; International Transport

the possibility of higher costs, there may be other trade-offs to make, for example, installing hard coastal defences has the potential to disrupt ecosystems or increase the rate of erosion of other properties and has higher embodied carbon.[11]

Coupling resilience building with maintenance spending presents an opportunity with potential to deliver benefits, both in the short and long term. The benefits of implementing resilience measures alongside maintenance interventions can be higher than the cost of inaction. Rozenberg and Fay find that,[12] without good maintenance, infrastructure capital costs could increase by 50% in the transport sector and more than 60% in the water sector. Kornejew, Rentschler and Hallegatte (2019) find that resilience measures for infrastructure projects produce an average of $4 in benefits for every $1 dollar spent and, in OECD countries, every additional $1 spent on road maintenance saves on average $1.50 in new investments, making better maintenance a very cost-effective option.[13] OPEX and other lifetime costs, such as damage repairs following adverse events, often are underestimated compared to CAPEX costs, due to uncertainties and insufficient available information. In the case of existing infrastructure, ageing and faster deterioration resulting from changes in use or environmental conditions, exacerbated by climate change, are straining operation and performance, and can lead to increased vulnerability and slower recovery in the event of failure.

The G20 Policy Agenda on Infrastructure Maintenance, endorsed in 2021 invites readers to look at spending on infrastructure maintenance not just as the cost of keeping assets

Forum (ITF), "The Bn Dollar Question: How Much Will It Cost to Decarbonise Cities' Transport Systems?", International Transport Forum, Paris, 2018.

[11] OECD, *Climate Resilient Infrastructure*, Policy Perspectives, OECD Environment Policy Paper No. 14, 2018.

[12] Rozenberg and Fay (2019).

[13] M. Kornejew, J. Rentschler, and S. Hallegatte, "Underutilized Potential : The Business Costs of Unreliable Infrastructure in Developing Countries", Policy Research Working Paper; No. 8899, Washington, DC., World Bank, 2019.

in good order, but rather as an investment yielding significant benefits both in the short and long term[14]. For countries, resilience is key for absorbing the impacts of adverse shocks, but it also creates a unique opportunity to ensure protection against future risks as part of their recovery efforts. Private investors are also increasingly recognising the business case for broader sustainability and require assets to meet ESG criteria to manage risks, respond to regulatory requirements and initiatives such as the EU Taxonomy for sustainable investment. Ultimately, this is an opportunity to propose a new delivery model for infrastructure that includes sustainability and resilience considerations on a routine basis.

Using Asset Management to Optimise Existing Infrastructure and Building Resilience

Need to leverage existing assets. Progress in delivering infrastructure has been relatively slow, despite the high priority for economies and societies and international and regional initiatives currently undertaken.[15] Ensuring affordable and reliable access to basic services remains a major challenge in lower and middle-income countries, while advanced economies are struggling with underinvestment in their ageing infrastructure.[16] Ultimately, a new holistic and comprehensive approach to asset management is needed to optimise existing assets and leverage new opportunities.

[14] *The G20 Policy Agenda on Infrastructure Maintenance* was endorsed by G20 Finance Ministers and Central Bank Governors at their meeting in Venice in July 2021.

[15] G20/OECD, *Report on the Collaboration with Institutional Investors and Asset Managers on Infrastructure: Investor Proposals and the Way Forward*, 2020; T. Serebrisky et al., *Financing Infrastructure in Latin America and the Caribbean: How, How Much and by Whom?*, Washington DC, Inter-American Development Bank, 2015.

[16] OECD, *Getting Infrastructure Right: A framework for better governance*, OCED Publishing, Paris, 2017; OECD, *Recommendation on the Governance of Critical Risks*…, cit.

BOX 1 - RESILIENCE DEFINITIONS[1]

Resilience is a key part of sustainable and quality infrastructure. Developed under the Japanese G20 Presidency, the *G20 Principles for Quality Infrastructure Investments* highlight the importance of "raising economic efficiency in view of lifecycle cost" and "Building Resilience against Natural Disasters and Other Risk".

Resilience is usually related to the structural integrity of systems and physical infrastructure during their lifecycle. The engineering concept of resilience is based on specific criteria outlined by four pillars of resilience: robustness, resourcefulness, rapidity, and redundancy.[2] **Resilience applies to both "normal" usage** of the infrastructure facilities which need to be resilient to time, usage, obsolescence, environmental impacts (including slow-onset impacts related to climate change), etc., as well as **"abnormal" pressures** such as those stemming from natural hazards (*e.g.*, earthquakes, tsunami, floods, storms etc., some of which may be exacerbated by climate-change impacts) or large health crises (*e.g.*, epidemics or pandemics), as well as other human-induced threats such as terrorism, industrial accidents, etc.

Transformative Resilience. The OECD defines resilience as "the capacity of systems to absorb a disturbance, recover from disruptions and adapt to changing conditions while retaining essentially the same function as prior to the disruptive shock".[3] Beyond simple adaptation, the Covid-19 emergency offers an opportunity for

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[1] See for further reference the forthcoming ICSI (2023). Upscaling infrastructure resilience through innovative financial approaches, governance, and practice. (Awaiting publication)

[2] Bruneau and Reinhorn, 2006.

[3] OECD, "Good Governance for Critical Infrastructure Resilience", *OECD Reviews of Risk Management Policies*, OECD Publishing, Paris, 2019.

transformative resilience,[4] and planning antifragile systems.[5] Beyond the physical infrastructure, the **UN definition for resilience** is: "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions".[6]

Investment in resilient infrastructure. Resilience of infrastructure focuses on the ability of infrastructure systems to absorb, adapt and transform in response to threats. An investment in resilient infrastructure can increase the robustness of an asset or group of assets (e.g. flood barrier), it can improve safety, continuity and reliability of the services provided by the infrastructure (e.g. early warning system) but can also adopt a systemic approach that delivers wider resilience outcomes, such as increased wellbeing of users, economic growth, improved ecosystem health (e.g. nature-based solutions). Resilience financing should adopt a lifecycle view and be agnostic to specific threats; however, given the significant and ubiquitous impacts of climate change and its interconnectedness with other risk drivers, resilient infrastructure investments should routinely include consideration of climate-related risks.[7]

Governance of infrastructure for resilience. Governance of infrastructure comprises the processes, tools, and norms of interaction, decision-making and monitoring used by governmental organisations and their counterparts with respect to making infrastructure services available to the public and the public sector. Good governance facilitates collaboration across sectors and levels (multi-level governance), allows for transparency and

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[4] E. Giovannini, P. Benczur, F. Campolongo, J. Cariboni, and A. Manca, "Time for transformative resilience: the COVID-19 emergency", EUR 30179 EN, Publications Office of the European Union, Luxembourg, 2020.

[5] N.N. Taleb, *Antifragile: Things That Gain from Disorder*, 1st edn, New York, Random House, 2012; I. Blečić and A. Cecchini, "Antifragile planning", *Planning theory Journal*, 2019.

[6] UNDRR (2009).

[7] National Infrastructure Advisory Council (2009).

public engagement, and spans the entire lifecycle of infrastructure projects. Governance of infrastructure for resilience is additionally characterised by an ethos of transformation and adaptation to new challenges and threats, consideration of complementary risk and resilience-based thinking and approaches in all decision-making across the lifecycle of infrastructure and an impetus to catalyse multi-stakeholder collective action to maximise the economic, social, environmental and development impact of infrastructure.[8]

Systemic resilience. Systemic resilience can be defined as the system's ability to reduce the frequency, scale, intensity and duration of cascade failures caused by resilience and sustainability challenges. These challenges are deeply interdependent and are best resolved synergistically through a diverse, long-term, collaborative, dynamic, multifaceted, multi-scale, cradle-to-cradle portfolio of systemically targeted interventions focused on transforming the wider system. Systemic resilience is a dynamic, emergent and intrinsic characteristic of an infrastructure system.

The need for systemically resilient infrastructure is a consequence of a combination of all three of the following: the dynamic complexity of the infrastructure system, the dynamic complexity of the external environment and the interdependencies between the two. Infrastructure governance is critical to change the systemic conditions that cause systemic resilience to be undervalued, underprovided and undermined, and opportunities to enhance whole-system resilience to be undervalued and overlooked.[9]

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[8] A. Kannan, O. Pritchard, C. Freakes, S. Carluccio, and N. Chauhan, *Governance of Infrastructure for Resilience*, White Paper, CDRI and The Resilience Shift, November 2021.

[9] Dolan (2021).

Proper asset management requires a long-term horizon. Proper asset management extends beyond operational and financial goals (internalised costs and benefits), but also explicitly considers environmental and social dimensions (externalised costs and benefits) and the long-term impacts on infrastructure assets. Current decisions on the infrastructure part of recovery packages will determine countries' capacity to reach their climate objectives for the near term (2030) and long term (2050 and beyond) OECD.[17]

Build on asset management best practice to facilitate and integrate climate resilience and adaptation. Effective asset management can become a tool for embedding climate resilience and adaptation and it should be informed by climate change data and risk assessments. An important first step to implementing climate-resilient asset management practices is the development of an asset management action plan that prioritises climate impacts based on the climate risk assessment, identifies actions to combat these impacts, and sets out how they are to be incorporated into asset management procedures.[18]

Recognise the need for risk-based inspection regimes informed by climate-change impacts and implement climate resilience measures beyond routine maintenance activities. Climate-informed, risk-based inspection regimes and proper maintenance practices are essential for minimising the deterioration and likelihood of failure of infrastructure assets. A report by the World Bank Group and UNECA (2016), on the transport sector in Africa, found that "adequate road maintenance is the most critical and most efficient way

[17] Recent OECD work prepared for the G20 Italian presidency has been looking at design of green recovery packages, establishing effective evaluation frameworks and monitoring, aligning recovery packages with climate objectives, and strengthening innovation and R&D. See OECD, "Aligning short-term recovery measures with longer-term climate and environmental objectives", 2021. Prepared at the request of Italy for the G20 meetings of the Energy Transition Working Group and Climate Sustainability Working Group under the 2021 Italian Presidency.

[18] ICSI (2021).

of reducing the impact of a changing climate on the road system".[19] This importance is amplified by the uncertainty of climate change, and maintenance activities can help manage some of this uncertainty.

Asset management and maintenance are critical for ensuring that assets can withstand extreme events. Enhanced monitoring of existing assets or modifying operational routines can reduce the risk of failure as climate conditions change or other vulnerabilities emerge (e.g., digital threats). This can include changing the timing or frequency of maintenance to account for changing patterns of energy demand and supply, investment in early warning systems or purchasing insurance to address financial consequences of climate variability. As climate change progresses, maintenance strategies may need to be reviewed and re-timed, not only to account for the change in risk but also potential changes in patterns of supply and demand.[20] By adopting these preventative maintenance approaches with a consideration of climate change, infrastructure operators will be able to improve the resilience of their assets progressively and responsively throughout their lifespan.

Asset lifecycle management and portfolio approach to infrastructure investment

A lifecycle approach to infrastructure investment takes into account the potential costs of operation and maintenance from the very inception of the project, notably looking at the cost of new projects' value for money (VfM) assessments and affordability estimates, which should include lifecycle costs.[21] An asset lifecycle management approach is key to the development and use of infrastructure assets, optimising balance sheets to maximise returns, managing risks better

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[19] R. Cervigni, A.M. Losos, J.L. Neumann, and P. Chinowsky, "Enhancing the climate resilience of Africa's Infrastructure: the roads and bridges sector", (English), Washington, D.C., World Bank Group and UNECA, 2016.

[20] OECD (2018).

[21] OECD, Implementation Handbook for Quality Infrastructure Investment, 9 July 2021.

and ensuring that assets can withstand disruptions. Climate change adds uncertainty to investment planning as well to the management of infrastructure assets over their long lifecycle. Adaptive management strategies to decision-making explicitly allow for evolving approaches to the management of climate risks. Adaptive management promotes flexible decision-making that can be adjusted in the face of uncertainty as new outcomes from management actions and other events develop.[22]

Portfolio management techniques can help governments understand and better manage current and future risks. Given that governments undertake multiple infrastructure investments at any one time, in aggregate the activity represents an investment portfolio that can be assessed and managed on the basis of a range of criteria, including implementation risk. New Zealand, for example, makes use of risk profiles for each investment project to determine which projects would benefit from monitoring assurance.[23] Beyond risk management, looking at the overall infrastructure asset portfolio through a government balance sheet approach **ensures value for money** (i.e., optimisation of return). According to the IMF (2018),[24] improved management of financial asset holdings and of non-financial public corporations could yield a revenue gain of 3% of GDP per year – equivalent to corporate income tax revenue in advanced economies. This is also relevant for emerging markets, with Africa's maritime ports, for example, operating at a productivity that is only 30% of the international norm.[25]

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[22] CEN-CENELEC, Guide 32: Guide for addressing climate change adaptation in standards, Brussels, European Committee for Standardization & European Committee for Electrotechnical Standardization, 2016.

[23] OECD, Compendium of Policy Good Practices for Quality Infrastructure Investment, 2 November 2020.

[24] International Monetary Fund (IMF), "Fiscal Monitor: Managing Public Wealth", Washington, DC, 2018.

[25] World Economic Forum (WEF), Strategic Infrastructure, Steps to Operate and Maintain Infrastructure Efficiently and Effectively, 2014.

Technology and Natural Solutions as Enablers for Better, More Resilient Infrastructure[26]

Infrastructure technology (InfraTech) as an enabler for resilient infrastructure

New technologies and data science encompassing earth observation, remote sensing, big data, Internet of things (IoT), cloud technologies and machine learning, are transforming how infrastructure is operated and maintained. For example, using blockchain throughout the project lifecycle, particularly in conjunction with Digital Twins, could significantly reduce the time and cost of infrastructure projects, and reduce fraud.[27] Building Information Modelling (BIM) can vastly improve planning, design, construction and – increasingly – operation of assets, while 3D printing is disrupting construction.[28]

Infrastructure technology, or InfraTech, can be described as the integration of material, machine and digital technologies across the infrastructure lifecycle – from development to delivery and operations. Innovations can be cross-cutting, impacting all infrastructure sectors (Artificial intelligence (AI), machine learning (ML), robotics, the Internet of Things (IoT), 3-D printing and batteries), as well as sector-specific ones (such as autonomous vehicles, electric vehicles, smart grids and new

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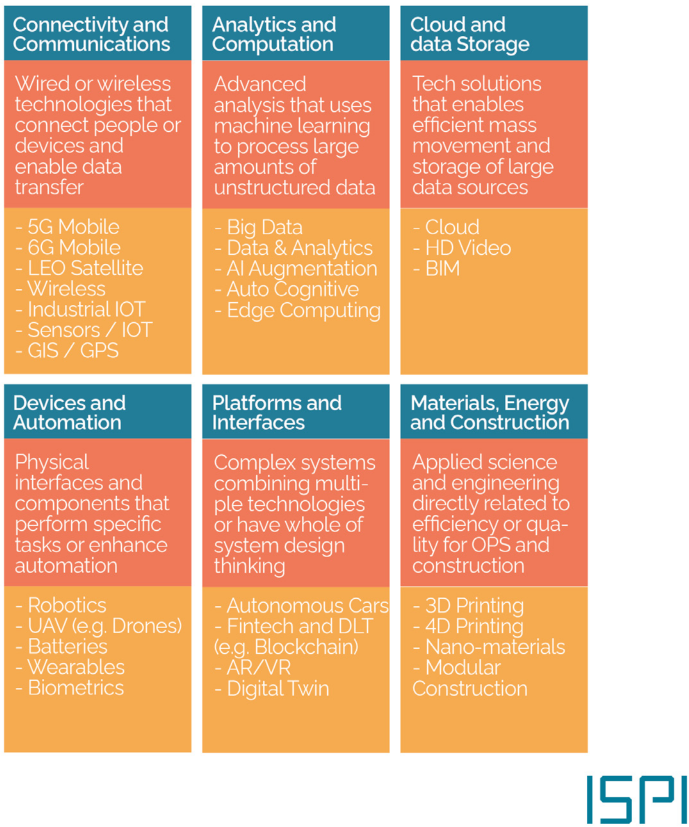
[26] The 2020 G20 Presidency mandated the Infrastructure Working Group (IWG) to develop an Agenda to accelerate the adoption and application of technology-enabled infrastructure (InfraTech). This Agenda supports the existing IWG initiatives, the Roadmap to Infrastructure as an Asset Class ("Roadmap"), and the G20 Principles for Quality Infrastructure Investment ("QII"). Three Reference Notes were produced supporting the Agenda: Value Drivers of InfraTech; InfraTech Stock Take of Use Cases; and InfraTech Policy Toolkit.

[27] OECD, "Blockchain technologies as a digital enabler for sustainable infrastructure", OECD Environment Policy Papers, No. 16, OECD Publishing, Paris, 2019.

[28] OECD, "Blockchain technologies as a digital enabler for sustainable infrastructure", OECD Environment Policy Papers, No. 16, OECD Publishing, Paris, 2019.

biological water filtration techniques). According to the World Bank (2020) there are six main broad technology categories relevant to infrastructure, as shown below:[29]

Fig. 14.2 - Infratech



Source: World Bank (2020)

[29] World Economic Forum (WEF), "4 big infrastructure trends to build a sustainable world", The Davos Agenda 2021, 18 January 2021.

Connectivity and Communications

Wired or wireless technologies that connect people or devices and enable data transfer

- 5G Mobile
- 6G Mobile
- LEO Satellite
- Wireless
- Industrial IOT
- Sensors / IOT
- GIS / GPS

Analytics and Computation

Advanced analysis that uses machine learning to process large amounts of unstructured data

- Big Data
- Data & Analytics
- AI Augmentation
- Auto Cognitive
- Edge Computing

Cloud and Data Storage

Tech solutions that enable efficient mass movement and storage of large data sources

- Cloud
- HD Video
- BIM

Devices and Automation

Physical interfaces and components that perform specific tasks or enhance automation

- Robotics
- UAV (e.g. Drones)
- Batteries
- Wearables
- Biometrics

Platforms and Interfaces

Complex systems combining multiple technologies or have whole of system design thinking

- Autonomous Cars
- Fintech and DLT (e.g. Blockchain)
- AR/VR
- Digital Twin

Materials, Energy and Construction

Applied science and engineering directly related to efficiency or quality for OPS and construction

- 3D Printing
- 4D Printing
- Nano-materials
- Modular Construction

InfraTech also improves resilience by enabling faster and more targeted response to disruptive shocks or shifts in supply and demand. For example, a quicker and more targeted crisis is possible using InfraTech to collect and analyse data effectively to track the outbreak and intervene quickly. As another example, a digital twin for infrastructure can be continuously updated with big data from multiple sources, enabling improved testing of what-if scenarios, analysis of the interdependency of multiple systems and simulation of risks and vulnerabilities – all toward the development of the asset's resilience.

Furthermore, InfraTech has huge potential to improve infrastructure maintenance and reduce related costs. Remote inspections through drone-mounted cameras and sensors can help gather better data on the condition of infrastructure assets, thereby informing targeted maintenance interventions, driving operations efficiency and enabling cost savings. Blockchain technology can also be useful to trace maintenance interventions across multiple stakeholders and improve transparency and trust.

Better and wider application, however, is needed

Even though smart technologies are available and tested, they are not necessarily widely implemented. Several surveys show that, for asset management purposes, companies still depend on traditional statistical modelling such as visual inspection, vibration monitoring and thermal imaging, and use MS Excel as a main analysis tool. This is partially evidenced by the fact that only 5% of enterprises in infrastructure sectors have started implementing digital twins and less than 1% of assets have one.[30]

Patterns of technological adoption vary according to industry. Research undertaken by the Global Infrastructure Hub (GIH), has shown that the uptake of digital technologies is relatively low in infrastructure compared with other sectors across the entire infrastructure project lifecycle, including the operation and maintenance phase.[31] There are in fact several practical challenges hampering the adoption of digital solutions in infrastructure. They include challenges in continuous data collection and management, integration into legacy systems, the investment required for acquiring and installing digital solutions, and, ultimately, a lack of vision on 'going digital' and its prospective benefits to the organisation from top management.

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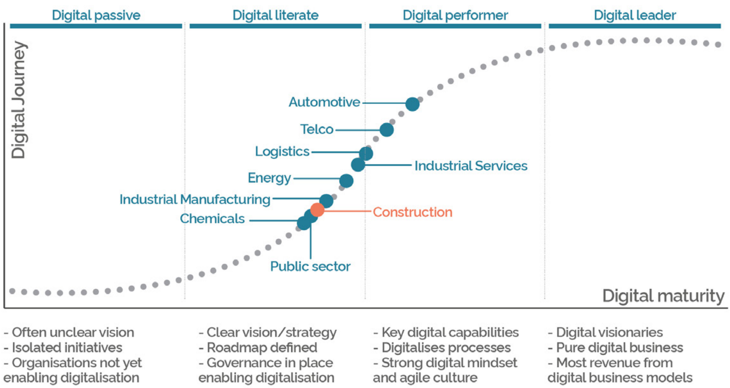
[30] A. Jalan, *The future of IoT predictive maintenance*, 2018; M. Mulders and M. Haarman *Predictive maintenance 4.0 predict the unpredictable*, 2017.

[31] Global Infrastructure Hub (GIH), *InfraTech Stock Take of Use Cases, Global Infrastructure Hub*, G20 Infrastructure Working Group Reference Note, July 2020.

FIG. 14.3 - DIGITAL MATURITY BY INDUSTRY



Source: GIH (2020)

ISPI

Digital passive Digital literate Digital performer Digital leader

Public sector
Chemicals
Energy
Telco
Automotive
Logistics
Industrial Services
Industrial Manufacturing
Construction

- Often unclear vision
- Isolated initiatives
- Organisations not yet enabling digitalisation

- Clear vision/strategy
- Roadmap defined
- Governance in place enabling digitalisation

- Key digital capabilities
- Digitalises processes
- Strong digital mindset and agile culture

- Digital visionaries
- Pure digital business
- Most revenue from digital business models

Digital maturity **Digital Journey**

There are also concerns about privacy, the environment, safety and security. Some technologies pose economic or social risks, as jobs or sectors are disrupted. Certain technologies may also have unintended environmental risks, due to a heavy reliance on energy or rare materials. Open and inter-operable interfaces and industry standards to enable data interchange imply challenges on data privacy and security. Policymakers must put into place appropriate risk management frameworks to manage or mitigate these risks.

Nature-based solutions (NbS) to climate-proof infrastructure and improve ecosystems

NbS are measures that "protect, sustainably manage or restore nature, with the goal of maintaining or enhancing ecosystem services to address a variety of social, environmental and economic challenges".[32] The concept of NbS is fundamentally based on the understanding that natural and managed ecosystems produce a diverse range of services on which human wellbeing depends. For example, floodplains and

[32] OECD, *Scaling up Nature-based Solutions to Tackle Water-related Climate Risks: Insights from Mexico and the United Kingdom*, OECD Publishing, Paris, 2021.

wetlands can protect communities from floods by increasing water retention (an ecosystem service), while simultaneously providing additional co-benefits, such as recreational value and an increase in biodiversity. Similarly, forestry or other interventions aimed at planting trees or restoring soils can increase carbon sequestration, protect against extreme temperatures, landslides, sandstorms or desertification, and provide other ecosystem services to neighbouring communities.[33]

NbS encompass a wide range of actions, such as the protection and management of the natural environment, the incorporation of green infrastructure into urban areas or the application of ecosystem-based principles to agricultural systems.[34] Interventions range from minimal or no interventions, including protection, conservation and monitoring strategies, to management approaches designed to restore entire ecosystems and optimise the generation of chosen ecosystem services, such as planning agricultural landscapes to minimise drought. But NbS can equally be integrated into infrastructure design and maintenance, where it can contribute to lowering the environmental impact of infrastructure assets and operations or enhance the resilience and sustainability of infrastructure itself. For example, the integration of green roofs or permeable surfaces around infrastructure assets can reduce energy consumption as well improve resilience against extreme heat and precipitation.

To fully exploit the potential of NbS, countries need to align their infrastructure policies and planning with national (and international) climate policies and related objectives, within the framework of SDGs or other environmental commitments, such as part of the Convention on Biological Diversity[35]. NbS

[33] OECD (2020).

[34] H. Eggermont et al. "Nature-based Solutions: New Influence for Environmental Management and Research in Europe", GAIA - Ecological Perspectives on Science and Society, vol. 24, no. 4, 2015, pp. 243-48.

[35] The EU has developed a green infrastructure plan as part of its EU 2020

have tremendous potential to reduce vulnerability and exposure to disruptive shocks, including the impacts of climate change, but can also play a key role in rendering infrastructure assets and services greener and more sustainable.

The use of NbS is often a key alternative to be considered for adaptation investments alongside better maintenance and structural measures.[36] Structural adaptation measures **"climate-proof"** infrastructure, by reducing the exposure or vulnerability of an infrastructure asset or network, whether from the outset or as part of a retrofitting process.

Such investment can take the form of **engineering work** with clearly identifiable additional costs, such as building a bridge higher than would otherwise be the case or building to higher design standards.[37] Interventions to develop more resilient assets include using **alternative materials**, digging deeper foundations, elevating assets, building flood protection around the asset or adding redundant components, changing the composition of road surfaces so that they do not deform in high temperatures, building sea-walls or using permeable paving surfaces to reduce run-off during heavy rainfall.[38]

Infrastructure mitigation and adaptation to climate change can be facilitated by **incorporating climate-risk into broader infrastructure planning frameworks**, as well as with critical infrastructure protection programmes. In the Netherlands, following national climate adaptation policy, the aim is to

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Biodiversity Strategy. The Strategy's target 2 requires that "by 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems".

[36] S. Agrawala and S. Fankhauser, *Economic aspects of adaptation to climate change: Costs, benefits, and policy instruments*, OECD, 28 May 2008; OECD (2018).

[37] For example, Brisbane is one of Australia's largest airports in terms of land area and is based on a low-lying coastal site. The consideration of potential climate change impacts (sea level rises, flooding events) led to the resilient design approach in relation to runway height. See Long-term Infrastructure Investors Association (LTIIA), ESG Handbook 2020, June 2020.

[38] OECD, Recommendation of the Council on the Governance of Infrastructure, OECD/LEGAL/0460, 2021.

have climate-proof infrastructure networks by 2050. An implementation agenda is planned for 2021, building on the Rijkswaterstaat climate resilient networks project started in 2018, and including analysis of stress tests and risk assessment, discussed with stakeholders through so-called risk dialogues.[39]

Integrated Approach for Optimising Existing Assets and Building Resilient Infrastructure

A new holistic and comprehensive approach to asset management would optimise existing infrastructure assets while making them more resilient. This approach is designed to get the best out of the asset over its lifecycle, across functions and tasks and the entire infrastructure system/network. As infrastructure will be affected by environment social and governance (ESG) risks, this approach makes it possible to identify trade-offs between objectives, and opt for more robust policy choices. Asset management frameworks offer several opportunities to embed and enhance climate resilience and adaptation over the infrastructure's long lifecycle.

Governments should aim to make the most of existing assets, while urgently adapting them to a changing climate. Asset management should minimise the total cost of owning and operating fixed capital assets (while providing the desired level of service), but also provide the greatest possible lifecycle revenues, user benefits and, hence, aggregate socio-economic

[39] The EC has recently published a methodology on **climate-proofing of infrastructure** to help mainstream climate considerations in future investment and development of infrastructure projects (including buildings, network infrastructure, built systems and assets). This methodology should be followed when performing the sustainability proofing of the climate dimension in the context of InvestEU direct financing to be aligned with the Paris Agreement and the EU climate objectives as required by Article 8(6) of the InvestEU Regulation (Technical Guidance on the climate proofing of infrastructure in the period 2021-2027). G20, "Policy Agenda on Infrastructure Maintenance – Annex – Infrastructure Maintenance Case Studies", 2021.

returns.[40] Climate-change impacts are already disrupting infrastructure across the world, and adapting infrastructure for the long term is no longer a nice-to-have.

New models are needed for private actors to gain community support and the social licence to operate infrastructure assets. A new narrative on infrastructure investment must reconcile the nature of infrastructure as a service with the development of infrastructure as an asset class (i.e., bankable risk-adjusted investment opportunities). This includes providing relevant information for infrastructure investors – in particular, long-term investors such as institutional investors – on the sustainability and resilience of assets in terms of the long-term horizon and of environmental, social and governance (ESG) impacts. To reflect this narrative, alternative models and products need to be developed involving all stakeholders through new forms of collaboration between the private sector, public sector and communities. The financial sector, by applying long-term thinking, has the potential to be a driver of change for the future.

InfraTech and digitalisation help reduce maintenance costs while improving operational reliability and efficiency, and building resilience. Technology development plays a critical role in responding to the Covid-19 crisis by enabling infrastructure to become more resilient to future disasters and pandemics and ensuring the continued operation of critical networks, such as utilities, transport and telecommunications, despite the large-scale disruptions and changing needs caused by the crisis. At the same time, digitalisation introduces new vulnerabilities and challenges, for example to security, confidentiality and platform interoperability.

Nature as a key asset for infrastructure sustainability and resilience. Green infrastructure development ensures that infrastructure itself does not undermine environmental sustainability goals, while also ensuring that infrastructure

[40] WEF (2014).

assets and services are better protected against the unavoidable impacts of environmental degradation and climate change. Climate-change adaptation, including through NbS, can help countries climate-proof their infrastructure, by reducing vulnerability and exposure to sea-level risks or extreme events such as storms or floods.[41] The Covid-19 crisis has highlighted the interconnections between healthy ecosystems and healthy communities. Fostering, replicating and scaling-up NbS where they provide a physically effective and cost-efficient alternative or complement to grey infrastructure solutions is a key opportunity for strengthening infrastructure sustainability and resilience.

Leveraging innovation to realise resilient infrastructure investments will require appropriate infrastructure governance, management capabilities and personal/organisational resilience. To smoothly integrate new technologies and the use of nature into the overall infrastructure system and ensure citizens' acceptance, governments must have good visibility of the rapidly developing concepts. To maximise benefits and minimise risks, existing rules will need to be reviewed and new rules set to engage citizens and businesses in decision-making, including about potential trade-offs for resilient and green infrastructure. To ensure that cost and benefit assessments yield more accurate valuations of the full costs of both grey and green infrastructure, project selection should take account of externalities and long-term impacts (such as the value of ecosystem services to protect against climate risks, the long-term liability and environmental costs of grey infrastructure, etc.). Ultimately, this is the key to developing human resilience, i.e., the ability of people and organisations to adapt to unknown situations, by informing and building the capacity of all the actors involved in infrastructure development and management processes.[42]

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[41] OECD (2018), Climate Resilient Infrastructure, OECD Environment Policy Paper Nb 14.

[42] Evans, Godart, and Kovarik (2021).

15. Digital Technologies for Resilient, Agile and Sustainable Supply Chains

Nicola Sandri, Stefano Napoletano, Luca Milani, Andrea Ricotti

Regions' Interdependencies, Volatility and Key Trends Shaping the Global Logistics and Supply Chain Markets

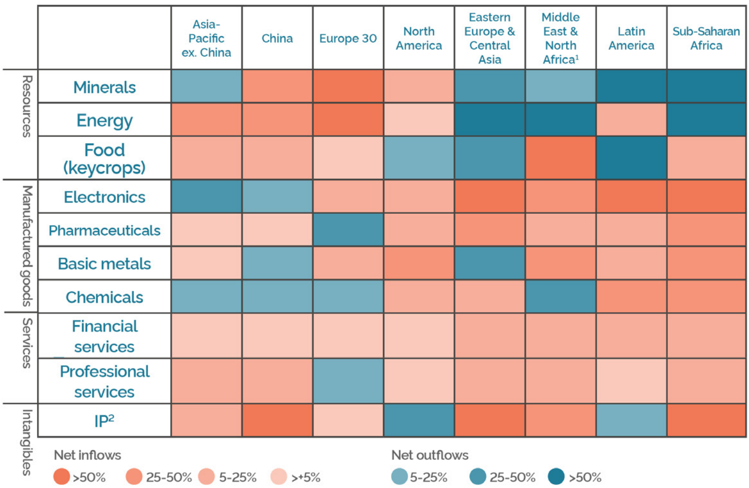
Geopolitical turbulence and recent extreme supply chain disruptions have prompted discussion about the potential for new supply chain architectures. Nowadays, no region is self-sufficient, and all regions are mutually interdependent, joined by large corridors of flows that crisscross the world. Today's global economy relies on the following particularly critical corridors joining different regions:

- **Asia-Pacific**, including China, is the leading global manufacturing exporter overall and the largest supplier of electronics, but it imports more than 25% of its energy resource needs as well as critical intermediate goods. China also imports more than 25% of its mineral needs; the largest mineral corridors in the world run from Australia, Brazil, Chile and South Africa to provide the inputs for China's manufacturing hub. Europe and North America provide much of the advanced machinery and the intangible know-how that supports production of advanced electronics such as semiconductors;

- **Europe 30** is also a strong manufacturing region but imports more than 50% of its energy resource needs. Prior to 2022, Europe 30's largest source of energy resource imports was Russia. Since Russia's invasion of Ukraine in early 2022, European economies have been attempting to diversify sources of natural gas away from Russia. Europe also depends on others for specific inputs into its manufacturing. For instance, while Europe 30 is a significant net exporter of pharmaceuticals, it relies on Asia-Pacific for crucial inputs of active pharmaceutical ingredients;
- **Resource-rich regions**, namely Eastern Europe and Central Asia, Latin America, the Middle East and North Africa (MENA) and Sub-Saharan Africa, tend to be net importers of manufactured goods and services. These regions import manufactured goods roughly equally from Asia-Pacific and Europe 30. Asia-Pacific is the largest partner of these regions for flows of electronics, textiles and basic metals, while Europe 30 is the largest partner for pharmaceuticals and machinery. Resource-rich regions are often also net importers of some types of resources. For example, MENA is the largest net exporter of energy resources, but it depends on other regions for more than 60% of the key crops it needs for food. Prior to the invasion of Ukraine by Russia, large corridors flowed into the region from these two countries. In Latin America, Brazil and Argentina are two of the world's largest grain exporters, but they rely on flows of fertilisers from the rest of the world. Notably, they have been sourcing more than 50% of their potash imports from Russia and Belarus;
- **North America** is a net importer of both manufactured goods and mineral resources; Asia-Pacific is its main partner for both. North America imports about 15% of its electronics consumption needs, and Asia-Pacific accounts for about 85% of these imports, roughly

split between China and other economies in the region. North America also imports about 10% of its mineral consumption, again with Asia-Pacific as its largest partner. North America's reliance on imports of minerals is even more pronounced when looking at a granular level. For example, the United States imports over 70% of its consumption needs for more than 30 mineral commodities.

Fig. 15.1 - No region is self-sufficient. Share of domestic consumption met by inflows, 2019 (%)



1. Limited sample for Middle East and North Africa (8 countries) and Sub-Saharan Africa (5 counries) in manufactured and services
2. IP calculated as net inflows as a share of total flows

Note: IP flows can be distorted by different tax regimes. If outliers with very large IP flows relative to their ....America is a net importer of IP

Source: International Energy Agency, USDA........, Trade in value added, OECD, McKinsey Global Institute analysis.

In this context of regional interdependencies and global connections, the global logistics and supply chain markets are also driven by several key trends around competition, digitalisation, market dynamics and products, which are expected to reshape the industry over the next ten years, further increasing complexities:

- **E-commerce boom, in both the B2C and B2B landscapes**. E-commerce B2C and B2B is expected to grow at an annual growth rate of ~10% and ~20% respectively in the next 5 years, with increasing importance of reverse logistics as well (i.e., return management of products sold online);
- **Near-shoring and regionalisation of flows**. Historically, supply chains have been spread across the entire globe to minimise cost. With supply shortages, difficulties in transport, e.g., container shortages or blockage of major routes, and focus on sustainability, near-shoring of production and regionalisation of supply flows becomes more important. Over the next three years the percentage of suppliers localised at local/regional level is expected to increase from 43% to 57%;
- **Ongoing consolidation in the market**. The logistics market is still fragmented, and digital players offer attractive multiples. Financial and strategic investors have started to inject capital into the market and major players are integrating incumbents and startups horizontally, i.e., acquisitions of competitors, and vertically, i.e., creation of end-to-end solutions;
- **Industry 4.0 and automation of warehouses**. Technologies for warehouse automation are expected to grow at 10-15% per annum in the next five years. Other digital tools, like digital design of warehouses, also have the potential to drive down the cost base by up to 20-25%;
- **Sustainable operations**. Roughly 40-50% of transport related CO2 emissions are caused by freight related

operations. Customers increasingly focus on sustainable supply chains and demand actions to reduce emissions from their suppliers and service providers;

- **Green cities & engine constraints**. Cities account for more than 50% of the global population, 80% of global GDP, two-thirds of global energy consumption and more than 70% of annual global carbon emissions. In this context, efforts to decarbonise cities by banning combustion engines are becoming more popular to tackle sustainability goals;
- **Freight rates volatility**. Market imbalances have led to steep increases in ocean and air freight rates in recent months. Even if shipping earnings will suffer a double-digit decline in the coming months, these are expected to remain considerably higher than pre-pandemic levels, with growth forecast to stabilise at 2-3% per annum;
- **Carriers disintermediating freight forwarders**. Carriers that have traditionally focused merely on the transportation of goods are increasingly moving into other fields of the value chain to build end-to-end services. In particular, shipping companies build and acquire new companies to offer door-to-door services including customs brokerage, warehousing and last mile delivery;
- **Autonomous trucking fleets**. Truck Original Equipment Manufacturers (OEMs), large technology firms and tech-based startups are co-developing autonomous vehicles for land transport, in particular mid-mile. Autonomous fleets can change the market structure in logistics and may provide significant advantages for early adopters, like cost reduction or overcoming driver shortages;
- **Price pressure**. Digitally savvy players enhance transparency of services and prices, through real-time pricing for instance. Transparency coupled with lower switching costs, e.g., via digital/automated onboarding

of new customers, enables easy selection of the best offers on the market and stimulates competition;

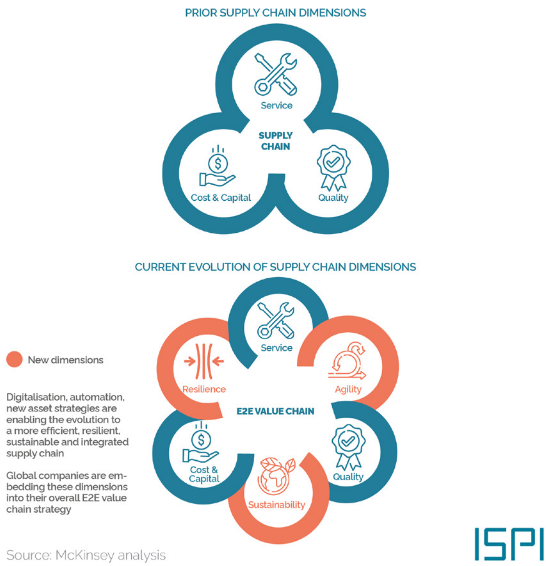
- **Digital capabilities as key selection criteria for choosing logistics providers**. Customers increasingly demand service providers with strong digital capabilities to match their digital initiatives such as process automation. Customer-friendly digital user interfaces, innovative online tools and easy active pharmaceutical ingredients (APIs) are key criteria in the selection process of logistics partners.

Chief supply chain officers now have an unprecedented opportunity to future-proof their supply chains, given the dynamic and ever-changing environment they are working in: besides the function's traditional objectives of cost/capital, quality and service, three additional priorities can be identified in supply chain redesign:

- **Resilience**: addresses the challenges that have made supply chains a widespread topic of conversation;
- **Agility**: ability to meet rapidly evolving and increasingly changing customer and consumer habits and needs;
- **Sustainability**: recognises the critical role that supply chains will play in the transition to a clean economy.

The following paragraphs will further deep dive into potential actions to achieve these new emerging priorities for global supply chains: resilience, agility and sustainability.

Fig. 15.2 - Next-normal supply chains increasingly becoming more complex



Boosting Resilience in Global Supply Chains

Supply chains have always been vulnerable to disruptions, including before the Covid-19 pandemic. Pre-pandemic research by the McKinsey Global Institute, found that, on average, companies experience a disruption of one to two months in duration of every 3.7 years and disruptions of more than two months every 4.9 years. As a matter of fact, in the consumer goods sector, the financial fallout of these disruptions over a decade is likely to amount to 30% of one year's EBITDA. In 2011, a major Japanese car manufacturer suffered six months of reduced production following the Tōhoku earthquake and tsunami, but the company revamped its production strategy, re-localised supply chains and addressed supplier vulnerabilities.

And when another major earthquake hit Japan in April 2016, the company was able to resume production after only two weeks.

Supply chains risks originate at the intersection of vulnerability (i.e., characteristics of the supply chain making it vulnerable to disruption) and exposure to unpredictable events (i.e., occurrence of events that could result in a negative impact on the supply chain). As far as the vulnerability factor is concerned, seven main areas might be examined for vulnerabilities:

- **Financial**: corporate liquidity, changing industry attractiveness;
- **Regulatory**: degree of oversight, potential regulatory changes;
- **Data security**: degree of cybersecurity posture and data-protection protocols;
- **Structural**: trade tensions, climate events, national events;
- **Operational**: visibility into suppliers beyond tier 2; planning accuracy and agility; manufacturing performance; product complexity; sourcing risks; environmental, health and safety performance; delivery performance;
- **Reputational**: presence of reputation issues;
- **Organisational maturity**: strength of risk management capabilities and culture, recent organisational changes.

For example, in 2021, many companies in North America were affected by labour shortages across supply chain operations. Addressing these labour shortages forced companies to redesign their hiring and staffing strategy. For instance, one food distributor created regional labour pools of drivers, warehouse workers and supervisors by recruiting employees in areas where they were more available and deploying them where they were most needed. To ultimately boost resilience in supply chains, corporates will also need a management infrastructure to steer a proactive response to the above-mentioned risks.

Increasing Supply Chain Agility

In the post-pandemic economy, established corporations will face new challenges, from continuously changing consumer habits to new players disrupting business environments. In this context, global corporations will be required to move at the same speed as consumers and new technologies. Whereas traditional supply chains sought to achieve stability and minimise costs, future supply chains will need to be much more agile in order to predict, prepare for and respond to a rapidly evolving environment.

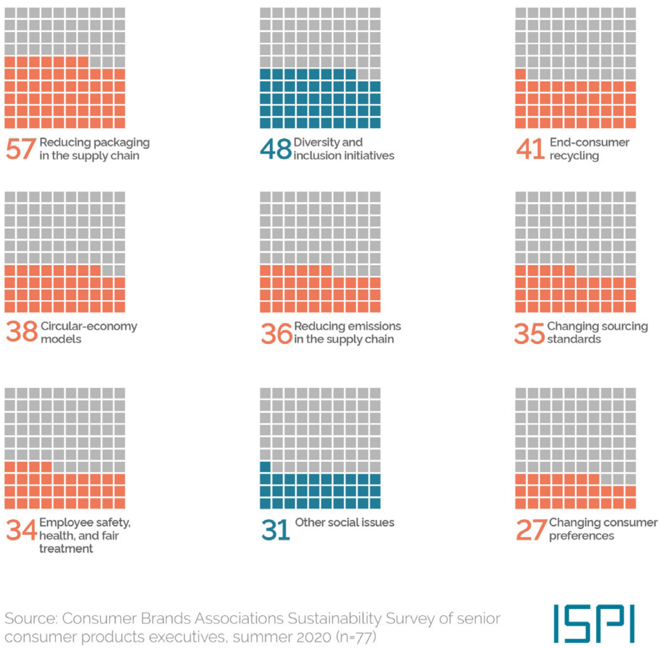
Agile supply chains will also need skilled and flexible people, with cross-functional teams working together to implement new concepts and solve issues within short timeframes. The creation of cross-functional teams, called integrated nerve centres, has surged over the past few years, as a consequence of supply chain shocks originating from the Covid-19 and Ukraine disruptions. Besides these specific situations, integrated nerve centres might be also created to consolidate organisational responses, and can be organised under four categories:

- People: define the nerve centre organisation (e.g., outline clear owners and accountabilities) and decision authority (e.g., clarify any changes in decision authority needed to guide response);
- Operating cadence: define the meeting cadence calendar;
- Decision-enabling tools: create a regular memo detailing the current situation, its potential evolution and immediate decisions needed, proactive definition of strategic actions needed as the situation evolves, description of the status of cross-silo initiatives relevant to the effort;
- Early warning system: cover any relevant developments and broader economic and social factors, monitor potential cybersecurity risks, monitor any supply chain disruption.

Achieving Supply Chain Sustainability

Global supply chains have a central role to play in enterprise sustainability transformation. For instance, based on a McKinsey research study on senior executives in the consumer packaged goods industry, out of the nine most common environmental, social and governance initiatives, seven involve the supply chain directly or have clear implications for supply chain setups: reducing packaging in the supply chain; end-consumer recycling; circular-economy models; reducing emissions in the supply chain; changing sourcing standards; employee safety, health and fair treatment; and changing consumer preferences.

FIG. 15.3 - SEVEN OF THE NINE MOST COMMON ENVIRONMENTAL, SOCIAL, AND GOVERNANCE INITIATIVES HAVE SIGNIFICANT SUPPLY CHAIN COMPONENTS



In the context of an ESG-focused transformation, a clear understanding of the organisation's baseline is of utmost importance. The process can include, for example, quantification of the resources consumed and emissions generated by the company's direct activities (Scope 1 and 2) and by participants in its wider supply chain (Scope 3). An accurate definition of the baseline will allow the organisation to identify the greatest opportunities for improvement, ultimately setting realistic goals that can be achieved within a feasible timeframe.

Technologies and Digital Capabilities as Essential Enablers To Achieve Resilient, Agile and Sustainable Supply Chains

To excel across the six supply chain dimensions previously described (cost & capital, service, quality, resilience, agility and sustainability), rapidly evolving technologies and digital capabilities can act as critical enabling factors to fuel the transformation.

Firstly, on the technologies side, the most interesting opportunities and innovations include:

- **Machine learning and advanced statistical modelling to predict demand**. These tools rely on multiple sources of available data and advanced algorithms to create better demand predictions, ultimately improving forecast accuracy and optimising inventory;
- **Clean-sheet models to streamline and monitor logistics and improve own operation or drive down third-party costs**. These systems are designed to analyse a service cost structure (e.g., road freight, warehousing) in order to identify potential inefficiencies and cost-reduction opportunities;
- **Flexible re-routing to optimise transportation flows**. Re-routing activity involves the act of changing planned routes as a consequence of unexpected roadblocks and/or any potential disruption in the supply chain;

- **Automation and robotics in production and logistics settings**. Big robotics companies are entering the space with specialist products, while manufacturers of conventional material handling equipment are adding automation to their products. These technologies can help warehouses to handle fast-changing multichannel and omnichannel requirements, and increase service levels to support same-day and next-day delivery;
- **Digital twins of the most critical parts of the supply chains**. A digital twin is a virtual replica of a business operation allowing companies to simulate how a product, process or service will perform before it is implemented in the real world. If building a digital twin is not feasible, alternative models to estimate where a product originates in the value chain can be constructed. This approach can help organisations pinpoint hidden suppliers or material flows and expose previously invisible interdependencies.

Coupled with technologies and systems, digital capabilities and a digital mindset at the heart of organisations is required to drive the digital transition:

- **Data modelling skills to model trade-offs between cost, inventory and service**. If a crisis like the ones seen in recent years occurs, the absence of a back stock of inventory or materials can seriously threaten supply chains. Many of today's most pressing supply shortages (semiconductors, for example) occur in supplier sub-tiers where manufacturers have little visibility. To achieve transparency beyond the first tier, companies could work to identify suppliers from spending data, N-tier mapping, or both. Some potential measures to mitigate risk include finding new suppliers, redesigning networks, resetting inventory targets, keeping safety stocks and sourcing locally or regionally;

- **Promote transparency through control towers to avoid long-term inventory build-ups or cost creep, also simulating and planning for extreme supply-and-demand disruptions**. This activity is based on risk analysis in supplier networks, labour, manufacturing and delivery to determine if any part of the value chain is exposed to internal or external disruptions;
- **Creation and testing of "what-if" scenarios**. Construction of what-if scenarios that can be tested quickly can support prioritisation and mitigation on the parts of the supply chain that fail most often. It may seem daunting to create a large number of scenarios almost continuously, with varying levels of detail and impact, but that is critical for this technique to provide insights. The vulnerabilities it reveals may make a big difference;
- **Data sharing with suppliers**. To minimise risk when sharing data, businesses could consider terms that require the disclosure of data under specific conditions. Even if data sharing is restricted, companies may be able to have clean teams share data with a third-party firm that analyses the supply chain for weaknesses and provides recommendations;
- **Value-driven solution design**. Identify the solutions available in the market and define which challenges each digital solution should address (e.g., who should be the primary user and which process should benefit from the enabled technology);
- **Promote co-creation within the organisation**. Improve data governance to facilitate high-quality data for enabling digital solutions and bring in expected end users to codesign digital solutions while upskilling them with the required technological abilities.

All in all, regional interdependencies and industry trends are rapidly changing global supply chains and the overall industry environment more broadly. In this context, shifting the paradigm towards resilient, agile and sustainable supply chains is of utmost importance. Technologies and digital capabilities can act as critical enablers to achieve this transition, ultimately achieving competitive advantage.

16. Green Transition and Energy Industry: The Key Role of Technology Innovation

Laura Cozzi

At the start of last year, the first truly global energy crisis brought about unprecedented energy prices, amid increasing energy security concerns. At the same time a question was asked: would the crises be a break or an accelerator for clean energy transitions.

A year on, the answer is clear: global energy transitions have been supercharged over the last year.

Deployment of solar increased by 40%, and the pipeline of manufacturing projects aligns with what is needed by 2030 to be on a track with a trajectory to meet the most stringent climate goals. Nuclear capacity addition was also up by 40%, and a number of countries are considering extending the lifetime of reactors. EVs reached 15%, up to less than 5% just three years ago. Heat pumps are also showing double-digit growth.

Looking at the current trend it is clear, for the first time this year investment in solar energy will outstrip spending in upstream oil, and investment in clean energy alone is set to reach attain $1.7 trillion – around 60% of total energy investments for the year. In other words, for every dollar invested in fossil fuels, about 1.7 dollars are now going into clean energy. Five years ago, this ratio was one-to-one.

Cost declines in clean energy technologies are driving investments, and so are government policies. The IEA

Government Energy Spending Tracker finds $1.34 trillion allocated by governments for clean energy investment support since 2020. Government spending has played a central role in the rapid growth of clean energy investment since 2020, which rose nearly 25% from 2021 to 2023, outpacing growth in fossil fuels in the same period. The newest outlays identified are predominately aimed at boosting mass and alternative transit modes, low-carbon electricity generation projects and low-carbon vehicle sales. Among all measures tracked since 2020, direct incentives for manufacturers aimed at bolstering domestic manufacturing of clean energy now total to around $90 billion.

The clean energy transition is opening large opportunities for a new industrial age, with important job and innovation opportunities. But an orderly transition will hinge upon managing new energy security risks on critical minerals and clean tech supply chains. We explore them one by one.

The New Energy Economy

Clean energy supply chains are a key indicator of the transformation ahead. In particular they clearly show the unique alignment among the energy security policy, climate policy and industrial policy are having, as remarked in May of this year in the **G7 Clean Energy Economy**

Action Plan

Change is already happening apace in sectors such as electric vehicles and solar PV, heralding a new era in manufacturing, with countries around the world introducing policies to shore up their position in the emerging clean energy economy. This fast-moving transition has been given added impetus by the current global energy crisis, which has increased energy security concerns and starkly illustrates the need for clean energy technologies with diversified supply chains.

The role of clean technology manufacturing in industrial strategy is today a critical consideration for governments, with policy makers committing to scale up investments and diversify supply chains. Strategic policy making in the area of clean technology manufacturing will require a clear understanding of the expected demand for clean energy technologies in different regional and policy contexts, and an assessment of bottlenecks that need to be addressed in order to fulfil climate ambitions.

Three key technologies – solar, batteries, electrolysers – are extremely dynamic, and the manufacturing pipeline is expanding and breakneck speed.

Solar PV manufacturing – which increased at a compound annual growth rate of 25% during the period 2010-2021 – shows no sign of slowing down. In 2022, global manufacturing capacity rose by nearly 40% to about 640 GW, with 90% of the growth relative to 2021 taking place in People's Republic of China.

As of late 2022, IEA's analysis of announced projects for solar PV suggested that manufacturers were already on track to meet projected demand in 2030 aligned with reaching net-zero emissions by 2050. As of end-Q1 2023, the project pipeline has expanded even further, increasing the total volume of planned capacity by 60%.

Major project announcements made in Q1 2023 include new manufacturing facilities for the world's top three producers – LONGi, Jinko Solar and Trina – as well as for other larger (e.g., Tongwei, Suntech) and smaller or emerging players (e.g., Solar Grids, REC Group, Hoshine, Royal), mostly based in China. These major projects account for 45% of the total additional capacity announced as of Q1 2023.

Battery manufacturing capacity is also booming, owing to rapid increases in electric vehicle (EV) sales. In 2021, battery manufacturing throughput stood at 340 GWh, with this figure nearly doubling to reach 660 GWh by 2022. 580 GWh of manufacturing capacity was added in 2022, up 85% from the capacity added in 2021. Looking at the pipeline of announced projects, from late 2022 to end-Q1 2023, planned manufacturing capacity has risen from around 5.5 TWh to 6.8 TWh per year – an increase of 25%. As of late 2022, the total potential output from these announced projects stood at around 80% of what was needed by 2030 to be on track with a scenario compatible with 1.5 degrees.

Electrolyser manufacturing for use in the production of hydrogen is still a nascent. In 2021, electrolyser manufacturing capacity stood at around 8 GW, increasing to 11 GW in 2022. Looking forward, announced projects as of end-Q1 2023 suggest nearly 125 GW of additional installed manufacturing capacity could be expected by 2030. The resulting throughput projected from these announced projects – together with that from existing installations – would achieve more than 60% of the levels needed in IEA's scenario compatible with 1.5 C.

The Role of Innovation

Achieving net zero emissions by 2050 will also need significant boost in clean energy innovation. The technologies presently available in the market offer nearly all the required emissions reductions until 2030, which sets the world on the path to achieving net-zero emissions by 2050. As highlighted in the International Energy Agency's **Net Zero Emissions by 2050 report**, however, the widespread adoption of technologies still in the developmental stage today will be necessary for achieving net-zero emissions beyond 2030. By 2050, approximately 50% of the CO2 emissions reductions will originate from technologies that are presently being demonstrated or are in the prototype stage. This percentage is even higher in sectors like heavy industry and long-distance transport. Significant innovation endeavours are crucial during this decade to ensure that the technologies essential for achieving net-zero emissions enter the market as quickly as possible.

In order to achieve net zero emissions by 2050, it is crucial to accelerate the development of early-stage clean energy technologies significantly compared to past achievements. The majority of clean energy technologies that are still in the experimental phase today need to be introduced to the market by 2030, at the latest. This means that the time it takes for these technologies to go from initial prototypes to being available in the market needs to be approximately 20% faster than the fastest energy technology developments in the past and around 40% faster than the case of solar PV.

At the moment, some technologies currently in the demonstration stage, like CCUS in cement production or low-emissions ammonia-fuelled ships, are expected to be commercially viable within the next three to four years. Hydrogen-based steel production, direct air capture (DAC), and other technologies in the large prototype stage are anticipated to reach the market later, in about six years. Similarly, most technologies in the small prototype stage, such as solid-state refrigerant-free cooling or solid-state batteries, are projected to become available in the market within the next nine years.

Achieving such a significant acceleration is undeniably ambitious. It will necessitate the rapid demonstration of technologies that are not yet available on the market, with a focus on scalability and applicability in various regional contexts.

The required acceleration will also call for a substantial increase in investment in demonstration projects – an investment of $90 billion will have to be mobilized as quickly as possible to create a diverse portfolio of projects, as also agreed by the 13th Clean Energy Ministerial (CEM) in September of last year. The objective is to facilitate rapid learning and facilitate the transition towards widespread deployment. These projects must encompass a range of technologies and must be aimed at proving their viability, scalability, and effectiveness on a larger scale, across four different areas:

There are numerous technologies that will play a key part in accelerating the clean energy transition:

- Clean fuels such as clean hydrogen, ammonia, and bioenergy: Electrification will have to play a crucial part in the transition to a more sustainable global energy system, but clean fuels will play a crucial role in some end-use sectors. These low-emission fuels include for example modern forms of bioenergy, whose consumption will have to increase from around 41 EJ today to more than 75 EJ in 2030, and 100 EJ in 2050. These fuels for example will provide high temperature heat to meet industry needs in cement or paper production. In the transport sector, biofuels from advanced feedstocks such as wastes and residues will be used. Other types of clean fuels which will be necessary for the energy transition include hydrogen and hydrogen-based fuels. Clean hydrogen will be necessary for industrial processes as well as the transport sector such as in shipping, just like hydrogen-based fuels such as ammonia which will be essential to cover around 45% of global shipping demand by 2050.
- **Flexibility**: The enhanced role of electrification to accommodate a scenario in which net greenhouse emissions are reduced zero will require to significantly increase the flexibility of both existing and new infrastructure, as well as supporting technologies. All sources of flexibility – advanced batteries, demand response and low-carbon flexible power plants, as well as smarter and more digital electricity grids, will need to quadruple investments by 2050, *vis-à-vis* a two-and-a half-fold increase in electricity supply. Some of these new technologies will also reduce dependence on critical minerals. Sodium-ion batteries, for example, have the potential to completely avoid the use of less abundant types of these resources, and do not require lithium. Technologies supporting the flexibility of electricity demand, as well as supply, will be equally important. These can be used in fields such as EV charging, with

the development of smart chargers to optimise profiles based on how much energy vehicles need over a specified span of time.
- **New advances in nuclear technology**: nuclear power plays a role globally in decarbonising the electricity sector. Advances in the technology involve the full commercialisation of Small modular reactors (SMRs), which are nuclear reactors with a capacity below 300 MW and with lower capital costs. The modular design of these reactors can sensibly increase the flexibility, as well as reduce the high upfront costs of nuclear technology.

Employment

The transition to a cleaner global energy system will simultaneously generate enormous employment opportunities, and require careful interventions to ensure that the process be as just, and as socially sustainable, as possible.

As stated in the IEA's ***World Energy Outlook 2022***, a scenario in which the world reaches net zero greenhouse gas emissions by 2050 will see employment opportunities in the energy sector increase from slightly over 65 million to 90 million by 2030, including both direct jobs within the energy sectors and indirect jobs involved in manufacturing essential components for energy technologies and infrastructure. By 2030, there could be nearly 40 million new jobs in clean energy. As a result, the proportion of employment in the energy sector linked to clean energy is expected to rise from approximately half to 80% by 2030.

Most of these jobs will be added by the power generation sector, complemented by 4 million jobs in power grids and electricity storage. Employment opportunities linked with solar PV, as well as wind power, will as a matter of fact experience an annual yearly increase of 10% to keep up with the necessary expanded capacity. Great numbers of employed individuals will also be added in vehicle manufacturing and business focused on enhancing equipment, industrial, and building efficiency. In vehicle manufacturing, three-fifths of the current jobs transition to electric vehicles (EVs) and their batteries. While EVs require fewer components and entail less labour-intensive assembly, additional jobs will be created in the battery supply chain. However, these jobs may not be concentrated in the same locations as the current manufacturing jobs.

To accomplish this growth in clean energy jobs within the next decade, it is crucial for industry, governments, and educational and training institutions to engage in strategic and proactive planning. This planning is necessary to prevent shortages of skilled labour from becoming a bottleneck for energy transitions. It will require a concerted effort to anticipate and address the demand for skilled workers, ensuring that the workforce is adequately trained and prepared to meet the requirements of the evolving energy sector.

Coal miners, particularly those involved in modern mechanized operations, may have skills that could be relevant in critical minerals production. However, the transition to this sector could be limited due to the smaller quantities of minerals required and the different geographical locations of coal and mineral deposits. It will therefore be essential to implement people-centred, and just transition policies to provide support for fossil fuel workers who will have limited prospects for transitioning to the energy sector or parallel industries. These policies will be vital in ensuring a smooth and fair transition for these workers and in countering the negative impact of job losses in fossil fuel industries wrought by electrification and decarbonisation efforts.

Critical Minerals

Global energy systems, including clean energy infrastructure and technologies, rely on a steady and secure supply of critical minerals, materials and manufacturing capacity needed. These minerals are crucial for the production of solar PV panels and wind turbines, but also for batteries to power the rising EV industry as well as electricity cables to sustain the needed electrification of energy systems. A study on critical minerals demand in the IEA's ***World Energy Outlook 2022*** indicates that, as clean energy transitions accelerate, the demand for these critical minerals from the energy system is bound to increase manifold, especially for minerals such as lithium, cobalt, nickel and graphite. Recent price spikes in these minerals have however made it clear how supply chain disruptions and rising mineral supply costs threaten to increase the cost of clean energy technology and slow their deployment. The strengthening and the diversification of these supply chains is therefore an objective of global importance and priority.

The first element of this fragility is in the raw materials required for the production of renewable technologies. These rely as a matter of fact on a wide array of critical minerals, whose uses vary by technology. Lithium, nickel, cobalt, manganese and graphite are crucial to battery performance, longevity and energy density. Rare earth elements are essential for permanent magnets that are vital for wind turbines and EV motors. Electricity networks need a huge amount of copper and aluminium, with copper being a cornerstone for all electricity-related technologies. Wind turbines, which will be used to generate electricity for example in Northern Europe, will require rare earth elements for their magnets.

Moreover, the quantities of the minerals necessary for energy transition technologies are substantially larger than the quantities required for their fossil fuel counterparts. For example, making a 55-kWh battery for a small electric car typically requires over 200 kg of a wide variety of critical minerals. In comparison, the powertrain of an internal-combustion engine will require only 35 kg of copper. Solar and wind power also require, comparatively, more materials and critical minerals such as steel, aluminium per unit of capacity. For example, an onshore wind plan will require, for the same capacity level of capacity of an equivalent gas-fuelled power plant, at least nine times more mineral resources.

The shift to a clean energy system is set to drive a huge increase in the requirements for these minerals, meaning that the energy sector is emerging as a major force in mineral markets. Until the mid-2010s, for most minerals, the energy sector represented a small part of total demand. However, as energy transitions pick up the pace, clean energy technologies are becoming the fastest-growing segment of demand. In a scenario that meets the Paris Agreement goals, their share of total demand will have to rise significantly over the next two decades to over 40% for copper and rare earth elements, 60-70% for nickel and cobalt, and almost 90% for lithium. EVs and battery storage have already displaced consumer electronics to become the largest consumer of lithium and are set to take over from stainless steel as the largest end user of nickel by 2040.

In climate-driven scenarios, mineral demand for use in EVs and battery storage is a major force, growing at least thirty times to 2040. Lithium sees the fastest growth, with demand growing by over 40 times in the SDS by 2040, followed by graphite, cobalt and nickel (around 20-25 times). The expansion of electricity networks means that copper demand for grid lines more than doubles over the same period. The rise of low-carbon power generation to meet climate goals also means a tripling of mineral demand from this sector by 2040. Wind takes the lead, bolstered by material-intensive offshore wind. Solar PV follows closely, due to the sheer volume of capacity that is added. Hydropower, biomass and nuclear make only minor contributions given their comparatively low mineral requirements. In other sectors, the rapid growth of hydrogen as an energy carrier underpins major growth in demand for nickel and zirconium for electrolysers, and for platinum-group metals for fuel cells.

This reality holds a series of sobering implications: there is the potential for numerous choke points along various nodes of these supply chains – raw mineral extraction, the production of materials, and finally assembling and manufacturing components. As of today, there is therefore an urgent need to increase investments across all these nodes to cover the gap between where we are today and where we need to be to reach net zero. The IEA estimates that the sums needed to sustain the additional mining, critical material production, and manufacturing of clean energy technologies needed from today to 2030 to secure supply chains will have to amount to $1.2 trillion. Moreover, these investments will need to be mobilised across different regions, technologies and supply chains.

The picture is however varied according to the type of mineral we are discussing. Some minerals such as lithium raw material and cobalt are expected to be in surplus in the near term, while lithium chemical, battery-grade nickel and key rare earth elements (e.g., neodymium, dysprosium) might face tight supply in the years ahead. However, looking further ahead in a scenario consistent with climate goals, expected supply from existing mines and projects under construction is estimated to meet only half of projected lithium and cobalt requirements and 80% of copper needs by 2030.

The general picture is therefore that critical mineral supply chains must be strengthened to sustain today's global energy system and to support the clean energy transition.

While there are a host of projects at varying stages of development, there are many vulnerabilities that may increase the possibility of market tightness and greater price volatility:

- **High geographical concentration of production**: Production of many energy transition minerals is more concentrated than that of oil or natural gas. For lithium, cobalt and rare earth elements, the world's top three producing nations control well over three-quarters of global output. In some cases, a single country is responsible for around half of worldwide production. The Democratic Republic of the Congo (DRC) and People's Republic of China (China) were responsible for some 70% and 60% of global production of cobalt and rare earth elements respectively in 2019. The level of concentration is even higher for processing operations, where China has a strong presence across the board. China's share of refining is around 35% for nickel, 50-70% for lithium and cobalt, and nearly 90% for rare earth elements. Chinese companies have also made substantial investment in overseas assets in Australia, Chile, the DRC and Indonesia. High levels of concentration, compounded by complex supply chains, increase the risks that could arise from physical disruption, trade restrictions or other developments in major producing countries.

- **Long project development lead times**: Our analysis suggests that it has taken 16.5 years on average to move mining projects from discovery to first production. These long lead times raise questions about the ability of supply to ramp up output if demand were to pick up rapidly. If companies wait for deficits to emerge before committing to new projects, this could lead to a prolonged period of market tightness and price volatility.
- **Declining resource quality**: Concerns about resources relate to quality rather than quantity. In recent years ore quality has continued to fall across a range of commodities. For example, the average copper ore grade in Chile declined by 30% over the past 15 years. Extracting metal content from lower-grade ores requires more energy, exerting upward pressure on production costs, greenhouse gas emissions and waste volumes.
- **Growing scrutiny of environmental and social performance:** Production and processing of mineral resources gives rise to a variety of environmental and social issues that, if poorly managed, can harm local communities and disrupt supply. Consumers and investors are increasingly calling for companies to source minerals that are sustainably and responsibly produced.

Without efforts to improve environmental and social performance, it may be challenging for consumers to exclude poor-performing minerals as there may not be sufficient quantities of high-performing minerals to meet demand.

- **Higher exposure to climate risks:** Mining assets are exposed to growing climate risks. Copper and lithium are particularly vulnerable to water stress given their high water requirements. Over 50% of today's lithium and copper production is concentrated in areas with high water stress levels. Several major producing regions such as Australia, China, and Africa are also subject to extreme heat or flooding, which pose greater challenges in ensuring reliable and sustainable supplies.

Diversifying Clean Energy Supply Chains

The IEA's report on ***Securing Clean Energy Technology Supply Chains*** indicates that the heavy reliance of clean energy technologies on critical minerals makes their supply chains particularly vulnerable on their geographic location and on the level of their geographic concentration. This vulnerability has been highlighted particularly in recent times, where the current model of international trade and sourcing of resources from different parts of the world are being put to the test by renewed and highlighted conflicts between world powers. The invasion of Ukraine by Russia, for example, has highlighted critical vulnerabilities in fossil fuels, and stressed the importance of avoiding a repeated scenario for the sourcing of critical minerals for clean energy technologies.

Currently, the People's Republic of China dominates the extraction of rare earth elements, accounting for 60% of their global output. Meanwhile, a reduced number of other countries specialise in the extraction of critical minerals – South Africa, for example, supplies more than 70% of the world's platinum needs for all uses. The Democratic Republic of Congo (DRC), on the other hand, holds 70% of the global extraction of ores of cobalt, a vital component for lithium-ion batteries and superalloys used in turbines, nuclear reactors and sensors. Lithium is also highly concentrated in Australia and Chile.

The processing and purification of these minerals are also heavily concentrated, and they are as much a vital component as their extraction. Again, China dominates this critical node of the supply chain, holding a 30% of the global share of processing for nickel, a 60-70% for lithium and cobalt, and a 90% share for rare earth elements.

Finally, we can see similar levels of concentration for technology manufacturing, be they for mass-manufactured technologies such as solar PV modules, wind turbine components and EV batteries, or for more large-scale, site-tailored technologies such as CCUS applications, synthetic hydrocarbon production or bioenergy-related technologies. In the former case, China dominates the market thanks to low manufacturing costs, a strong base in materials production and sustained policy support. For both solar PV module and wind turbine component production, Chinese companies feature among the world's top 10 and 15 suppliers, respectively. Similarly, China dominates production at every stage of the EV battery supply chain, with policies in support of the EV sector finally bearing fruit on the world stage. Even the production of heat pumps, which are at the centre of major energy transition plans such as the EU's RePowerEU, is dominated by China with almost 40% of total manufacturing capacity and with Chinese companies also presiding over the manufacture of refrigerants.

China's dominance of these supply chains, especially in material production and in component mass-manufacturing, is not a coincidence. It is instead the result of decade-long policies in industrial development, which have put this country squarely at the centre of all component-related international trade networks. Other countries, or other geographical groupings, are now beginning to follow the same path. The new EU industrial strategy for domestic battery production, for example, alongside policies to cut CO2 emissions from road transport, have led to large investments in the production of batteries in Europe, although no large-scale production has yet taken place. The United States' Inflation Reduction Act (IRA), meanwhile, has spurred recent investments into battery giga factories, although some components of the same act prohibit the import of other vital components for EVs that are not produced in countries with which the USA have bilateral trade agreements, which could slow down the production of EVs.

Conclusion

This is pivotal moment of the global energy crisis, as the covid pandemic and Russia's invasion of Ukraine ushered the world into the new energy economy. Ensuring the transition is orderly, secure and affordable will hinge on tackling new energy security challenges, namely critical minerals and clean tech supply chains.

To balance all of these requirements, governments will have to closely align energy security policies, climate policies, and industrial policies, scaling up investments, devising specific strategies and diversifying supply chains.

The vulnerability of clean energy supply chains based on geographic location and concentration highlights the importance of strengthening and diversifying these chains on a global scale.

Achieving the net zero emissions target by 2050 will require a significant boost in clean energy innovation and the introduction of technologies not yet in the market. Timely market entry of these technologies is crucial, necessitating faster development compared to past achievements. The transition to a clean energy system presents vast employment opportunities, with the energy sector projected to witness a substantial increase in jobs, but these will have to be accompanied by just transition policies to absorb the workforce made redundant in certain parts of the energy sector.

While it is clear that the scale of this task is large, the economic case and energy security benefits are before us. A possible new clean energy golden age awaits us, but it will be up to us to steer it and to reap its benefits.

17. Climate and Hazard Resilient Infrastructure Networks. The Case of China's BRI

Bilal M. Ayyub, Sherief M. Elsibaie

Resilient Infrastructure and Hypernetworks

Climate- and hazard-resilient infrastructure[1,2] is crucial for establishing and sustaining geo-economic and geopolitical strategies, managing the impacts of natural disasters, ensuring economic stability, and supporting regional and global cooperation. Global infrastructure can be represented as a hypernetwork,[3] defined simply as a network of networks with shared network nodes, and can play a significant role in achieving geo-economic and geopolitical influence. By establishing and improving connectivity, facilitating trade, and fostering cooperation, they can enhance a country's economic influence and strategic position. Such infrastructure offers geo-economic opportunities and risks for the use of economics by

[1] B.M. Ayyub et al., *Climate-Resilient Infrastructure: A Manual of Practice on Adaptive Design and Risk Management*, ASCE Manual of Practice (MOP) 140, American Society of Civil Engineers, Reston, VA, 2018.

[2] B.M. Ayyub et al., *Hazard-Resilient Infrastructure: A Manual of Practice (MOP) on Analysis and Design*, Infrastructure Resilience Division #144, American Society of Civil Engineers, Reston, VA, 2021.

[3] M. Newman, *Networks*, Oxford University Press, New York, 2018.

states for power projection and advancing political objectives.

Every year, governments and the private sector invest trillions of dollars in infrastructure that may not withstand future risks from climate change, since most current planning and design practices do not consider non-stationarity and climate projections.[4] Most of the world's new infrastructure will be built in developing countries, which face the dual challenges of disaster response and urbanisation; but responding to natural disasters is also a major challenge in developed countries. As an example, in the United States, damage from the 2017 Hurricanes Harvey, Maria, and Irma totalled approximately $265 billion.[5] Long-lived infrastructure must be resilient to weather extremes, including the effects of climate change, and other hazards. Designing for climate-resilient and broadly hazard-resilient infrastructures requires the use of reliable climate and hazard projections and information, and a design philosophy that enables using real option for adaptive strategies with partnership to achieve economic efficiency and securing necessary finances.

Global transportation infrastructure as hypernetworks, for example, can facilitate trade by providing efficient transport corridors, including roadways, railways, air routes and sea lanes, and enabling the smooth movement of goods and services, thus facilitating international trade and economic integration. They offer large-scale investment opportunities of infrastructure projects for countries in other nations' critical assets, thereby gaining economic influence and fostering long-term relationships. They offer access to vital resources, such as energy, minerals, and water, which are essential for economic growth and industrial development. They also give access to consumer markets for manufactured products. These networks enable regional integration by connecting countries with shared interests, which can foster economic cooperation, create new

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[4] Oxford Economics, *Global Infrastructure Outlook*, Sydney, Global Infrastructure Hub, 2017.

[5] National Oceanic and Atmospheric Administration, *Costliest US tropical cyclones tables updated*, 26 January 2018.

markets, and reduce the likelihood of conflicts. They offer soft power projection, as countries that build or finance major projects can earn goodwill and improve their global reputation, thus increasing their geo-economic influence. They provide ways to deploy technology and innovation, which can enhance economies and competitiveness, leading to economic growth. Large-scale infrastructure projects can create jobs, stimulate economic activity, and attract foreign direct investment, which in turn can contribute to a nation's geo-economic standing. This strategic positioning can serve as a means for countries to project their strategic presence by establishing bases, securing supply lines, or controlling strategic chokepoints, such as ports, canals, or corridors. Well-connected and resilient infrastructure transportation networks can help countries better adapt to global challenges such as climate change, natural disasters, and pandemics, ultimately enhancing their geo-economic stability. Infrastructure projects can be used as diplomatic tools to build or strengthen alliances, as countries work together on joint ventures, share resources, or negotiate deals, thus enhancing their geo-economic influence.

Developing and participating in global infrastructure networks requires a vision, a strategy and analytical methods to enable the following key considerations to be examined:

1. Risk assessment[6] by identifying potential climate and hazard risks in the region, such as floods, hurricanes, earthquakes, or droughts, and assessment of their potential impacts on infrastructure;
2. Climate adaptation based on planning and designing infrastructure for a changing climate by integrating climate projections, such as temperature changes, sea-level rises, and changing precipitation patterns, into current practices;[7]
3. Structural resilience by designing and constructing

[6] B.M. Ayyub, *Risk Analysis in Engineering and Economics*, Chapman & Hall, 2014.
[7] B.M. Ayyub and A. Hill, "Climate-Resilient Infrastructure: Engineering and Policy Perspectives", *The Bridge*, National Academy of Engineering (NAE), June 2019.

infrastructure with materials and designs that can withstand extreme weather events and natural hazards, such as using seismic-resistant materials in earthquake-prone areas or flood-resistant materials in flood-prone areas; [8]

4. Redundancy and flexibility to ensure the continued functionality of critical infrastructure in the event of partial failures or unexpected changes, such as having backup power sources or multiple transportation routes;
5. Nature-based solutions involving the use of ecosystemic approaches and natural infrastructure to enhance resilience, such as constructing wetlands to absorb floodwaters or planting vegetation to prevent landslides; [9]
6. Interconnected infrastructure networks as a hypernetwork for enhancing regional connectivity by investing in transportation, energy, and communication networks that cross borders, thereby promoting cooperation and increasing resilience in the event of disruptions in one area;
7. Technology and innovation by leveraging emerging solutions and means to monitor, predict, and adapt to climate and hazard risks, such as early warning systems, digital-twinning, remote sensing, and data analytics;[10]
8. Vulnerability and security by examining criticalities of different components of infrastructure networks with associated impacts that might lead to security risks;
9. Microeconomic efficiency and macroeconomic risks and opportunities by enabling integration with economic models for these purposes;
10. Governance and policy by establishing strong

[8] B.M. Ayyub, "Systems Resilience for Multi-Hazard Environments: Definition, Metrics and Valuation for Decision Making", *Risk Analysis Journal*, 2013.

[9] B.M. Ayyub, *Practical Resilience Metrics for Coastal Infrastructure Features*, Coastal Systems Resilience Initiative, Coastal and Hydraulics Laboratory, Engineer Research and Development Center, ERDC/CHL CR-19-1, U.S. Army Corps of Engineers, Washington, DC.

[10] M.R. Taha et al., "Emerging Technologies for Resilient Infrastructure: A Conspectus and Roadmap", *ASCE-ASME Journal, Risk Uncertainty Eng. Syst.*, Part A: Civil Engeneering, vol, 7, no. 2, June 2021.

institutional frameworks that promote climate- and hazard-resilient infrastructure, including regulatory standards, risk assessments, and financial incentives;

11. Financing by securing adequate funding for resilient infrastructure projects, including public-private partnerships, multilateral development banks, and international aid organisations;
12. Capacity-building and knowledge-sharing by fostering cross-border collaboration and the exchange of knowledge on best practices and technologies for climate- and hazard-resilient infrastructure, and building capacity within local governments and communities to implement these strategies.

By addressing these considerations, nations can create infrastructure that is more resilient to climate and hazard risks, thus bolstering their geo-economic and geopolitical standing while protecting their citizens and economies.

Analysis Methods for Infrastructure Hypernetworks

Analysing infrastructure hypernetworks requires a multi-faceted approach that takes account of various factors, including physical, economic, social, political, environmental, and strategic considerations, such as the following analysis categories:

- Network analysis commonly used to assess the connectivity, efficiency, and resilience of infrastructure networks by examining their physical characteristics, including nodes, links, and hubs, and identifying potential chokepoints, bottlenecks, or vulnerabilities for their geo-economic and geopolitical implications, as illustrated for assessing the connectivity and vulnerability of China's Belt and Road Initiative (BRI);[11]

[11] Y. Cai and Y. Zhang, "Network Analysis of China's Belt and Road Initiative: Connectivity, Vulnerability, and Implications", *Asian Geographer*, vol. 35, no. 1,

- Economic analysis for assessing the economic impacts of infrastructure networks, including their role in trade facilitation, job creation, and regional integration, by using economic models, cost-benefit analysis, and input-output analysis, such as the econometric analysis of transportation infrastructure on regional development in Taiwan;[12]
- Geospatial analysis for assessing infrastructure networks, using satellite imagery to visualize and analyse the spatial distribution of infrastructure networks, their proximity to strategic locations, e.g., resources, borders, maritime routes, and their potential environmental and other impacts. Involving the mapping of infrastructure networks and analysing their spatial distribution and accessibility, such as assessing the potential impacts of the Trans-Asian Railway network on regional integration and economic development;[13]
- Scenario analysis for modelling different futures to assess the potential impacts of infrastructure networks on geo-economic and geopolitical outcomes, such as assessing the potential impacts of the China-Pakistan Economic Corridor on regional integration and economic development; [14]
- Political analysis for examining issues relating to sovereignty, security, and political risk, for example, assessing the political risks and opportunities associated with China's BRI.[15]

2018, pp. 27-47.

[12] Y.T. Chien and T.W. Hu, "Econometric Analysis of Transportation Infrastructure and Regional Development in Taiwan", *Journal of Urban Planning and Development*, vol. 146, no. 3, 2020.

[13] L. Wenz et al., "Spatial Analysis of Trans-Asian Railway Network Development: Integration and Economic Development", *Journal of Transport Geography*, vol. 80, 2019.

[14] M. Ahmed et al., "Scenario Analysis of China-Pakistan Economic Corridor for Regional Integration and Economic Development", *Frontiers in Sustainable Cities*, vol. 3, no. 14, 2021.

[15] H. Gao and Z. Yu, "China's Belt and Road Initiative: Political Risk and Opportunities", *China Economic Review*, vol. 47, 2018, pp. 114-24.

Other methods can be integrated into a mix of the above to formulate concerted methodologies. Such methods include: (1) risk and vulnerability assessment; (2) policy and institutional analysis that shapes infrastructure development, financing, and governance for assessing their implications in the context of geo-economics and geopolitics; (3) stakeholder analysis for identifying and evaluating the interests, relationships, and power dynamics of various stakeholders involved in infrastructure networks, such as governments, private sector actors, international organisations, and local communities; and (4) environmental and social impact assessment for analysing the potential environmental, social, and cultural impacts of infrastructure networks by conducting comprehensive impact assessments, considering factors such as resource use, emissions, biodiversity, and community well-being.

Costs and Benefits of Climate-Resilient Infrastructure

The cost differential for making infrastructure climate-resilient varies depending on the specific project, region, and type of climate risk being addressed. Generally, climate-resilient infrastructure requires higher upfront investment but can lead to significant long-term savings by reducing the costs associated with damage, repairs, and disruptions caused by climate-related events. Estimates suggest that the additional upfront costs for climate-resilient infrastructure typically range from 5% to 50% more than conventional infrastructure, depending on the context and measures taken. However, these costs should be considered against the potential long-term benefits, which can far outweigh the initial investment. According to the Global Commission on Adaptation,[16] investing $1.8 trillion in climate adaptation measures, including resilient infrastructure, between

[16] Global Commission on Adaptation, https://gca.org/about-us/the-global-commission-on-adaptation/

2020 and 2030 could generate $7.1 trillion in net benefits. This indicates a benefit-cost ratio of almost 4 to 1. Some factors influencing the cost differential for climate-resilient infrastructure include:

- Hazard type: The type of climate risk being addressed, such as flooding, storm surges, or extreme heat, will influence the cost of resilience measures.
- Project location: Infrastructure projects in areas with a higher risk of climate hazards will require more extensive and potentially more expensive adaptation measures.
- Project scale and complexity: Larger and more complex projects may require more advanced technologies and engineering solutions to ensure resilience, thus increasing the overall cost.
- Life-cycle costs: Climate-resilient infrastructure can have lower life-cycle costs due to reduced maintenance, repair, and replacement expenses resulting from enhanced durability and reduced vulnerability to climate risks.
- Co-benefits: Climate-resilient infrastructure can provide additional benefits, such as reduced greenhouse gas emissions, improved public health, and increased property values, which can offset some of the upfront costs.
- Timing: Incorporating climate-resilience measures during the planning and design phases of a project can be more cost-effective than retrofitting existing infrastructure.

While climate-resilient infrastructure may require higher upfront investments, the long-term benefits and potential cost savings can be substantial, especially considering the increasing impacts of climate change on infrastructure systems worldwide. The examination of costs and benefits, with associated uncertainties, informs planning and design decisions.

Case Study: Network Attributes of China's Belt and Road Initiative (BRI)

China's Belt and Road Initiative (BRI)[17,18] is a prime example of how countries can leverage global infrastructure networks to achieve geo-economic and geopolitical objectives. Launched in 2013, the BRI aims to create a vast network of infrastructure projects, including railways, highways, ports, and energy facilities, connecting Asia, Europe, Africa, and beyond. The initiative encompasses several strategic interests for China, including trade facilitation by improving connectivity between China and other countries along the Silk Road Economic Belt and the Maritime Silk Road, facilitating the movement of goods and services and enhancing China's trade relationships. It offers investment opportunities accompanied by the means to gain significant influence in participating countries, by entering new markets and securing contracts for infrastructure projects. It gives access to vital resources such as energy, minerals, and food by providing a link to resource-rich regions in Central Asia, Africa, and the Middle East. It enables regional integration, particularly in Asia, for soft power by promoting its development model and gaining goodwill from participating countries. The BRI facilitates the exchange of technology and ideas, enabling China to export its technological advances, such as high-speed rail and telecommunications, to other countries. It feeds into employment and economic growth, access to markets, and strategic positioning in global supply chains, particularly along the Indian Ocean over vital maritime routes. The BRI enhances China's ability to adapt to global challenges such as climate change and geopolitical risks by diversifying trade routes and securing access to alternative sources of resources, and serves as a diplomatic tool for China to build or strengthen alliances with participating countries, by creating a network of partners

[17] J. McBride, N. Berman, and A. Chatzky, *China's Massive Belt and Road Initiative*, Council on Foreign Relations, 2 February 2023.

[18] B. Steil, *Belt and Road Tracker*, Council on Foreign Relations, 1 June 2022.

that share China's development vision and support its geo-economic interests.

The BRI has had several direct and indirect impacts on the other players in the marketplace, including the United States and Europe, by influencing the economic, geopolitical, and strategic landscapes. Some of the key impacts include: economic competition, geopolitical influence, military and strategic concerns, and impact on global norms and standards. The BRI has prompted other countries to re-evaluate and strengthen their own engagement in regions targeted by the initiative, leading to new policies, programs, and investments. For example, the United States has launched the "Build Back Better World" (B3W) initiative, a global infrastructure plan aimed at countering the BRI, in partnership with the G7 countries. The BRI involves significant investments in energy and infrastructure projects, some of which may contribute to environmental degradation and increased greenhouse gas emissions. Strategies to leverage BRI, however, include promoting alternative development models and fostering more sustainable, transparent, and inclusive global infrastructure initiatives. Other strategies include offering alternative financing options; promoting transparency and accountability; strengthening regional partnerships; providing technical assistance and capacity-building in advocating for environmental and social safeguards; competing on quality and innovation; leveraging the works of multilateral development banks; fostering public-private partnerships; collaborating on global initiatives; and engaging in dialogue with China to address risks and opportunities relating to the BRI to encourage collaboration on projects that align with international standards and best practices.

To illustrate infrastructure network analysis, the BRI is treated as a hypernetwork with on-land railroad routes and related sea-trade routes, with a node and link representation drawn from information and maps reported in the literature. These map sources include the Mercator institute, Iran

International and other publicly available data sources such as Google Maps satellite data.[19,20] The global sea and land trade network is represented by visually superimposing it on the world map, using the Python library "networkx" and "matplotlib", as shown in Figure 17.1. The sea routes are drawn as blue lines, while the on-land railroad routes are drawn in green. Nodes are drawn as circles and those that are close to major cities are labelled with numbers, with numerical labels mapped to cities in a table legend at the bottom of the map. Nodes that are not near a major city but represent key waypoints where the routes may divide or terminate are drawn as small white circles and are not numbered, but are still considered as nodes for the purpose of network analysis.

Network characteristics of interest may include the number of nodes *n*, the number of links *m*, and several other related characteristics, including the average node degree, the characteristic path length, and the network efficiency. The network characteristics for the combined on-land and sea trade routes, as well as the on-land and sea-only trade routes separately, are provided herein, noting that some nodes are shared between the two networks.

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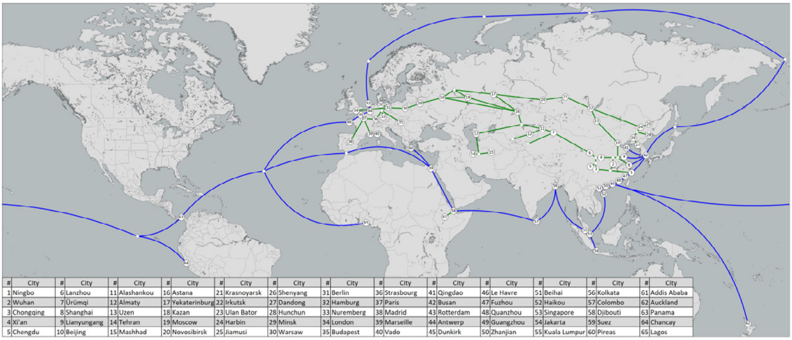
[19] G. Vaisi, "Belt And Road Initiative, China's Great Game", *Iran International*, 2022.

[20] "Mapping the Belt and Road initiative: this is where we stand", *MERICS*, 7 June 2018.

FIG. 17.1 - BELT AND ROAD INITIATIVE NETWORK WITH MAJOR ON-LAND AND SEA TRADE



#	City	#	City	#	City	#	City	#	City	#	City	#	City	#	City	#	City	#	City	#	City	#	City	#	City
1	Ningbo	6	Lanzhou	11	Alashankou	16	Astana	21	Krasnoyarsk	26	Shenyang	31	Berlin	36	Strasbourg	41	Qingdao	46	Le Havre	51	Beihai	56	Kolkata	61	Addis Ababa
2	Wuhan	7	Ürümqi	12	Almaty	17	Yekaterinburg	22	Irkutsk	27	Dandong	32	Hamburg	37	Paris	42	Busan	47	Fuzhou	52	Haikou	57	Colombo	62	Auckland
3	Chongqing	8	Shanghai	13	Uzen	18	Kazan	23	Ulan Bator	28	Hunchun	33	Nuremberg	38	Madrid	43	Rotterdam	48	Quanzhou	53	Singapore	58	Djibouti	63	Panama
4	Xi'an	9	Lianyungang	14	Tehran	19	Moscow	24	Harbin	29	Minsk	34	London	39	Marseille	44	Antwerp	49	Guangzhou	54	Jakarta	59	Suez	64	Chancay
5	Chengdu	10	Beijing	15	Mashhad	20	Novosibirsk	25	Jiamusi	30	Warsaw	35	Budapest	40	Vado	45	Dunkirk	50	Zhanjian	55	Kuala Lumpur	60	Pireas	65	Lagos

A node's degree k_i is the number of links connected to it. The average number of links connected to the nodes in a network is the average node degree $\overline{K}$, calculated as $\overline{K} = \sum_{i=1}^{n} \frac{k_i}{n}$. The count of links of the shortest possible path connecting nodes *i* and *j* is considered the shortest path to a destination p_{ij}. The characteristic path length of a network $\overline{L}$ is computed as the mean of all p_{ij} as $\overline{L} = \frac{1}{n(n-1)} \sum_{j=1}^{n} \sum_{i=1}^{n} p_{ij}$, where $i \neq j$. The efficiency of the network, $\overline{E}$, is defined as the average of all multiplicative inverses of p_{ij}: $\overline{E} = \frac{1}{n(n-1)} \sum_{j=1}^{n} \sum_{i=1}^{n} \frac{1}{p_{ij}}$, where $i \neq j$. Therefore, the most efficient network possible, where all nodes are directly connected to all other nodes, has an efficiency of 1.

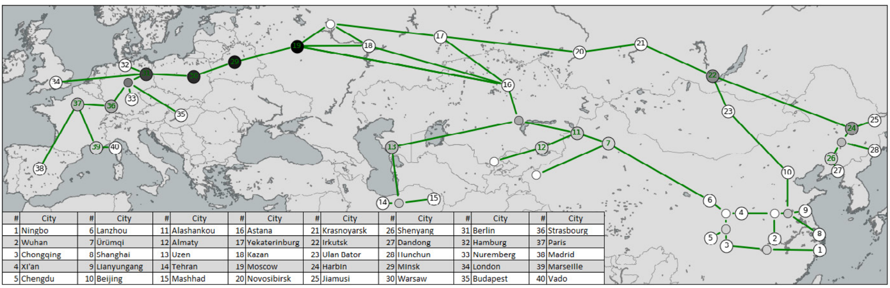
Table 17.1 summarises computed network characteristics for the three cases of the separate and combined on-land and sea network. The three most efficient city nodes for the combined on-land railroad and sea trade network, in order, are Busan, Ningbo, and Astana. Additional importance should be placed on these nodes in terms of their impact on the network's ability to distribute goods. The three most efficient city nodes for the on-land railroad network, in order, are Astana, Moscow, and Alashankou. The three most efficient city nodes for the sea-only network, in order, are Guangzhou, Busan, and Panama.

TAB. 17.1 - CHINA'S BELT AND ROAD INITIATIVE NETWORK CHARACTERISTICS WITH TWO NODES SHARED BETWEEN THE ON-LAND AND SEA-ROUTE NETWORKS

Network characteristics	Combined on-land and sea-route	On-land railroad network	Sea-route network
Number of nodes n	87	52	37
Number of links m	96	57	38
Average node degree $\overline{K}$	2.21	2.19	2.05
Characteristic path length $\overline{L}$	10.67	7.38	6.26
Network Efficiency $\overline{E}$	0.155	0.209	0.241

Network blockage analysis was performed only on the on-land railroad network, where a node in the network is identified as a blocking node and coloured grey or black if its removal cuts off completely some other node or nodes from the rest of the network. The darker the colour of the node, the greater the impact in terms of the number of other nodes that are cut out. This type of analysis on the sea routes might be less informative since, except for certain canals or sea-route chokepoints, sea vessels are not constrained to travel from node to node and may reach virtually any node directly from any other node; however, the sea-route network can be analysed in a similar manner if needed. The blockage analysis of the rail network is shown in Figure 17.2. The nodes are labelled by numbers representing cities with a legend table in the figure. Moscow is identified as the blocking node with the greatest impact if there is a disruption at or near its location, cutting off approximately 34% of nodes from the larger network. The other darker coloured blocking nodes could also be considered as major single points of failure in the railroad network with major impacts.

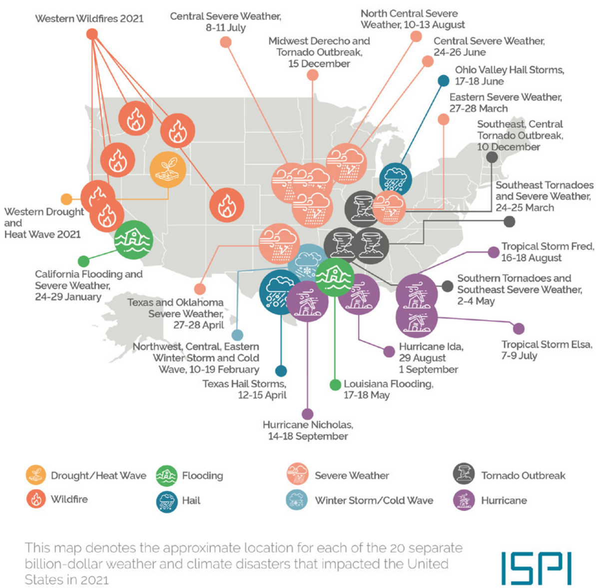
Fig. 17. 2 - Blockage analysis of the Belt and Road Initiative network based on contiguous railroads with blocking nodes colored on a grey-to-black scale with black used to represent the greatest impact



#	City	#	City	#	City	#	City	#	City	#	City	#	City	#	City
1	Ningbo	6	Lanzhou	11	Alashankou	16	Astana	21	Krasnoyarsk	26	Shenyang	31	Berlin	36	Strasbourg
2	Wuhan	7	Ürümqi	12	Almaty	17	Yekaterinburg	22	Irkutsk	27	Dandong	32	Hamburg	37	Paris
3	Chongqing	8	Shanghai	13	Uzen	18	Kazan	23	Ulan Bator	28	Hunchun	33	Nuremberg	38	Madrid
4	Xi'an	9	Lianyungang	14	Tehran	19	Moscow	24	Harbin	29	Minsk	34	London	39	Marseille
5	Chengdu	10	Beijing	15	Mashhad	20	Novosibirsk	25	Jiamusi	30	Warsaw	35	Budapest	40	Vado

Extreme weather/climate disaster events, such as rainfall, flooding and wildfire, have left paths of destruction through communities around the world. In 2021, 20 disaster events with losses exceeding $1 billion each (CPI adjustment to 2021) affected the United States, as reported by the National Oceanic and Atmospheric Administration (NOAA) as illustrated in Figure 17.3, including 1 drought event, 2 flooding events, 11 severe storm events, 4 tropical cyclone events, 1 wildfire event, and 1 winter storm event. Figure 17.4 provides a global view, noting land use changes and increases in infrastructure development, particularly in urban areas and areas that have already been identified as being especially vulnerable to climate-related disasters. The critical nodes and links identified in Figures 17.1 and 17.2 can be examined in relation to these results reported in Figures 17.3 and 17.4, and examined further using climate projects of extremes in developing adaptation strategies for climate- and hazard-resilient infrastructure[21,22]. The 2019 Special Report on the Ocean and Cryosphere in a Changing Climate provides examples of attribution studies that are mapped globally by the categories shown in Figure 17.4, with a tabulated lists of applicable extreme events attributable to a changing climate, with assessments of extremes and abrupt or irreversible changes in the ocean and cryosphere in a changing climate. It also identifies regional hot-spots, cascading effects, their impacts on human and natural systems, and sustainable and resilient risk management strategies.

FIG. 17.3 - US BILLION-DOLLAR ($2021) WEATHER AND CLIMATE DISASTERS[23]

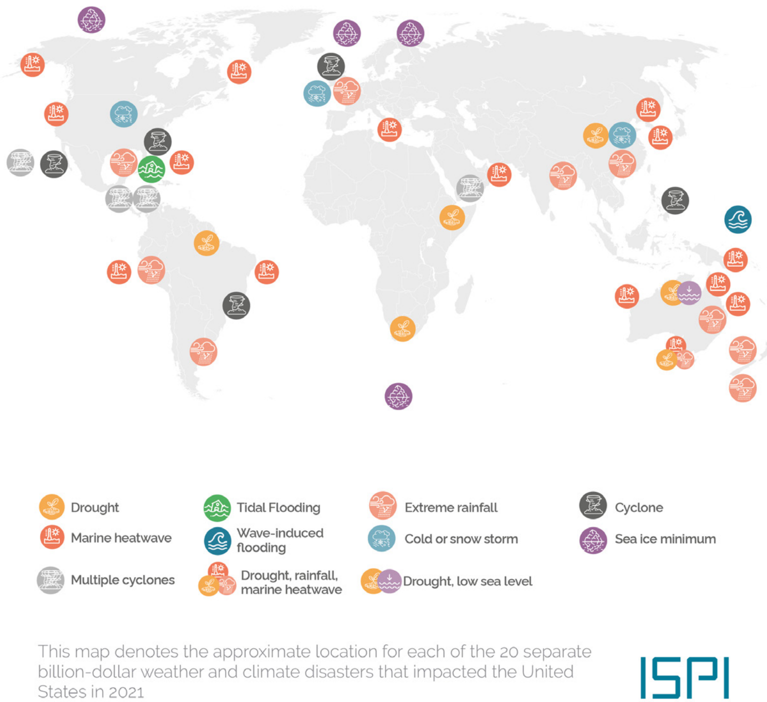


[21] Ayyub et al. (2018).

[22] Ayyub et al. (2021).

[23] National Center for Environment Information, National Oceanic and Atmospheric Administration (NOAA), *Billion-Dollar Weather and Climate Disasters*, 2022 (accessed 8 March 2023).

Fig. 17.4 - Locations of extreme events with identified attributions to climate-driven ocean changes [24]



[24] M. Collins, et al. 2019. "Extremes, Abrupt Changes and Managing Risks", in H.-O. Pörtner et al. (eds.), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*, Cambridge, UK and New York, NY, Cambridge University Press, pp. 589-655.

18. Increasing Resilience: The Transformation of Logistics

Sebastian Kummer, Alexander M. Geske, Eveline Beer

Times of Crisis and a Changing Logistics Supply Chain

Effects of global shocks on logistics and supply chains

The world has been facing an unprecedented number of global shocks in the past few years. Most of them have even occurred simultaneously. The Covid-19 pandemic, the war in Ukraine and global supply chain disruptions put a strain not only on economies, but also on societies.

Global shocks like war, economic recession, pandemic, or revolution can increase the pressure on our interconnected world and thus interconnected supply chains to unknown extents. Currently, the developed world is one short, but only one. The situation is different in other less developed parts of the world. This puts an enormous strain on international supply chains and supply chain logistics. Crises like these can have cascading effects and consequences across all scales, ranging from local to global. While first looking at current times and crises, this article would like to shed light on how these challenging times are forcing global supply chains to reconfigure the modi operandi and how to increase resilience in global supply chains and supply chain logistics.

The frequency of crises and black swan events seem to be increasing. While international supply chains have seen various crises in the past decades, the cycle in between seem to shorten. Between the oil crisis in 1973 and the Asian crisis in 1997, there was a period of 24 years. However, only 4 years later, the dot-com bubble hit the market and global stock markets stumbled into crisis. Adding onto this, the Global Financial Crisis in 2008 caused the biggest shock to the system so far until Covid-19 caused the interconnected world to standstill in 2020 and set off the beginning of a continuous sequence of crises with the following supply chain crisis, the war in Ukraine and consequently an energy or gas price crisis in Europe.

Supply chains are highly sensitive to disruptions in the underlying markets and these past crises made no exception. The Covid-19 pandemic in particular had long lasting effects on international supply chains driving a shift in demand, leading to supply shortages and changes in logistics and transportation.

Demand changed during the Covid-19 pandemic due to restrictions and a strong move towards e-commerce. However, these new demand patterns have not gone back to pre-pandemic times as might have been expected, but rather caused a shift amongst consumers that is still ongoing as per today. Supply shortages have increased, in particular on the labor side. There is furthermore a rather slow capacity adaptation and unfortunately to say, wrong forecasting across supply chains. A situation well known in many countries with specific reference to basic goods and medication.

While philosophies like global sourcing and local sourcing[1] as well as just-in-time were largely not in the focus of global supply chain stakeholders, the current crises have moved them back on the table, questioning the status quo. Regarding logistics and transportation, the pandemic not only highlighted current trends and challenges for airfreight and container shipping,

[1] S. Kummer and M. Lingnau, *Global Sourcing und Single Sourcing*, Wirtschaftswissenschaftliches Studium, vol. 8, 1992, pp. 419-22.

but also put the focus back on importance and reliability of rail and road transport. Rail specifically showed great resilience during the pandemic in accommodating abnormal volumes and demand requests. The road transport sector though has always played a crucial role in global supply chains. A fact that was further reiterated during the multiple recent crises.

Change in the sector is evident, but it raises the question of its implications on the logistics supply side. These challenges show that a holistic view including all stakeholders and their respective areas of business is key for infrastructure operators along the supply chain. An integrated approach is required that supports not only operations, but includes human resources, the entire transport supply chain, its staff, and customers, and especially the technological side of the business.

Effects of Global Shocks on Transport Modes

The crises of recent years have had different effects on the modes of transport. In order to be able to react quickly and flexibly to crises, air transport is the most flexible option, especially in global supply chains. Because of this the demand for air transport services has been very high in the recent crisis. Especially at the beginning of the Covid-19 crisis, there were major problems due to the high proportion of air freight that is transported with passenger flights (belly freight). But the challenges could be solved.

The flexibility of airfreight would clearly speak for more demand in crisis scenarios. However, as a lessons learned from the crisis near shoring is getting more and more common. This leads to less airfreight demand another effect is the fact, that air freight is also very much under discussion due to the high energy consumption and high CO2 emissions. If we sum up the positive and negative effects it can not be expect that there will be significantly more air freight. But also it is clear that crisis management will not work without aviation either.

In the case of international sea traffic, the availability of containers and the handling of the sea aids were a particular challenge. In response, some shippers used smaller container ships and even soon converted bulk ships into container ships. However, the significantly higher costs speak against the fact that this trend will continue. As the shippers noticed a huge dependency from the container shipping companies, more and more larger shippers are setting up their own shipping companies in order to have greater independence.

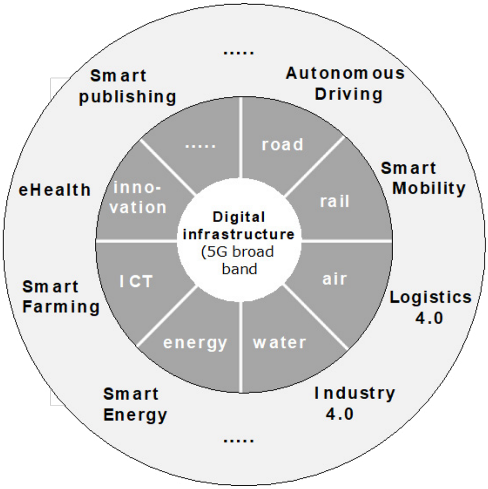
The big loser in the crises of recent years is the railways. The main reason is that the crises have led to short-term transport decisions and smaller transport lots. For both, railway is very poorly suited. Even if there is a great willingness to use railways as an environmentally friendly mode of transport due to the efforts of companies towards more sustainability, one must realistically say that in most crisis scenarios the railway is the least preferred means of transport.

The truck has proven to be very flexible and adaptable in the crises of the past few years and even during the times of lockdown, when drivers found it difficult to find supplies and cross borders, truck transport has always worked.

Digital Infrastructure as a Meta Infrastructure to Secure Supply Chain Resilience

Digitalization has been viewed as meta infrastructure to improve supply chain resilience for some time. Recent macroeconomic events however increased the importance of the role digital products play for the global supply chain industry. Digital infrastructure in the form of hardware, especially broadband expansion and 5G, but also software, here especially the increasing use of artificial intelligence play a paramount role in the resilience of supply chains and economies. Digital infrastructure has evolved into a synergistic meta infrastructure that enables efficient and effective use of all infrastructure sectors. In interaction with the other infrastructure sectors, digital infrastructure can lead to other infrastructure sectors being used more efficiently and effectively. In the figure below, this is represented by the first circle.

Fig. 18.1- Importance of digital infrastructure for different supply chains[2]



In connection with the other infrastructures (which are represented in the second circle) or in direct use, the 5G network and broadband connections can offer new services, of which only a few important ones are mentioned as examples in Figure 18.2 in the third circle. It is obvious that Europe cannot play a (global) leading role in all areas, but without digital infrastructure, European companies cannot develop and roll out solutions on the home market. Neither can Europe benefit from solutions developed in other countries. In addition, digital infrastructure also plays a critical role in establishing security of supply.

Digital infrastructure enables efficient and effective use of rail, air, and road infrastructure in the first place. In interaction with the other infrastructure sectors, digital infrastructure can

[2] S. Kummer, "Industrieökonomische Analyse der österreichischen Infrastruktur 2022", p. 51 in D. Ungar-Klein and M Podoprigora, (eds.), *Osterreichischer Infrastrukturreport 2022 der Initiative Future Business Austria*, Create Connections Networking & Lobbying GmbH, 2021, pp. 50-53.

increase a more efficient and effective usage of infrastructure and supply chains.

Digitization is currently changing not only the way people live and work, but also the way they create value. This comes with comprehensive networking of all areas of the economy and society and is characterized by the ability to collect and analyze relevant information and translate it into actions. In interaction with sensors and artificial intelligence (AI) applications, autonomous systems that control themselves and are capable of learning are also increasingly being developed. This enables a wide range of „smart" services. Finally, these technologies increase efficiency and open new avenues regarding the design of flexible and adaptable supply chains. As a result, companies can respond quickly to changing customer requirements and manufacture individualized products in small quantities at low production costs.

In modern economies, digitization and the digital infrastructure thus form the basis for economic, but also increasingly social activities. Nevertheless, there are also technical and social risks associated with this development. These must be considered, and digital infrastructure investments must be combined with investments in cyber security, new laws, and a socially acceptable design. One thing is clear though: Not investing in digital infrastructure means, with almost absolute certainty, the loss of competitiveness of European supply chains and is therefore a much greater risk. However, infrastructure policy is not only well advised to step up its efforts, but there also needs to be a rethink in terms of implementation. Current approaches towards digital infrastructure and, above all, the dispute over who pays for what, are hampering development.

On Resilience and How to Build Resilient Supply Chains

Resilience capabilities

Against the backdrop of a multitude of different crises as described above and their effects and manifestations, the development of resilience capabilities is indispensable. In this context, Wilding (2013) distinguishes between four different properties:

- Supply Chain Design and Engineering.
- Supply Chain Risk Management Culture.
- Supply Chain Collaboration.
- Agility.

Supply Chain Design and Engineering consciously applies principles of network design in order to balance out efficiency and redundancy. Thereby it is vital that all actors along the supply chain understand the underlying network for its own organization to upstream suppliers and downstream customers, including the end customers. This also includes infrastructure providers and transportation agents. In case of disruptions, companies along the supply chain must not only be capable of drawing on reserves/stocks and alternative suppliers, but must also be able to swap modes of transport. **Supply Chain Risk Management Culture** refers to how corporate culture and practices affect risk mitigation and disruption management. It requires leadership sponsorship and assessments to understand how risk profiles are impacted by corporate policies and practices. This aspect also involves the definition of formal responsible persons or teams for resilience as well as business continuity actions. As crises rarely only involve certain actors along the supply chain, but rather affect all stakeholders, investments into **Supply Chain Collaboration** is advisable. Thereby organizations must invest into and allocated resources for the management of relationships, in order to establish a collaboration, which is effective and provides benefits for all stakeholders. Lastly, **Agility** refers to supply chains, which on the one hand are network based, but on the other hand have a high market sensitivity.[3]

According to Geske and Novoszel (2022), four key capabilities serve as main enablers to develop supply chain resilience:

- Agility,
- Flexibility,
- Collaboration and
- Visibility.

The authors stress the importance to distinguish between agility and visibility as two separate capability as Jüttner and Maklan (2011)[4] did. **Agility** as a resilience capability in the context of supply chains refers to an ability on a strategic level which allows a response to often unpredictable disruptions or alterations with the value change in a cost-efficient and timely manner. Thereby it does not only provide a mean to response to crises, but it even enables strategic management to benefit from new business opportunities. In contrast, **flexibility** refers to the relocation of resources, the change of modes of transports or the switch between nodes and edges of a supply chain network, in order to adjust the supply chain in response to changes at partners or of external factors. **Collaboration** means the ability of different stakeholders in a supply chain to pursue a mutual goal in terms of operations planning and execution, which results in a mutual benefit for all parties involved. As a key prerequisite of collaboration synchronized decision making as well as information-sharing have been identified. **Visibility** can be described as the ability have transparency of the supply chain to be able to view both upstream and downstream processes and

[3] R.D. Wilding, "Supply chain temple of resilience", *Logistics & Transport focus*, vol. 15, 2013, pp. 54-58.

[4] U. Jüttner and S. Maklan, "Supply chain resilience in the global financial crisis: an empirical study", *Supply Chain Management: An International Journal*, vol. 16, no. 4, 2011, 246-259. doi:10.1108/13598541111139062.

structures. Thereby it supports the identification of variations quickly and enables short response times to effectively handle these variations.[5]

Supply chain design and the Illusion of a bird's eye view

It is important to learn/acknowledge that the number of connections multiplies when viewed from the perspective of the focal company. Let us imagine an important Austrian manufacturer, e.g., KTM. If this company has e.g., 300 tier 1 suppliers, each of these suppliers has e.g., 200 tier 2 suppliers and each of these suppliers has 100 suppliers then the number of connections is up to 3 level 300 x 200 x 100 = 6.000.000 connections. But this number may not even include the source of raw materials such as the mine from which raw materials used in the battery of the vehicle come from.

This demonstrates that "birds eye view" approaches like it is very often published in scientific or semi-scientific literature is an illusion. The number of connections is simply too high to update all, and control all. This is in particular the case as long as we do not have a complete supply chain digitalization, for example by using digital supply chain twins. Similar challenges appear with companies, that have many products and product variants.

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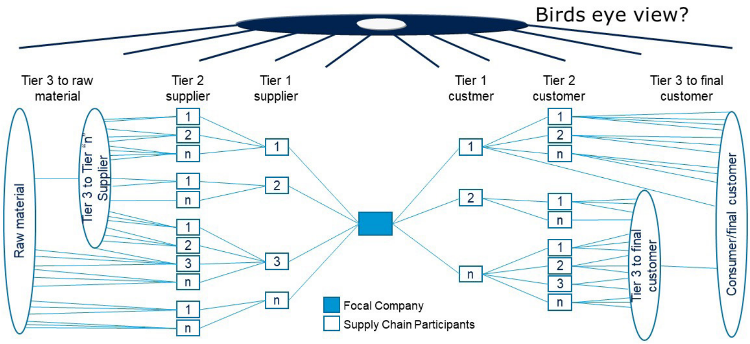
[5] A.M. Geske, and L. Novoszel, "Definition and Development of Supply Chain Resilience", in S. Kummer, T. Wakolbinger, A.M. Geske, and L. Novoszel (eds.), *Supply Chain Resilience -Insights from Theory and Practice*, Springer, 2022.

Fig. 18.2 - Typical Supply Chain Design[6]



Against the backdrop of numerous crises, this stresses the importance of increasing supply chain resilience capabilities. The example above demonstrates the relevance of increasing visibility and collaboration to manage and overcome crisis situations more effectively. In parallel, supply chain management must segment and simplify. Without being able to go into all the details here, one will end up having to focus on the most important products and connections. In other cases, you might analyze certain country risks, neglecting product and supplier level. The exact same thing needs to be done at the state level. Through a detailed analysis of the supply chain and its partners, critical connections and infrastructures can be identified. Based on this, contingency plans need to be developed on how to deal with disruptions of the critical components. By improving the capability flexibility, it is possible to minimize the negative impact of crises on one‘s supply chain by redesigning the supply chain by serving other nodes and using other modes of transport as well as infrastructures. Investing into such a

[6] S. Kummer, "Industrieökonomische Analyse der österreichischen Infrastruktur 2023", in D. Ungar-Klein and M. Podoprigora (eds.), *Osterreichischer Infrastrukturreport 2023 der Initiative Future Business Austria*, Create Connections Networking & Lobbying GmbH, 2022. (own translation).

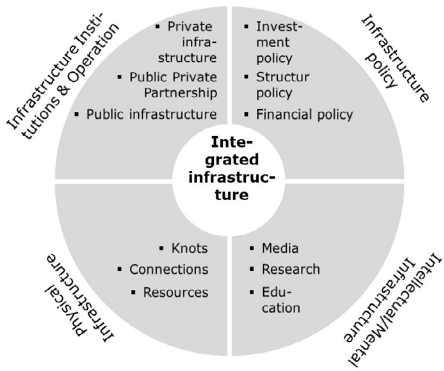
preparedness does not only support crisis response actions, also provides new business opportunities when other supply chains are still struggling in the aftermath of a disruption.

The depth of hazard analysis might also differentiate further. Perhaps in most cases simple metrics are sufficient. However, for critical materials and/or suppliers the manufacturer, perhaps even the governmental institution, may want to obtain inventory, available capacity, and/or current and future order data, and/or real-time information on the status of orders and shipments (tracking and tracing).

Resilient Integrated Infrastructure

A crucial part of the supply chain involves transportation and in particular transportation infrastructure. Efficient and resilient infrastructure is a key competitive advantage for supply chains. As Figure 18.3 shows an integrated infrastructure view is needed.

Fig. 18.3 - Elements of an integrated resilient Infrastructure[7]



[7] S. Kummer (2021).

1. Infrastructure policy and Financing resilient supply chains and infrastructure

Financing resilient infrastructure policies is one of the biggest challenges at both the microeconomic and macroeconomic levels. Previously, supply chains were primarily designed for efficiency. This orientation is proving problematic for both governments and continents, but also for companies, given the dependencies, for example, for Europe on Russian gas, but also for the world on Chinese batteries or Taiwanese microchips. A shift away from the predominance of economy and efficiency in the narrow sense of the term is intended to clarify the following issues:

- which investments are made (investment policy),
- in which infrastructure areas and in which regions, which infrastructure should be provided (structural policy),
- how the infrastructure is to be financed, for example, through user financing or through state pay-as-you-go financing.

At the microeconomic level, the main question is to what extent the shareholders of the companies are willing to finance investments in resilient supply chains. For example, whether the shareholders are willing to forego profits in the present to make supply chains more resilient and make companies fit for future challenges. Even if the financial contribution of the employees to resilient supply chains will probably be rather small, they will tend to have more work and burdens waiting for them. It is already visible today that companies with a good market position are involving customers in the financing of resilient supply chains by raising prices, whether they want to or not.

2. Actors and institutions of resilient supply chains and infrastructures

Due to the magnitude of the challenge at the macroeconomic level, establishing resilient supply chains can only be achieved with the involvement of diverse government institutions:

EU, federal states, local, non-governmental organizations, associations, and advocacy groups, businesses, and private households. There are three common forms of public and private involvement in the construction and operation of infrastructure:

- public construction and/or operation,
- private construction and/or operation,
- public-private partnership (PPP) projects.[8]

But also on a microeconomic level, many corporate divisions are involved in the design of resilient supply chains. The importance for purchasing and the transport and logistics areas is obvious. But supply chain transformation has a major impact and needs the involvement of all business units, starting from the development which may need to redesign parts. For example, it was reported that in the microchip crisis, some companies reacted quickly to the lack of availability of high performance microchips and redesigned products or their software so that (more) simpler chips took over the tasks originally done by high performance chips. Production must react to bottlenecks to become much more flexible than it was the case previously. Marketing and sales must also be involved, as they have to communicate the appropriate resilience measures to customers.

3. Resilient design of the physical infrastructure

The resilient physical infrastructure does not only concern the challenges of international supply chains but also the national infrastructure, especially the digital and with the energy transition also the energy infrastructure have to become more resilient. on a macro level have to be analyzed and designed:

- edges, essentially pipelines and transport routes,
- nodes,
- resources necessary for creation and maintenance.

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[8] S. Kummer, *Einführung in die Verkehrswirtschaft*, (2nd ed.), Vienna, UTB, 2010.

4. Shaping resilient intellectual/mental infrastructure

While the first points are controversial but more or less known, it is equally important for an integrated infrastructure policy to create an intellectual infrastructure:

- In the field of education and training, programs should be created that address infrastructures and their management, or infrastructure issues should be built into existing education and training programs. Initial offerings exist in Austria, for example at the FH St. Pölten.
- The state should support infrastructure research at least in priority areas: Austria is one of the leading countries worldwide in the field of railroad infrastructure.
- In order to create an understanding of the importance of infrastructure among companies, but above all among the general public, the media should report on it. Here, too, Austria has made some progress in recent years.
- Building personal resilience.

In the discussion about resilient supply chains and macroeconomic crisis management, technological or organizational measures to strengthen supply chain resilience are often discussed.

However, the Covid-19 crisis as well as the subsequent supply chain crisis have shown that the burden on the employees in Norm were but above all thing also with the current state of (IT) technology due to the novelty of the problems and challenges as well as the necessary improvisation the employees were necessary. In order to be able to maintain an operation at all during the crisis, not only the workload but also the physical strain on the employee increased enormously.

Accordingly, one of the main tasks in building resilience in supply chains is to increase the personal resilience of employees. Here, it is not only the managers who are challenged, but part of the measures for rebellion rise should also be psychological training of the employees, so that they can better cope with the tasks in crisis situations.

At the macro-economic level, the crises of the past few years have shown that in crisis situations, in addition to the associations, strong extremist currents occur, which can endanger social cohesion but also the economic foundations. In the area of transport and logistics, it is helpful to emphasize the importance of this sector, especially in times of crisis, in order to increase understanding of the need for transport. Of course, the political task of building a resilient society is much greater.

Building Personal Resilience

In the discussion about resilient supply chains and macroeconomic crisis management, technological or organizational measures to strengthen supply chain resilience are often discussed.

However, the Covid-19 crisis as well as the subsequent supply chain crises have shown that the novelty of such challenges and problems required improvisation of the workforce as the current state of (IT) technology could not cope with it. To be able to always maintain operations during a crisis, not only the workload but also the physical strain on single employees increased enormously.

Accordingly, one of the main tasks in building resilience in supply chains is to increase the personal resilience of employees. Here, it is not only the managers who are called into action, but part of the measures against rebellion rise should also be psychological training of the employees to allow them to better cope with the tasks in crisis situations.

At the macroeconomic level, the crises of the past few years have shown that in crisis situations strong extremist currents occur, which can endanger social cohesion and economic foundations. In the area of transport and logistics, it is helpful to emphasize the importance of the sector, especially in times of crisis, to increase understanding of the need for transport. Of course, the political task of building a resilient society is much greater.

Conclusion

Transport, logistics and supply chain management proofed their flexibility and although not everything went well and the employees had to work for two years in a fire fighting modus most of the challenges could be solved. Now is the time to draw the right conclusions of the crises of the last years and that is that the companies as well as the states have to improve their resilience. The article tried to show some developments and proposed measures. For sure companies will be prepared better for the next crisis. For the states especially on the infrastructure level there is still a lot to do and its´s not easy to create a resilient infrastructure fast but if we don´t start now than we will never start.

19. Infrastructure Resilience to Natural Hazards

Gian Michele Calvi

Risk and Resilience for Infrastructures

The risk to which an infrastructure is subjected is commonly defined as the convolution of hazard, vulnerability and exposure, where the first term refers to the probability of attaining a challenging situation inducing potential actions on the asset, the second to the propensity of the infrastructure to incur damage, independently of hazard, and the third to the relevance of losses consequent to any sort of damage.

In this context, resilience may be intended as the opposite of risk, and its reduction essentially as a reduction of vulnerability, since hazard is difficult to modify and exposure has a tendency to increase in developed countries.

However, the combination of the three items induces complexities hidden in the simplification expressed above with the intent of clarification. For example, similar theoretical levels of vulnerability (of attained damage levels) may result in different losses depending on the effects connected to specific situations. By the same token, interactions between different infrastructures (e.g.: the accessibility of a bridge and the usability of a hospital) can result in different overall losses at identical levels of damage.

This chapter refers mainly to earthquake hazard and to transportation infrastructure, such as bridges, as illustrative cases.

Vulnerability of Infrastructures

It is commonly stated that the 1960s were an extraordinary time for the construction of freeways. The era of great bridge construction had started much earlier but bridges were perceived as standalone masterpieces to cross rivers or straits, rather than as parts of a roadway system.[1] It was on 29 June 1956 that President Eisenhower signed the Federal-Aid Highway Act in the US, initiating the "*Greatest Decade*",[2] or the construction of the Interstate System that originally included around 60,000 km of roadways. When the Eisenhower administration ended in January 1961, about one fourth of this system had been opened to traffic. With an average construction of about 5,000 km per year, President Eisenhower's successor, President Kennedy, refused to follow the suggestions of cutting back the programme and opposed the reduction of a temporary US$$0.01 gas tax per gallon (≈ 3.8 litres) established to fund the Interstate Program. By the end of 1966, some 29,000 km of highways had been completed, with a total cost of about US$25 billion. According to a document submitted to the US Congress in 1965,[3] the complete system (which required additional funding estimated to be about US$20 billion) would have included "12,957 interchanges requiring 22,252 individual structures, as well as 20,748 other highway grade-separation structures, 4,361 railroad grade separations, and 14,806 other bridges and tunnels".

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[1] H. Petrovsky, *Engineers of Dreams: Great Bridge Builders and the Spanning of America*, Alfred A. Knopf, Inc., 1995.

[2] R.F. Weingroff, *The greatest decade 1956-1966 – Part 2: The Battle of its life*, Public Roads (FHWA), May/June 2006b; Id., *The greatest decade 1956-1966 – Part 1: Essential to the national interest*, Public Roads (FHWA), March/April 2006a.

[3] Weingroff (2006b).

In Europe, the construction of freeways started much earlier with the initial but limited experience in Italy in the 1920s and a massive programme in Germany in the late 1930s, where some 4,000 km of roads were built between 1935 and 1940, which inspired President Eisenhower to say: "Germany had made me see the wisdom of broader ribbons across the land".[4] However, it was after the Second World War and mainly in the 1960s that most European countries constructed the backbone of the modern freeway system. In Italy, the 760 km "*Autostrada del Sole*" freeway system linking Milan to Rome and Naples was designed and built between 1956 and 1964, coinciding with the American "greatest decade". In spite of its relatively small length, this freeway represented an achievement of sorts, due to the ingenuity required for its conception and construction, as a result of the challenging topography of the Italian territory, particularly in the mountainous area between Bologna and Florence. Indeed, a total of 853 bridges and viaducts (and an additional 572 overpasses) and 38 tunnels needed to be constructed.

There is little need for any detailed analysis to state that a significant fraction of both North American and European infrastructure has reached or is reaching its nominal design life, requiring the allocation of relevant resources for their assessment, repair and upgrading.

The collapse of the Morandi bridge in Genoa has attracted media attention worldwide,[5] with *The New York Times* noting that:

- in France, the highway system comprising 12,000 bridges is in a state of chronic underinvestment, with 7% having damage that could eventually result in collapse if not addressed;
- in Germany, of the 39,621 bridges monitored by the Federal Government, 10.6% are in a condition that is not satisfactory and 1.8 % are in "inadequate" condition;

[4] Weingroff (2006a).

[5] G.M. Calvi et al., "Once upon a Time in Italy: The Tale of the Morandi Bridge", *Structural Engineering International*, vol. 29, no. 2, pp. 198-217.

to name but a few, with similar examples reported for other European countries.[6]

Ageing and inadequate maintenance measures resulted in an exponential increase of propensity to damage and collapse. As a consequence, the vulnerability of infrastructures is generally very high and entire inventories are in need of assessment to allow rational prioritisation in the allocation of the limited resources available. This implies the application of rapid assessment methods to perform an initial screening, followed by the enactment of more refined approaches (with a proportional acquisition of more data) for a limited number of cases and possibly the implementation of effective and well-focused monitoring systems in specific situations.

What was described above with reference to roads may be extrapolated to most classes of infrastructures, with a few exceptions, such as airports, which culminated in more recent times, such as airports.

Hazard for Infrastructures: Earthquakes

Seismic hazard is normally expressed as the yearly probability of attaining a certain level of ground motion intensity at a specific location.[7] The fundamental tool to estimate the expected demand is called PSHA (probabilistic seismic hazard analysis), as originally proposed and articulated by Cornell (1968).[8] In the introduction of his seminal paper he noted the following points.

- Owing to the uncertainty in number, size and location of future earthquakes it is appropriate that engineers express seismic risk in terms of return period.

[6] R. Pérez-Peña, "After Italy collapse, Europe asks: how safe are our bridges?", *The New York Times*, 21 August 2018.

[7] J.J. Bommer, "Earthquake hazard and risk analysis for natural and induced seismicity: towards objective assessments in the face of uncertainty", *Bulletin of Earthquake Engineering*, vol. 20, 2022, pp. 2825-3069

[8] C.A. Cornell, "Engineering seismic risk analysis", *Bull. Seismol. Soc. Am.*, vol. 58, pp. 1583-1606, 1968.

- The relevant information to engineers is better transmitted in terms of intensity versus average return period than through ill-defined single numbers as maximum credible intensity.
- The locations and activities of potential sources of tectonic earthquakes may be not well known. In such circumstances a higher level of conservativism should depend on engineers' views, since they have more information than seismologists to determine an optimal balance of cost, performance and risk.
- The proposed method integrates the individual influences of potential earthquake sources, near and far, more active or less, into the probability distribution of maximum annual intensity. The average return period follows directly.

In fifty year of applications, PSHA provided the background to define the intensity (normally expressed in terms of a single parameter, the peak ground acceleration expected at determinate return periods) to be considered in design and assessment, even if it has been shown that displacement, rather than acceleration, has a much better correlation to damage.

The focus has traditionally been on avoiding collapse, but it became progressively clear that the effect of an interrupted functionality of infrastructures, even in case of lower magnitude events and lower intensity ground motions, may have unacceptable consequences in terms of societal loss.

Two enlightening examples are the earthquakes that hit Japan in 1995 and 2011.

The first one had a relatively small magnitude ($M_w = 6.9$), but the focus was inland and shallow. The most relevant economic loss was induced by the interruption of all the three major connections between Tokyo and Kyoto, with the collapse of the 1960's Hanshin Expressway (which remained closed for twenty months), severe damage to the recently completed Meishin Expressway (with all four lanes reopened to traffic six months later) and the entire line of the Shinkansen high speed rail shut down for about one month. In addition, many of the facilities of the Kobe Port were ravaged to an extent causing inoperability of the most important container port of the country. The sheer effect on transportation capacity had a major impact on economy, with bank failures and stock market decline.

In 2011, the energy release was more than 1,000 times greater (M_w = 9.1, one of the largest ever recorded), but the epicentre location was about 70 km off the coast and the main effects were induced by the tsunami, which in turn caused the meltdown of three of the reactors of the Fukushima nuclear facility. A further consequence of this chain reaction was the government's decision to close and upgrade the majority of the nuclear power plants in the country.

It is clear that the parameters of intensity used to represent hazard must be significant in relation to the capacity of inducing damage and loss.

Exposure of Infrastructures

The examples discussed introduce the subject of exposure of infrastructures, which is largely dominated by indirect effects, i.e. the loss connected to service interruption is much greater than the cost of repairing and possibly upgrading the facility.

Consider as a comparative example the case of residential buildings: an obvious form of indirect loss is the cost of relocating the displaced building occupants, during the emergency phase and for the time required to repair and refurbish the damaged building. In this context one could reasonably estimate the potential maximum indirect loss by assuming a daily cost of relocation per person of C_{rl} = 35 €/(day/person), a tributary area per person of S_p = 25 m^2/person, a cost of reconstruction of C_R = 1000 €/m^2, and a required time for total reconstruction of T_{rc} = 730 days. Using these arbitrary but reasonable values, the maximum indirect loss (L_{IM}) parametrised on the reconstruction cost (R_C) would be:

$$\frac{L_{\Im(res)}}{C_R} = \frac{C_{rl} \cdot T_{rc}}{S_p \cdot C_R} = \frac{35 \cdot 730}{25 \cdot 1000} = 1.02 \approx 1$$

This value indicates that the maximum indirect loss in case of total disruption of a residential building would possibly be in the same range of the reconstruction cost, i.e. of the maximum direct loss.

The same exercise indicates that the daily cost associated to the unavailability of a residential building is approximately 0.14% of the cost of reconstruction. Thus, for example, a downtime of three months implies an indirect loss approximately equal to 12 % of the reconstruction cost.

In the case of a bridge, similar simple calculations could be based on the number of vehicles (N_v) crossing the bridge and on the required detour length (D_d [km]) in case of collapse, assuming a unitary cost per added travelled km (C_{km}), a cost of reconstruction (C_R) and a time required to reconstruct or repair the bridge (T_{rc}):

$$\frac{L_{\Im(bridge)}}{C_R} = \frac{N_v \cdot D_d \cdot C_{km} \cdot T_{rc}}{C_R}$$

In this case the only parameter with relatively little variability is C_{km}, possibly in the range of 0.5 €/km. Some parametric analyses of possible combinations of the other parameters lead to reasonable ratios between indirect and direct loss for relevant bridges in the range of 5 and to a daily cost associated to downtime in the range of 0.8% of R_C. The implication is that the entire cost of reconstruction of an important bridge is repaid in after about a four-month interval of downtime.

Similar exercises are possible for all sorts of infrastructure, such as ports and airports, power plants, lines of power transportation and industrial buildings, universities and hospitals, generally obtaining even higher ratios between indirect and direct loss.

While the simple examples above have referred to the effect of a complete failure for simplicity, the point becomes even more relevant considering the loss induced by more frequent, lower intensity ground motions (possibly induced by lower magnitude closer distance or by larger magnitude far distance events), where collapse is not an issue, but loss of functionality becomes the crucial problem.

As pivotal cases, consider two recent events: the 2010 Maule earthquake in Chile (M_w = 8.8) and the 2001 Nisqually (Seattle) earthquake (M_w = 6.8) in the United States.

The Chile case is interesting for the widespread damage it caused to non-structural elements (NSE), especially airports and hospitals, in a country with a long and solid tradition in seismic resistant design. The Santiago (more than 300 km from the epicentre) and Concepcion (about 100 km from the epicentre) airports were closed for several days mainly because of severe damage to NSE, particularly to suspended air handling units, ceiling tiles and sprinkler piping systems. Two thirds of the Chilean air traffic was interrupted and the total cost for repairs of NS damage at the Santiago airport was estimated at US$40 million. LAN airline alone suffered a loss of revenue of US$10 million.

Most of the estimated two billion dollars loss resulting from the Nisqually earthquake resulted from damage to NSE, again in a region with a solid tradition in seismic design. Even though building structures generally performed well during the earthquake (the ground shaking was relatively low), the inferior performance of non-structural components reduced the overall performance of many buildings (Filiatrault et al., 2001),[9] including the shattering of glass windows of the control tower of the Sea-Tac airport (about 50 km from the epicentre), which shut down for four hours.

The disproportionate ratio between the cost of substituting a few glasses and that of closing a major airport for a few hours is striking.

[9] A. Filiatrault, A., C.-M. Uang, B. Folz, C. Christopoulos, and K. Gatto, *Reconnaissance Report of the February 28, 2001 Nisqually (Seattle-Olympia) Earthquake*, Rep. N. SSRP-2000/15, Dep. of Structural Engineering, UC San Diego, CA, 2001

Applicable Logic to Increase Infrastructures Resilience

From the discussion above, it appears highly desirable to define a design parameter able to condense the global tendency to reduce losses, direct and indirect. Such a parameter can be identified in the *expected annual loss* (EAL), defined as the integral of the yearly probability of exceedance of a ground motion intensity over the expected loss for that level of intensity. The definition may sound obscure, so let's try to explain the concept in simple words. Assume that the average return period of a ground motion inducing collapse is 2000 years; its yearly probability of exceedance is $P_e = 1/2000$, while the associated direct loss is the 100% of the cost of reconstruction (R_c). The contribution of this event to the EAL is thus 100% of R_c divided by 2000 years, i.e.: EAL (collapse) = 0.05% R_c. Assume now that the average return period of an event inducing direct losses equal to 30% R_c is 100 years: its contribution to EAL is EAL (30%damage) = 30% / 100 = 0.3% Rc. If the integral is regarded as a sum of discrete items, EAL is the sum of a number of contributions similar to those described above.

Using the same example, it would appear that reducing the probability of collapse to one half will reduce EAL of 0.025% R_c, while reducing the probability of attaining 30% R_c damage to 0.005 (average return period 200 years) will reduce EAL of 0.15% R_c.

Generally speaking, maintaining functionality will contribute more to containing losses than reducing the probability of collapse. For a major bridge it may be more important to maintain the functionality of joints than to make it stronger; for an airport the functionality of fingers and control tower for frequent ground motions may be more relevant than reducing the probability of collapse of a terminal for very rare actions.

When indirect loss enters the game, the considerations above are all the more applicable.

Strengthening interventions are thus assuming the meaning of reducing the expected loss and the convenience of strengthening now has a clear metric: investing a sum to reduce EAL means to reduce the expected average annual cost and a break-even time can be immediately estimated, including indirect loss.

In this framework, resilience has a quantitative meaning that should guide our investment choices.[10]

[10] G.M. Calvi, (in preparation, to appear 2024), *The art of seismic design – from forces to displacements and losses*, Master Series, IAEE.

20. Infrastructure, Durability and Sustainability in One Concept

Federico Laino, Simone Barile, Erika Muzzupappa

In the past, "concrete restoration" was based on a concept that involved the replacement of the deteriorated parts with any cement-based product, without considering a very important factor, durability, which must be guaranteed to any structure about to be restored. Durability also contributes to environmental sustainability, a topic that is now of primary importance in all fields and especially in construction.

Products related to the concrete restoration sector fall under the guidelines dictated by the European standard EN 1504, which defines intervention procedures and minimum product requirements. The choice of materials must be based on "the concept of system". According to this key concept for the purpose of durability it is important not to rely on a single product, but rather on a cycle composed of several materials, each specific to address a given issue.

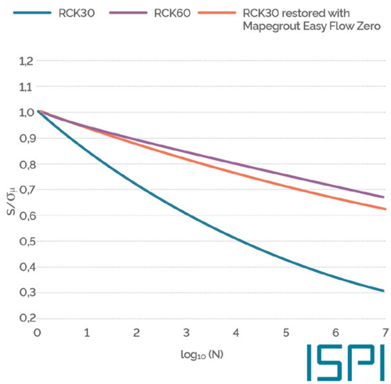
Below we present some tests performed on two different innovative materials, aimed at identifying their greater durability compared to more traditional ones.

Restoration of Infrastructures with High Fatigue Strength Mortars

An experimental campaign conducted at the University "Federico II" of Naples on Mapegrout Easy Flow Zero aimed to determine the fatigue behaviour under flexural loads of concrete elements restored with this cementitious fibre-reinforced mortar. For this purpose, three different series of specimens were tested. The first and second series were composed of concrete elements having a characteristic compressive strength respectively of 30 MPa and 60 MPa, and the third by concrete elements having a characteristic compressive strength of 30 MPa and restored with Mapegrout Easy Flow Zero. The resulting fatigue properties consist of experimental *S-N* curves which are represented by analytic curves in the logarithmic scale. To end scope, four-point bending tests were performed; the specimens are first statically loaded up to failure in order to determine the ultimate flexural strength of the material σ_u, and then dynamically by applying loading force steps (50250 cycles each) with increasing amplitude. The Palmgren-Miller rule was applied to determine the S-N Curves and of the estimated fatigue life of the concrete element subject to repair.

Fig. 20.1 - Restored specimens under flexural test

Fig. 20.2 - Graphic representation of S-N Curves of the 3 series



As described in Figure 20.2, the RCK 30 specimens restored with Mapegrout Easy Flow Zero show an improved fatigue behaviour than that shown by the standard concrete element with a characteristic compressive strength of 30 MPa. Furthermore, this behaviour can be assimilated to that of concrete with a characteristic compressive strength of 60 MPa.

In addition to this experimental campaign conducted on a small scale, cyclic flexural tests on real scale beams, both repaired and unrepaired, were performed. These tests were designed and executed according to the state of the art and implemented through an ad-hoc experimental procedure based on:

- accelerated corrosion;
- structural repair with Mapegrout Easy Flow Zero;
- application of dynamic loads.

The resulting cyclic properties and cracking behaviour of the structural elements have been related to the level of corrosion achieved through the accelerated test and the effectiveness of the structural repair made with Mapegrout Easy Flow Zero. For the cyclic tests at the structural scale, four reinforced concrete beams were fabricated. The first beam was named B1_R, where

"R" stands for "reference" because it is the only beam that has been tested without any application of repairing mortar after accelerated corrosion (3%). The remaining beams, named B2_8%, B3_6% and B4_3%, have steel rebars with different levels of corrosion; the percentage number denotes the level of corrosion, which ranges from 3% to 8% expressed in terms of (theoretical) steel mass loss. All beams have been designed according to NTC2018.

Once the accelerated corrosion test was completed, the concrete cover of B2_8%, B3_6% and B4_3% was removed by chiselling to prepare them adequately for structural repair. The exposed surface was subsequently cleaned, and the concrete cover has been restored through a 5-cm layer of Mapegrout Easy Flow Zero.

All specimens were loaded in four-point loading configuration. The flexural load was applied using a large-scale steel testing frame equipped with a servo-hydraulic actuator with 200 kN load capacity. The schematic representation of the testing setup and of the designed specimens are shown in Figure 20.3.

Fig. 20.3 - Fatigue test set up

Fig. 20.4 Fatigue curves envelope of the four beams

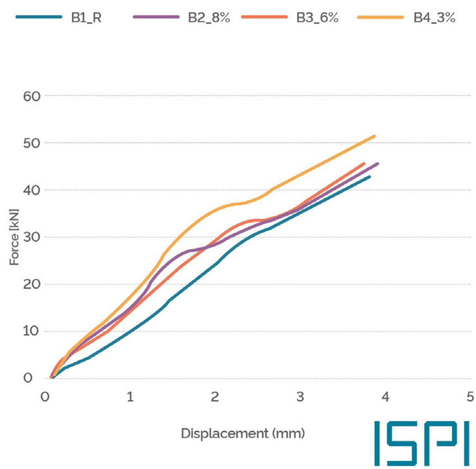


Figure 20.4 represents the comparison of the results made in terms of recorded force vs displacement, by overlapping the envelope obtained from the fatigue curves for the four beams having three different corrosion rates. B1_R beam and B4_3% beam, characterised by a lower theoretical rate of corrosion, reached higher force values at first cyclic cracking whereas B3_6% and B2_8% are characterised by a lower cracking moment, although they show similar behaviour to the reference beam despite being affected by a much higher corrosion rate. Other important considerations were made about how cracks propagated during the tests.

- In the cases of similar low-to-moderate corrosion levels, the restoration of the damaged cover with Mapegrout Easy Flow Zero tends to increase the first cracking load of the beam in comparison with the non-repaired counterpart; the application of the repairing mortar is able to stabilise cracking openings and avoid unexpected cracks in the longitudinal direction of the beam as detected in the bottom surface of B1_REF;

- In the cases of higher corrosion levels, the restoration of the damaged concrete cover with Mapegrout Easy Flow Zero would seem to be able to induce a positive multi-cracking stage under cyclic loads at increasing deflection amplitudes. The higher the number of cracks, the fewer the openings.

Fig. 20.5 - Crack Opening vs Load Comparison
Fatigue Test - Maximum Crack Opening Comparison
Crack opening measured by digital microscope

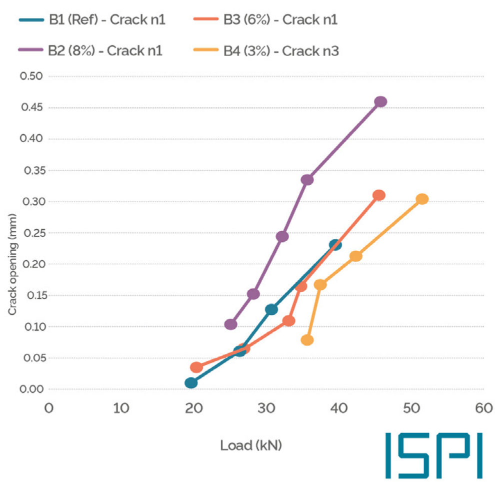


Figure 20.5 shows the trend of the first crack opening in function of the applied load. Comparing unrepaired reference B1_R beams and restored B4, having the same corrosion level, the same crack opening occurs for higher load values for the restored beam. Analysing the behaviour of the B2 beam having a corrosion level of 6%, double that of the reference beam, the crack opening trend is similar to that of the reference beam despite having a significantly higher corrosion level.

Fig. 20.6 - Spray application of Mapegrout Easy Flow Zero, by plastering machine equipped with premixer

Infrastructure Protection Impervious to Aggressive Agents

Mapelastic Guard *complies with the principles defined in EN 1504-9 ("Products and systems for protecting and repairing concrete structures: definitions, requirements, quality control and conformity assessment. General principles for the use of products and systems*") and the requirements of EN 1504-2 coating (C) according to principles PI, MC and IR ("*Concrete surface protection systems*").

Besides, thanks to its high flexibility, the material can act as a bridge on the cracks that may be present in the concrete (crack-bridging ability).

Moreover, according to the tests carried out by external laboratories as described below, the results show that Mapelastic Guard is highly resistant to chemical aggression and offers an efficient protection for concrete against the penetration of CO_2 (carbonation) and chlorides.

Both types of aggression trigger corrosion in reinforcing steel, resulting in a loss in structural integrity. Carbon dioxide (CO_2) penetrates into the concrete at a parabolic rate:

$$\mathbf{x = K \cdot t^{1/2}}$$

where:
x is the thickness of concrete penetrated by the CO_2;
K is the diffusion coefficient of CO_2;
t is the period of exposure to an atmosphere containing CO_2.

The value of K depends mainly on the characteristics of the concrete (type of cement, additives where applicable, water/cement ratio, curing time, etc.) and on the environmental factors (humidity, temperature, concentration of CO_2, etc.) and must be determined experimentally, therefore, for each case. Tests carried out by the Società Autostrade per l'Italia (Italian Motorways Society) research laboratories have measured the value of the diffusion coefficient K on concrete with 0.5 and 0.6 water/cement ratios.

Results gave an average K value of 7.6 for concrete with a 0.5 water/cement ratio, and of 8.0 for concrete with a 0.6 water/cement ratio. If we assume a thickness of concrete cover of x=30 mm and these values are applied in the formula $x = K \cdot t^{1/2}$, we get:

$t_{concrete} = 900\ mm^2 / 57.76\ (mm^2\ year{-}1) \sim 15.6$ years for concrete with a 0.5 water/cement ratio

$t_{concrete} = 900\ mm^2 / 64\ (mm^2 \cdot year\ {-1}) \sim 14$ years for concrete with a water/cement 0.6 ratio

where t represents the time required for carbon dioxide to penetrate through all the concrete cover.

The same tests were carried out on concrete samples protected with Mapelastic Guard, and the results showed K values of 0.25 to 0.29. If we assume an average K value for

Mapelastic Guard of 0.27 ($mm \cdot year^{1/2}$) and then use the formula:

$$\mathbf{x = K \cdot t^{1/2}}$$

where x is the thickness of Mapelastic Guard equal to 2 mm, we can affirm that, by applying Mapelastic Guard on the surface of concrete, it is possible to increase the durability of structures by providing an efficient barrier to the penetration of CO_2 to more than 50 years.

To ensure a protection similar to the one given by Mapelastic Guard (50 years), but using a concrete with 0.5 water/cement ratio (with K equal to 7.6 $mm \cdot year^{1/2}$), a concrete cover thickness of over 50 mm would be necessary. In fact, using the a.m. formula, we have:

$$\mathbf{x = K \cdot t^{1/2} = 7.6 \cdot 50^{1/2} \approx 53.7\ mm}$$

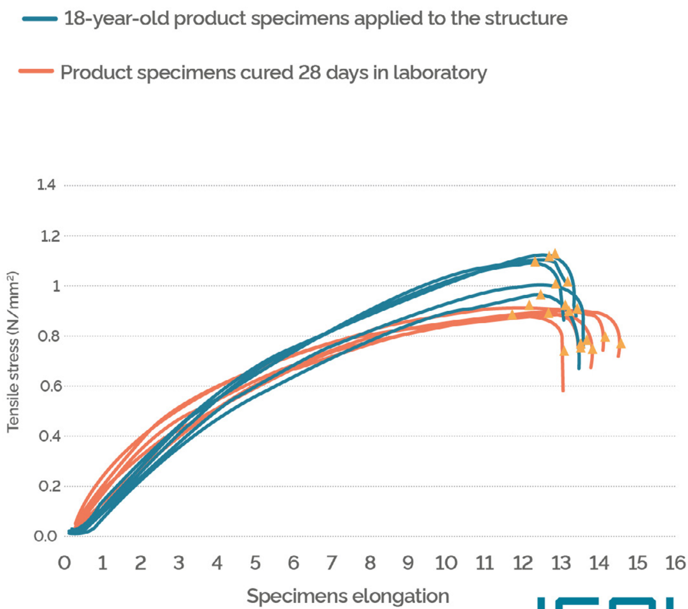
As far as the aggression from chlorides is concerned, according to the Danish certification body COWI (Consultancy within Engineering, Environmental Science and Economics), a 2.5 mm thick layer of Mapelastic Guard corresponds to 30 mm of concrete cover made from concrete with a 0.45 water/cement ratio.

In support of what has been previously described, to emphasise the resistance of the elastic cementitious membrane to aggressive agents, we report below the results of tests carried out on samples of the product, applied for 18 years on viaduct pillars, which show that the characteristics of Mapelastic Guard remain unchanged over time. The structure from which the samples were taken was continuously exposed to the atmosphere, repeated freeze-thaw cycles and contact with de-icing salts.

To verify the mechanical properties, elasticity tests according to modified DIN 53504 were performed in the laboratory, and adhesion and carbonation tests were performed directly in situ.

The graph in Figure 20.7 compares elasticity test results obtained on 18-year-old product specimens and those obtained on specimens cured for 28 days in the laboratory.

Fig. 20.7 - Comparison of tensile stress and elongation value between material specimens cured 28 days in laboratory and those aged 18 years



By analysing the values of tensile stress and percent elongation at failure, we can conclude that the mortar maintained its elasticity unchanged over time.

Finally, Figure 20.8 shows an image related to the carbonation tests performed directly in situ on the specimens taken from the structure.

Fig. 20.8 - Sample taken from the structure and analysed with phenolphthalein: the total absence of carbonation in the concrete thickness can be seen

The colorimetric type test designed to detect the presence of carbonation revealed the total absence of degradation in the substrate, demonstrating that the membrane has effectively counteracted carbon dioxide penetration throughout its life.

The 100% CO_2 Offset Mortars

Mapei's commitment to an increasingly sustainable world of construction continues, where the client, designer and professional can choose to build using products with zero impact on climate change, high performance, and durability.

Research and Development laboratories have worked hard to reduce the carbon footprint to offer quality, sustainable products formulated with recycled materials and developed to reduce energy consumption at very low volatile organic compound (VOC) emissions.

Residual CO_2 is offset through the purchase of certified carbon credits to support renewable energy projects and forest protection. The environmental impact of products is calculated using the LCA (Life Cycle Assessment) methodology and is certified and disclosed through the EPDs (Environmental Product Declarations) available on our website.

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