

ADAPTATION & RESILIENCE THROUGH LAND TRANSPORT INFRASTRUCTURE SYSTEMS PROTECTING COMMUNITIES AND ECONOMIES

A Boston Consulting Group and UN Climate Change High-Level Champions Joint Publication

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PROTECTING COMMUNITIES AND ECONOMIES



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Climate change poses a grave threat to transport systems. The repercussions of their vulnerability extend beyond mere inconvenience—our economy and society bear the brunt, disproportionately affecting the livelihoods of the most vulnerable populations. To meet the ambitious objectives for transport infrastructure set by the Sharm el-Sheikh Adaptation Agenda we need to act together, and we need to act now

Dr. Mahmoud Mohieldin

UN Climate Change High-Level Champion from COP27 Presidency

A Note About This Report

This report was written based on extensive stakeholder engagement in the infrastructure adaptation & resilience space. This engagement included interviews, research, and industry roundtables at the Middle East and North Africa Climate Week (MENA CW). This report also benefits from close alignment with external partners such as the International Coalition of Sustainable Infrastructure (ICSI). The Contributors and Acknowledgment sections at the conclusion of the report provides a comprehensive list of associated contributors and collaborative partners.

EXECUTIVE SUMMARY

Land transport infrastructure (LTI) is central to our global economy and society. It is a highly complex network that transports passengers and goods via roads and tracks, including those used by rail, subway, and trams.

This essential infrastructure is heavily exposed to changing climate conditions and climate hazards that can often lead to physical damage and connectivity disruptions, with rippling negative impacts on society, economies, and the environment. This presents a mandate for not only investments in adaptation to changing and extreme climate conditions but also in increased resilience against climate hazards. Delaying action will impose additional costs, estimated to range from 15% to 45% for low and middle-income countries, if resilience measures are delayed until 2030. Increasing impacts of climate change on continued exposed assets and thus the economy, and society drive these costs for companies, countries, but also people, including company utility losses and GDP loss.¹ Infrastructure is also embedded in natural ecosystems and thus adaptation & resilience (A&R) measures need to be evaluated for potential environmental impacts such as biodiversity loss and higher carbon emissions.

Adding to the immensity of the challenge is the fact that A&R investments take place in a highly constrained and challenging environment. A lack of consensus when it comes to defining and measuring A&R in infrastructure continues to hamper the setting of global resilience targets and tracking progress, thus impacting investments. Further constraints exist in adaptation finance, awareness, and the capacity of decision-makers hindering the development of prioritized project pipelines. Moreover, despite current efforts to upskill practitioners and educate future professionals, a lack of capacity and expertise in A&R fields such as construction and engineering further impedes scaled implementation across the project life cycle. Furthermore, A&R timelines and planning need to factor in complex and long infrastructure project deliveries, along with potential time and budget overruns to create a long-term view.

This complexity calls for A&R planning to be done in an integrated manner and embedded throughout the LTI life cycle. This requires an overarching network-level view of both priorities and capacity to coordinate action and de-risk projects. Furthermore, this integrated planning must be translated into local A&R projects that consider A&R elements across the LTI life cycle, supported by cross-cutting enablers.

A&R in LTI faces several challenges and obstacles that risk derailing investment and implementation efforts; however, numerous best-practice case studies show that it can in fact be done effectively. Thus, this report identifies eight immediate calls to action related to setting global standards, targets, and taxonomy, advancing finance flows, and providing a conducive environment for A&R project setup and delivery. These can be catalyzed by the Sharm El-Sheikh Adaptation Agenda (SAA)—particularly by mobilizing stakeholders behind the adaptation outcomes that call for transport infrastructure to be resilient to climate hazards by 2030 through the adoption of new technology, design, and materials and to enhance access to low-cost, clean mobility solutions.

¹ Based on estimated cost of delaying action for infrastructure beyond LTI of \$1 trillion from 2020 to 2030 (Hallegatte, Rozenberg, Fox, Nicolas and Rentschler, 2019).



I. A CRUCIAL IMPERATIVE

Climate change is fundamentally reshaping our world, our societies, our economies, and our day-to-day lives on levels both large and small. From seemingly minor changes in weather patterns such as steady temperature increases to the gradual eradication of species and the desertification of land all the way to the catastrophic impact of supercharged storms and drought-fueled wildfires, nearly every aspect of human life is being affected by it.

There were nearly 12,000 disasters stemming from weather, climate, and water-related hazards between 1970 and 2021, at a cost of more than 2 million lives and \$4.3 trillion in economic losses.² Furthermore, the world's least-developed countries have suffered a disproportionate impact in terms of both lives lost and GDP reduction.³

Climate hazard-related disasters are accelerating at an alarming rate. In 2022 alone, losses from such disasters were estimated at \$200 billion, a 40% increase over the average from the last 20 years.⁴ If the public and private sector do not accelerate efforts for A&R, it is expected that up to 23% of global GDP by 2100 and up to 15% of companies' EBITDA by 2040 will be at risk.^{5,6,7} The scope of impact is global and massive, with countless implications beyond disasters, including increased temperatures and sea level rise. One of the most important of these implications concerns impact upon an essential infrastructure: the network of roads and tracks—including both railway and urban modes—as well as their operations, service, and utilization, all of which are vital to our interconnected world.

Society Depends on Land Transport Infrastructure

Roads and tracks, including those used for rail, subways, and trams, as well as connecting bridges, stations, and hubs and their operations and utilization, comprise the backbone of our modern society.⁸

Land Transport Infrastructure:

is a highly complex network that transports passengers and goods via roads and tracks, including those used by rail, subways, and trams.⁹

These networks' complexity derives from their many interconnections, interdependencies, and scope—and includes systems serving both urban and non-urban areas. The robustness and functioning of this system are of crucial importance—including the system's ability to adapt to, withstand, respond to, and recover from the consequences of climate change.⁹ This depends on such networks being planned, designed, built, and operated in a way that anticipates, prepares for, and adapts to changing climate conditions.¹⁰ Indeed, the resilience of our infrastructure is fundamental to ensuring the resilience of our economy and society as a whole.

² United Nations News (2022).

³ Ibid.

⁴ Centre for Research on the Epidemiology of Disasters (CRED) (2023), excluding earthquakes.

⁵ Based on 4C warming scenario as top end estimate in Burke, Hsiang & Miguel (2015).

⁶ Earnings before interest, taxes, depreciation, and amortization (EBITDA).

⁷ Based on BCG project experience.

⁸ Based on the definition used in UNFCCC (2021) considering rail and road as part of land transport infrastructure.

⁹ OECD (2018).

¹⁰ Ibid.

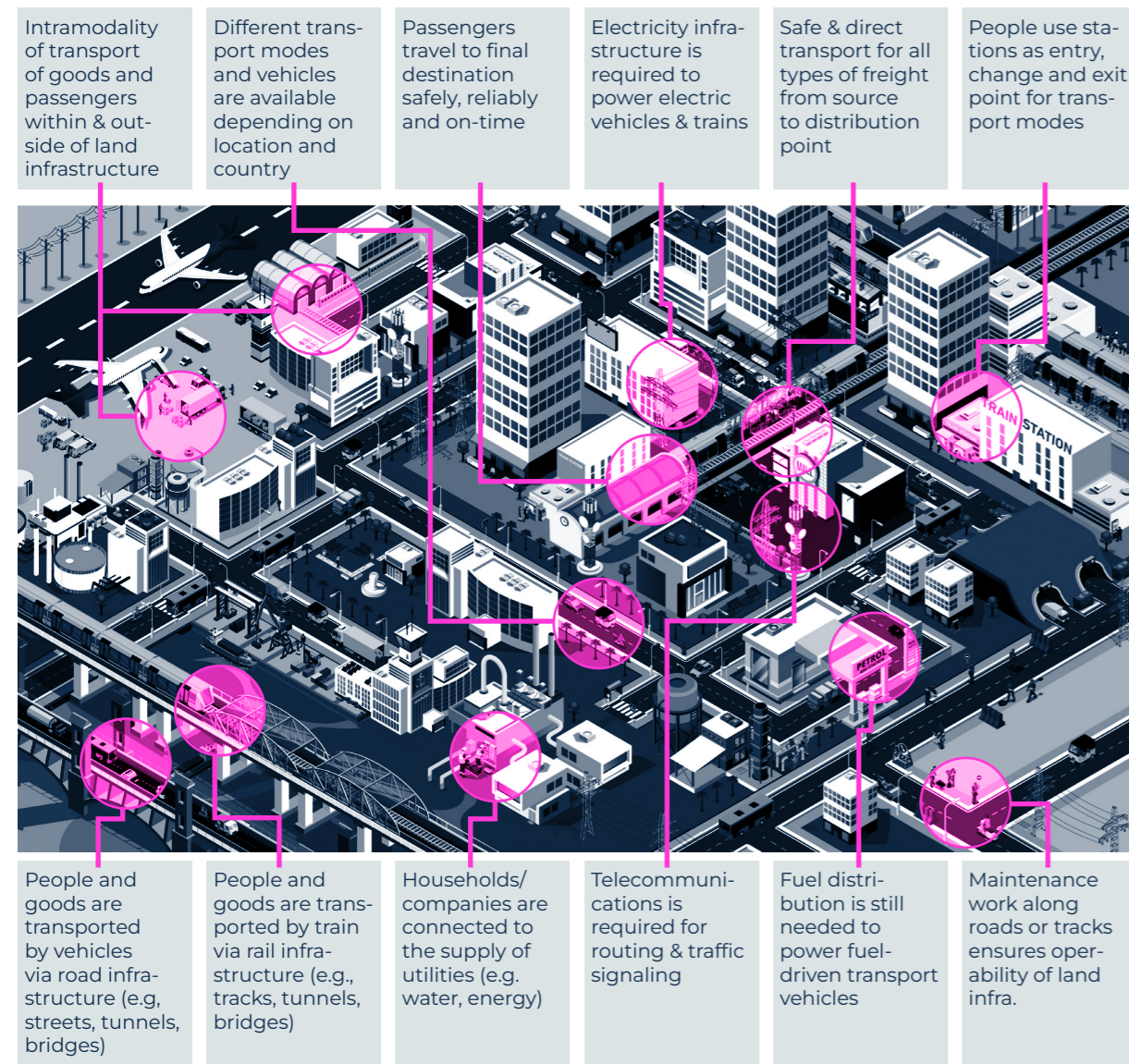
Our economy and society hinge on our physical ability to move ourselves, our raw materials, and our manufactured products around the globe. Our LTI, through its network operations and the connectivity it ensures, moves billions of people and billions of tons of freight every day:

- In G20 countries, LTI conveys 94 billion passenger kilometers per day, which includes 7 billion for rail and 87 billion on roads.¹¹
- In G20 countries, 66 billion ton-kilometers of freight are transported every day (26 billion rail; 40 billion road).¹²

LTI serves as the last mile in supply chains, connecting manufacturers to consumers and end users. The fundamental services that define civilized society depend daily on this network, including access to health care and education. LTI enables humanity to live, grow, and prosper.

Interconnectivity with Other Infrastructure Drives Complexity

Much of LTI complexity comes from the essentially interconnected nature of the network and its operations with other infrastructure and transport modes. For example, roads and rail networks are interconnected with seaports and airports—and as such, circumstances that affect any one transport mode have a cascading impact.



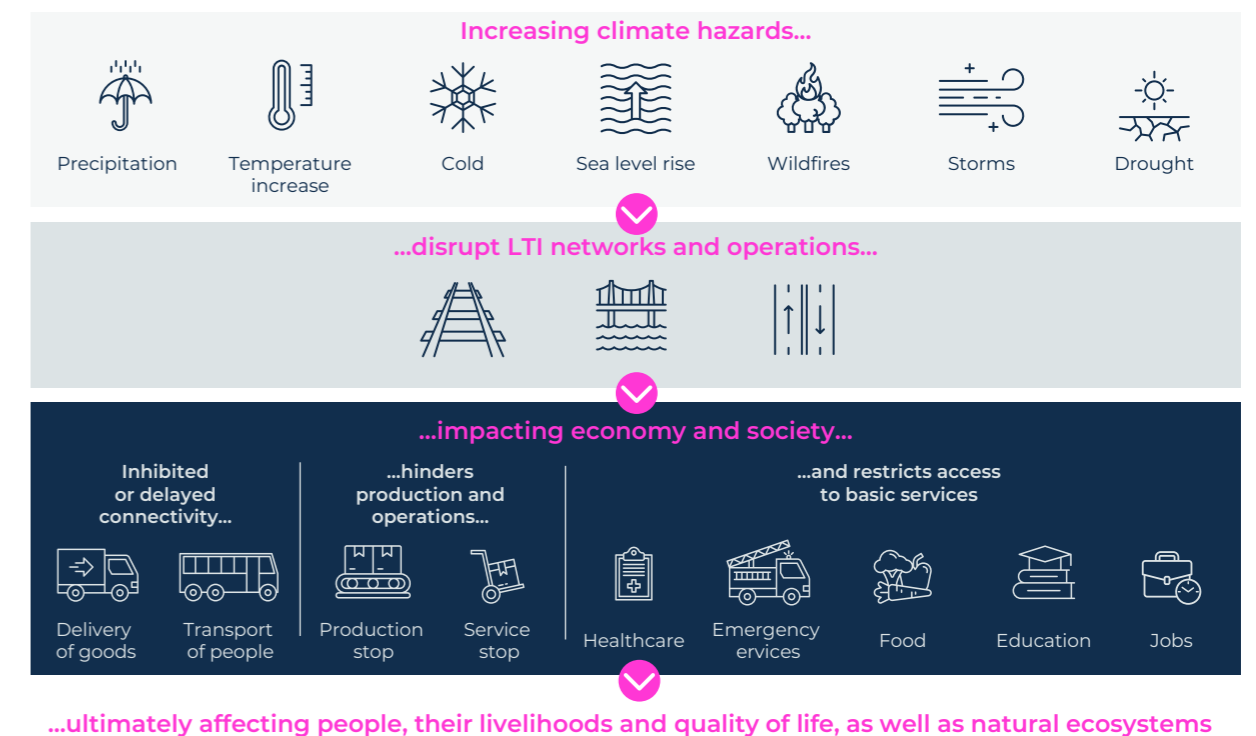
¹¹ Based on OECD (2023a); year selected to weight G20 country coverage and be most recent per transport mode; for road transport, using data from 2017 and missing data for Brazil, Canada, China, Indonesia, Mexico, Saudi Arabia, and South Africa; for rail, using data as of 2019 and missing data for Argentina, Brazil, India, Indonesia, Saudi Arabia, and South Africa.
¹² Based on OECD (2023); year selected to weight G20 country coverage and be most recent per transport mode; for road transport, using data from 2017 and missing data for Argentina, Brazil, Indonesia, Saudi Arabia, and South Africa; for rail, using data as of 2019 and missing data for Brazil, Indonesia, Saudi Arabia, and South Africa.

Moreover, the operations of LTI are highly dependent on supporting infrastructure, such as energy, telecom, and water. Furthering the complexity is the fact that LTI is serviced and utilized by varied stakeholders, including a broad range of service providers, community services, and individuals, all of whom vary vastly between and among geographies. The disparate levels of formality, sophistication, and capability of these various stakeholders—along with differences in utilization—mean that LTI looks very different from place to place. Indeed, the core of a major city in an advanced economy with robust public services differs in countless ways from a remote town in an emerging and developing economy with fewer public sector resources. Both, however, are linked by and dependent on LTI.

Land Transport Infrastructure Is Highly Exposed to Climate

Given the broad scope of the networks that comprise LTI, it is highly exposed to changing climate conditions, such as sea level rise and temperature increase, as well as increasing climate hazards, resulting in considerable risk. This risk is multifaceted, along with the potential for physical damage and disruption of the network and its operations, other considerations exist in parallel, including economic and societal implications, such as hindered production and limited access to basic services due to inhibited or delayed connectivity. Infrastructure is intricately embedded in the natural ecosystem. Thus, its failure or improper planning, design, construction, operations, and/or maintenance might lead to breached environmental safeguards, directly causing environmental impacts such as pollution and/or wildlife and biodiversity loss, which in turn affect the stability of natural ecosystems and thereby our communities.¹³ For example, LTI projects can split habitats and affect migration routes, or create opportunities for animal-vehicle collision.¹⁴ Ultimately, people, their livelihoods, and quality of life as well as the natural ecosystem are affected.

These interdependent impacts make it integral to consider both the resilience of and resilience through LTI. Resilience of LTI implies ensuring that the infrastructure itself is resilient to prevent its operation and utilization from being hampered. Resilience through LTI in turn contributes to increased socioeconomic and environmental resilience as the cascading effects of non-functioning LTI are minimized.



¹³ WWF (2023).
¹⁴ Ibid.

Infrastructure Is Vulnerable to Physical Damage

Adverse effects of climate change are numerous. Examples include gradually rising sea levels that lead to network undercutting, extreme temperatures that can lead to asphalt or steel expansion, and the sudden catastrophic damage caused by intense storms that destroy infrastructure assets. This can render crucial parts of the network ineffective or even non-functional, interfering with the delivery of products, daily transportation, and even access to essential human services such as those provided by hospitals—together, ultimately affecting people's livelihoods.

Flooding is one of the most frequent hazards that have a devastating impact on LTI, with 30% of global rail and roads already exposed to heavy flooding and cyclone events alone.¹⁵ Projections regarding future hazard frequency indicate that this exposure will only increase. Flooding wreaks havoc on transport infrastructure, from the destruction of roads and tracks to the erosion of underlying land. Additionally, of course, flooding can destroy the buildings, stations, and tunnels essential to LTI, along with other non-LTI infrastructure assets such as seaports and airports.

Numerous projections point out the physical damage likely to affect LTI. Consider Costa Rica, where precipitation already caused \$2.2 billion in damage to infrastructure from 2005 to 2017, with more than half being to road infrastructure.¹⁶ In the UK, the projected 8% increase in erosion from high river flows will place 1 in 20 bridges at high risk of failure by the 2080s, adding over 3,500 bridges to the already large backlog of more than 3,200 bridges that require repairs today.^{17,18} The US currently has 129,000 deficient bridges, with more than 100,000 potentially vulnerable to increased river flows.¹⁹ And analysis concludes that heat waves will be the most significant risk to EU transport infrastructure in the 2080s, resulting in the buckling of rail tracks and cracking and melting of road pavement.²⁰

Disruptions Impose Significant Economic Pain Points

Disruptions to LTI have implications for business continuity, as infrastructure disruptions can hinder commerce and thus profitability. Beyond this, the negative effects on service providers—both in the public and private sectors—have serious implications for economic well-being. Supply chain disruptions reduce GDP and slow down economic growth. As such, resilient LTI can play a key role in stabilizing and ensuring economic resilience and growth by facilitating connectivity and the transport of people and goods. In Nicaragua, for example, the introduction of trail bridges has eliminated the 18% decline in labor output typically experienced there during flood events.²¹

Consider citizens' daily commutes to work and what happens when the roads, bridges, tracks, and tunnels that enable them suffer damage or breakdowns. Disruptions affect informal service providers and workers that require daily LTI usage for their livelihoods. For example, heavy flooding in a place such as Kampala would increase average travel time by 55%—a finding that is based on a simulation that considers key network hubs breaking down due to flooding.²² As these factors increase poverty and reduce quality of life, ultimately, people at all levels of the economy feel the pain of LTI problems.

Supply chains are seriously affected whenever there is a blockage of goods and service delivery, leading to a domino effect on utilization, production, and consumption. For example, following heavy flooding in Thailand in 2011, the production of hard disks was decreased by roughly 30% for six months, and Toyota suffered approximately \$1.4 billion in lost profits from supply chain impact, including LTI disruptions.²³

This implication bears even greater significance for countries that are already more vulnerable to climate impacts, where such events can have a disproportionately more crippling

impact on GDP. Also, consider that in places where much of the economic base is concentrated in a small number of industries, the negative impact of LTI damage is likely to be felt more profoundly, as it impairs or paralyzes a potentially large element of GDP. For example, it is estimated that transport disruptions from flooding in Tanzania cause an annual loss of 0.4% of GDP, or \$150 million.²⁴

Additionally, it's worth noting that LTI disruptions present a compounding, rather than linear, impact—after all, the repair of damaged assets is slowed by damage to those very assets, as it takes longer and becomes more complicated to put repair crews and resources in place. For instance, if the road a construction crew has to drive on to reach a damaged bridge is itself destroyed, this presents quite a conundrum—even more so if power lines are down. This underscores the interwoven nature of LTI with other supporting infrastructure such as energy systems.

Society Suffers from Damaged or Inadequate Infrastructure

Back in 2018, heavy rain in Dar es Salaam caused flooding that rendered roads impassable; as a result, 80% of households in the region had at least one child miss some time in school.²⁵ This is just one example of the kind of broad societal impact that can be traced to climate change and the negative effects it can have on people and their livelihoods. Consider the ripple effects, as well: for every child at home, there might be a parent unable to go to work; moreover, this compounds the problem as teachers and childcare providers—who are often parents themselves—become unavailable.

Effectively functioning LTI is crucial for personal and community well-being. Access to everything from critical emergency care to preventative care—including hospitals as well as other services provided by pharmacies and clinics—hinges on the ability to move people and goods. Following a 2008 flood, 70% of Hanoi's population that was unable to access its usual medications and health care services for a month reported it being due to road disruptions.²⁶ As a result, there was a notable uptick in dengue fever, pink eye, dermatitis, and other conditions that likely emerged as a result of flood impacts (such as from a lack of clean water) and the resulting lack of treatment opportunities.²⁷

While incidents such as severe flooding catch headlines, such societal impacts should not be viewed simply as isolated incidents that are merely short-term events. The problem is that such impacts, taken together, comprise longer-term aggregated detrimental effects on education, employment, and social mobility—again, often with a disproportionate cost to emerging markets and developing economies.

While disruptions to LTI have devastating effects on society and people, by implication, increased LTI resilience leads to more societal resilience. Examples of the critical role resilient LTI can play can be found around the globe, such as access to rural roads having been shown to decrease poverty by 10% in Ethiopia; while in India, it has increased school enrollment by 5% in villages with new rural roads.²⁸

15 Koks, Rozenberg, Zorn et al. (2019).

16 Funk, Fritzsche, Baumert & Lotzen (2018).

17 HR Wallingford (2014).

18 RAC Foundation (2022).

19 Wright et al. (2012).

20 Forzieri et al. (2018).

21 Ibid.

22 Rentschler, Braese, Jones & Avner (2019).

23 Haraguchi & Lall (2015); Chee Wai & Wongsurawat (2012).

24 Rentschler, Kornejew, Hallegatte et al. (2019).

25 Erman et al (2019).

26 Bich et al. (2011).

27 Ibid.

28 SLOCAT (2023a).



II. THE SCOPE OF THE CHALLENGE

Building and improving LTI with the A&R needed to meet the challenges that lie ahead will take substantial investments in time, money, resources, and capacity alike. While the most obvious obstacles are financial, there are other factors that further exacerbate the situation, including capacity constraints, both in terms of planning capabilities and delivery complications.

Text to be replaced with: A&R Efforts Need to Be Financed

A&R investment is needed on top of the already sizeable gaps in finance for LTI. The large acceleration of investments might seem impossible to cover, but A&R measures offer high positive returns, and delaying action can be very costly.

A&R Needs Substantial Funding and Early Investment Offers High ROI

Meeting A&R outcomes demands major investment. To begin with, there is already a large investment need for infrastructure to cope with population growth and urbanization trends, which is relevant for LTI for both rural and urban areas. On top of this investment demand, there is an increasing need to address A&R for LTI. According to the United Nations Environment Programme (UNEP), there will continue to be a yearly investment need for adaptation in infrastructure (including LTI) of \$56 billion in developing countries alone until 2030.²⁹ At the same time, the Climate Policy Initiative shows that current adaptation flows for buildings and infrastructure and transport are only \$24.4 billion despite a peak in adaptation finance in 2021/2022.³⁰

The steep acceleration curve required to cover this gap is intimidating, but there is a strong incentive to make such investments—particularly early on. A&R measures offer high returns, estimated at an average \$4 return on every dollar invested, when accounting for broader economic and societal effects of infrastructure disruptions.³¹ Moreover, as much as there is an incentive to act early, delaying investments just a few years until 2030 could result in up to 45% higher costs, as estimated for low and middle income countries.³² These increases would emerge due to damage to assets from climate hazards in the delay period and resulting operational/revenue losses, economic losses, and other societal costs. It's vital that, when business cases are being articulated, the cost of inaction is included. Indeed, it can be the basis for a positive return and thus the creation of financially attractive projects that can secure private funding.

Finance Is Only the Tip of the Iceberg for A&R

As important as financial investment is to addressing A&R challenges, it's only the tip of the proverbial iceberg, with many other factors lurking below the surface. Even with sufficient investment, there are practical difficulties associated with implementing A&R projects needed to meet the climate challenge.

Human Resources and A&R Expertise Shortage Further Exacerbates Capacity Constraints

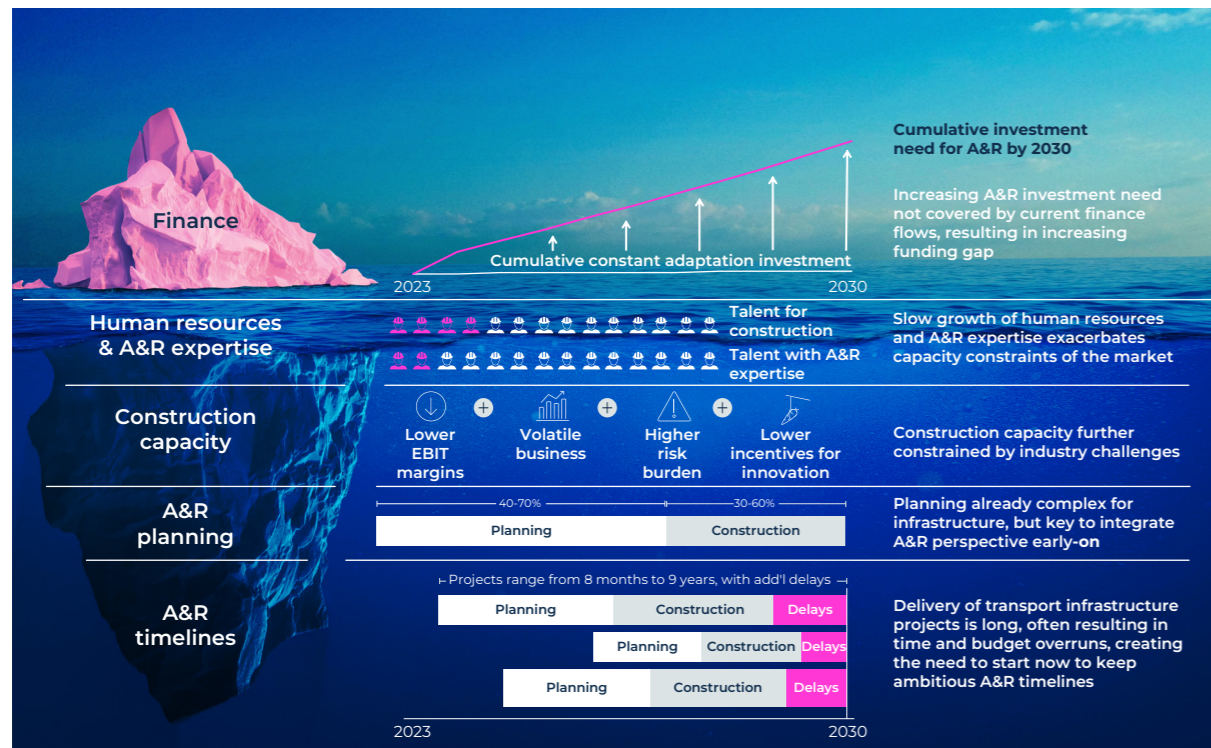
Capacity limitations are a significant issue for A&R projects in LTI, as the capacity of both the relevant industries and the market currently does not meet the growing need for A&R in LTI and other infrastructure; moreover, with rising climate hazards, the demand will only increase. This is further exacerbated by the slow response times of supply chains.

²⁹ UNEP (2023).

³⁰ Buchner, Naran, Padmanabhi et al. (2023).

³¹ Hallegatte, Rozenberg, Fox, Nicolas, & Rentschler (2019).

³² Ibid, based on delay from 2020 to 2030.



One of the major factors driving capacity constraints is human resources and expertise. In fact, 89% of construction companies in the US report difficulties in recruitment.³³ Complicating factors include the lack of targeted investment for recruitment as well as the lack of supporting policies to develop new resources. Moreover, the construction industry is contending an aging workforce, for example in the US 45% of the current workforce is over age 45.³⁴

Beyond the construction industry, despite ongoing upskilling efforts, there's a shortage of the kind of expertise needed for A&R projects in LTI. For example, when it comes to engineering, only 30% of the top 30 engineering universities around the globe according to the Times Higher Education Ranking 2022 include A&R modules in their curricula.³⁵ This is a problem because A&R expertise is essential for the next generation of engineers. It will be vital to incorporate climate impact uncertainty and climate scenarios into engineering thinking, standards, and infrastructure design to avoid catastrophic failures. This new kind of expertise and thinking will be needed to implement new outcome-led approaches that take into consideration uncertainty and relevant design criticalities for network operations and whole-system interconnectivity, including risk-absorbing infrastructure and regenerative networks.³⁶

Construction Capacity: The Construction Industry Faces Crucial Capacity Challenges for A&R Project Delivery

The construction industry plays a significant role in project delivery of A&R in LTI. Construction companies already face challenges, such as low profitability in light of the risks they bear, talent shortages, and slow adoption of innovation, digitalization, and artificial intelligence. Given its crucial role to play, however, the construction industry needs to expand both its capacity and capability to fulfill the growing and demanding requirements of infrastructure and, in particular, A&R projects of the next decades. To rise to this increasing demand and meet the adversities facing the construction industry in a climate-changed world, it is necessary to increase investments and capabilities in terms of innovation, technology, and digitalization—and to develop public procurement regulations that foster technical progress and reward risks appropriately.

³³ The Associated General Contractors (AGC) of America (2021).

³⁴ Zachary (2023).

³⁵ BCG analysis based on the Times Higher Education (2022).

³⁶ Infrastructure Pathways (International Coalition for Sustainable Infrastructure, The Resilience Shift and Atup, 2023).

A&R Planning: Infrastructure A&R Considerations Often Not Included in National Plans

An extensive and holistic planning phase is key in infrastructure projects due to the interconnectivity of the LTI network, potential environmental impacts, a broad stakeholder environment and approval processes, and complex decision-making—particularly in contexts with higher fragmentation and informality. According to BCG project experience, the planning phase currently takes up 40% to 50% of the overall project time for rail—and even more so for road projects, where it takes up 50% to 70%.³⁷

A&R cannot just be an afterthought; rather, it needs to be integrated in infrastructure projects from the start. An additional layer of complexity is the dependency of informed decision-making in the planning phase on A&R considerations. These require detailed data on existing and new assets, ranging from monitoring their current state, to the exposure and vulnerability of the whole network. Furthermore, resilient transport is not yet strongly represented in most countries' planning efforts. Even though 94% of countries include transport in some way in their nationally determined contributions (NDCs), these NDCs still mostly relate to decarbonization of the sector and not to climate resilience, with only 27% (13 out of 47) of national adaptation plans submitted to the United Nations Framework Convention on Climate Change (UNFCCC) mentioning transport as a key sector for resilience.^{38,39}

A&R Timelines: Complex Infrastructure Delivery Competes with A&R Timelines

One of the challenges facing A&R efforts in LTI lies with the complexities involved with CapEx project delivery, which of course must be considered as part of integrated planning. To begin with, infrastructure projects take a long time—according to BCG analysis, ranging up to ~5 years on average for highway projects, and even up to ~9 years on average for new railway projects. On top of this, when it comes to rail projects, 41% are delayed and 73% run over budget, which compounds the timing problem with budget overruns. The figures for roads are better but still problematic, as 26% of projects are delayed and 43% are over budget. The problem increases with project size, with 45% of initiatives with budgets exceeding \$5 billion being delayed; moreover, their budgets end up doubling, on average.⁴⁰ The long project durations and overruns are in direct competition with the ambitious A&R timeline set by the SAA, which calls for transport infrastructure to become resilient by 2030. This means resilient LTI projects need to start now.

Lack of Agreement Regarding Definition of A&R Hampers Global Action

On top of project-specific gaps, a challenge to the overarching and integrated view of A&R for LTI is that consensus on a definition for "A&R" is missing. There is currently no common taxonomy for resilient LTI, nor are there sufficient standards and guidelines to support countries and the industry in its transition. A common taxonomy for A&R in LTI, including consensus on metrics and acceptable risk thresholds, could enable global resilience target setting, accelerate investments, and support multi-stakeholder coordination. However, several aspects contribute to the lack of an established and agreed upon taxonomy.

³⁷ Based on BCG project experience.

³⁸ SLOCAT (2023b).

³⁹ NAP Global Network (2023).

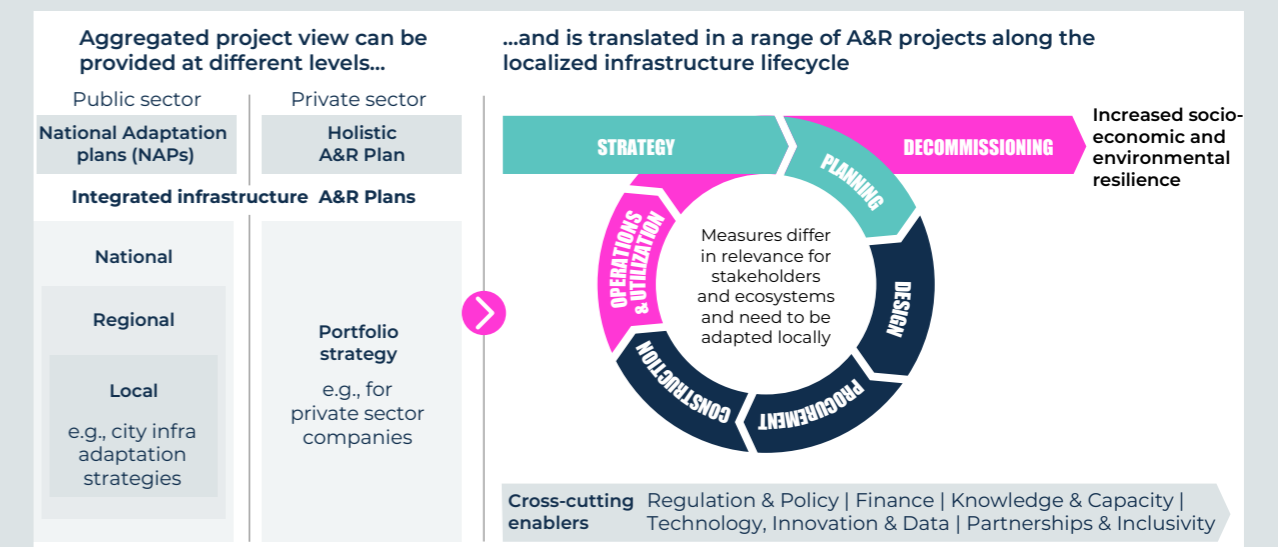
⁴⁰ Data from GlobalData (2023); for schedule adherence/time delay: N=139; for budget adherence: N=121.

Currently, there are several definitions from different stakeholders that focus on different dimensions. For example, the Organization for Economic Co-operation and Development (OECD) focuses on the process of infrastructure planning, building, and operations to be prepared for climate hazards, while the United Nations Office for Disaster Risk Reduction (UNDRR) considers prevention, absorption, recovery, adaptation, and transformation of national infrastructure against climate impacts.^{41,42} Meanwhile, the World Bank looks at the ability of infrastructure systems to function and meet users' needs during and after natural shocks.⁴³ There is no agreement on the right risk threshold levels, and due to uncertainty of climate scenarios, risk levels are difficult to measure and it is hard to agree on one threshold across the board. Additionally, climate hazards and the feasibility of solutions and capabilities to implement them vary strongly by location and context, which means climate impacts affect assets, operations, societies, and economies differently, potentially leading to different definitions of A&R being considered. All these factors make finding a global definition highly challenging.

III. THE INTEGRATED A&R APPROACH

With the scope of the challenge laid out, it's clear that the only practical approach to effective A&R in LTI is a holistic, integrated one. This enables broad, overarching plans to be adapted for maximum effectiveness all the way down to the local level and across the life cycle. Public sector national adaptation plans provide guidance on overall adaptation objectives, and the integrated A&R plan focuses in detail on infrastructure, which can be at the national, regional, or city/local level. For the private sector, as part of a holistic A&R plan, the integrated infrastructure A&R plan is at the portfolio level and considers all assets. Integrated, however, also implies addressing A&R infrastructure planning from a broader socioeconomic and environmental impact perspective.

Infrastructure Life Cycle:
The sequence of stages infrastructure runs through over the course of its lifetime, beginning with strategy and planning and ending with decommissioning



Integrated Infrastructure A&R Plans Are Key

An integrated approach to A&R depends on an overarching, macro perspective that takes climate impacts as a whole into consideration. This crucial aspect needs to be considered to avoid catastrophic impacts on economic growth, people's livelihoods, and the stability of the natural ecosystem.⁴⁴ Integrated infrastructure A&R plans include the following elements:

- **Ecosystem:** Overview of economy, geography, population, etc. relevant for infrastructure A&R, including aspects of current demographics and statistics, economic activity, and biodiversity and natural habitats
- **A&R Vision and Process:** Vision, outcomes, and principles for A&R, including the target state, targets, and guiding principles for implementation in alignment with other long-term climate strategies such as biodiversity and environmental protection targets; timelines and governance set up with clear roles and responsibilities
- **Climate Risk Assessment and Business Case:** Historical climate observations; exposure and vulnerability analysis, including socioeconomic and environmental impacts; overview of priority areas and assets; information on cost of inaction, including co-benefits and opportunities

41 OECD (2018).
42 UNDRR (2022).
43 Hallegate, Rentschler & Rozenberg (2019).

44 OECD (2019).

- **Portfolio of A&R Actions:** Prioritized A&R actions with cost estimates, considering socio-economic and environmental aspects such as low-emission or nature-positive solutions; A&R implementation plan linking to existing frameworks and plans
- **Monitoring & evaluation:** Process for data collection on A&R with data analytics and review within fixed timelines also regarding environmental impacts

An integrated plan thus provides an aggregated infrastructure view to fulfill multiple functions. One such function is **prioritization**, enabling planners to arrange projects by exposure and vulnerability and to decrease risk. Another is **allocation** of funding, resources, and capacity to ensure what is needed is provided. Alignment of stakeholders on a **unified, tangible strategy** is a crucial element, as is ensuring that plans are crafted with a **long-term view** for multi-year efforts and consecutive measures. Planning across transport modes also gives the option to introduce multi-modal response measures in case of disruptions. And finally, the lens of **de-risking** keeps a focus on the integrity of the project portfolio with frequent review cycles.

To mitigate risks from climate hazards on LTI, both new and existing infrastructure needs to be considered. For existing infrastructure, there is a need to focus on decreasing vulnerability by adapting infrastructure to new climate conditions, such as higher temperatures, and increasing resilience to withstand and recover from increasing climate hazards. This may also involve building supporting structures to protect existing assets. And, of course, it means maintaining and monitoring existing infrastructure to ensure it is coping with new climate conditions. When it comes to new infrastructure, plans should focus on reducing exposure and vulnerability to new climate conditions from the start. This involves re-thinking existing design concepts to create solutions adapted and more resilient to new climate scenarios, as well as incorporating trends such as urbanization. Finally, new infrastructure planning should consider demographic and environmental developments such as climate migration.

Plans Are Implemented in Local Projects along the Life Cycle

An integrated A&R plan is implemented with projects on the local level. This includes numerous stakeholders, both in the public and private sectors. When translating the integrated plan to local-level projects, it's crucial to think across the entire life cycle, from strategy and planning all the way through to decommissioning.⁴⁵ This consideration has to extend to both existing and new infrastructure. What matters is that, for each project, there is close alignment with the integrated plan along the life cycle to optimize capacity, funding allocation, and the use of resources.

In the overall landscape of A&R action, the community is growing more aware that the whole life cycle needs to be considered by government and corporate leaders in their A&R planning. In order to implement full A&R plans, this requires a whole project portfolio and set of actors with different levels of involvement along the life cycle. The measures themselves comprise a broad landscape that very much differs by stakeholder and location; as such, it's vital to take into consideration contextual matters such as feasibility, constraints, and capability.

Consider the first stage of the life cycle: **strategy**. It builds the basis for A&R action. Among other things, it must incorporate a clearly articulated A&R objective and consider network interdependencies—in other words, how LTI impacts—and is impacted by—other transport and infrastructure networks and an understanding of the relevant stakeholders and communities affected. This understanding is the basis for assessing exposure and vulnerability and prioritizing the solutions with the best business case, considering impacts to economy, society, and environment, while consulting relevant stakeholders.

⁴⁵ Infrastructure life cycle adjusted for A&R and LTI based on Infrastructure Pathways (International Coalition for Sustainable Infrastructure, The Resilience Shift and Arup, 2023).



Once the strategy is set, the **planning** stage focuses on setting up the project and securing funding. In this phase, a project plan with key milestones and responsibilities is developed, taking into account constraints affecting A&R projects, including market capacity such as people and resources. Among other things, this stage is when funding options for A&R are evaluated and secured and internal standards and guidelines for A&R across the life cycle are established.

Detailing of the selected A&R solution, such as defining the technical specifications and material selection, takes place at the **design** stage. It is also important to consider network interdependencies during this phase, designing a solution that ensures systemic A&R resilience and not merely of a single asset. This results in a broad spectrum of solutions that can be employed, from gray and green solutions to the combination of both. A&R LTI solution design should strive to incorporate harmonizing measures with nature while moving toward nature positivity by delivering gains to the natural ecosystem, such as improved biodiversity.^{46 47} To ensure this, it is vital to conduct compliance studies, including environmental assessments.

Gray infrastructure⁵

Gray infrastructure refers to human-made structures such as dams, seawalls, roads, railways, and water treatment plants.

Green Infrastructure⁴⁸

Green infrastructure refers to natural systems including forests, floodplains, wetlands, and soils that provide additional benefits for human well-being, such as flood protection and climate regulation plants.

Moving toward project delivery, **procurement** plays a central role in securing the contracts required to move a project from planning and design to construction. There are several elements to be considered at this phase, such as defining a contracting model for A&R projects that ensures that decisions at planning and design are carried out accordingly and designing a resilient supply chain strategy for market capacity.

During **construction**, the plans and design become reality. Among other elements to consider, the process itself can be made resilient by enabling tech support (for example, automation)—and needs to be adapted to new climate conditions (for example, with technologies to build under extreme temperatures). Ensuring worker safety and that no harm to the natural ecosystem is caused also plays a central role. A detailed engineering plan and a process to make sure that the A&R solution selected gets properly implemented helps ensure the successful implementation of the A&R objective.

Existing LTI assets need to be monitored to ensure their ability to adapt to changing climate conditions and resilience to climate hazards as part of the **operations & utilization** phase of the life cycle. This includes the use of climate hazard data to inform utilization optimization, maintenance, and active control in disaster situations, including of supporting infrastructure. This requires monitoring and up-to-date network and operations models, as well as guidelines to safeguard against potential environmental impacts to land use, biodiversity, and natural ecosystems.

The last stage in the LTI life cycle includes its **decommissioning**. Existing assets need to be assessed for their potential need to be decommissioned with changing climate conditions, such as sea level rise, and increasing vulnerability to climate hazards, such as floods. If a decommissioning decision is made, several aspects should be considered, including the impacts to the network connectivity, the environment, and society; what to do with the materials and the site to safeguard environmental resilience; and what alternatives are required to ensure societal and economic resilience in a specific location.

Cross-Cutting Enablers Make Progress Possible

Implementing A&R along the LTI life cycle depends on **cross-cutting** enablers that comprise both quantitative and qualitative elements; taken together, they are essential to making such a complex undertaking possible. They include the following:

- **Policy & Regulation:** Enact laws and craft official standards that establish a regulated environment conducive to A&R building while creating guidelines and incentives that accelerate and support integration of A&R
- **Finance:** Include A&R in finance instruments and develop new instruments for A&R; secure funding for each life cycle stage of A&R projects
- **Knowledge & Capacity:** Foster knowledge development and best-practice sharing for A&R; ensure resources and people for A&R project delivery and long-term A&R expertise; ensure workforce safety for A&R projects; build local A&R capabilities
- **Technology, Innovation & Data:** Develop new technology and methods for A&R; facilitate high-quality data collection for A&R; create A&R data analytics tools that empower decision-making; ensure accessibility of data and tech
- **Partnerships & Inclusivity:** Build platforms for exchange and collaboration on A&R that take into consideration local communities (including marginalized groups); accelerate innovation for A&R; align communication among stakeholders involved in A&R projects

Deep-Dive Cross-Cutting Enabler: Accelerate Finance to Initiate A&R Projects

To achieve ambitious A&R targets and implement A&R projects, financing needs to be secured. For companies, this means investing in the A&R of their own business, and also contributing to financing public A&R initiatives. For governments, particularly in emerging and developing economies, this means mobilizing capital from public and private sources to close the large A&R financing gap.

A&R Projects Must Be Financially Attractive

A key lever to unlocking finance is for governments and companies alike to have a holistic view of the cost of inaction due to increasing climate impacts from changing climate conditions and climate hazards. For companies, this can include damage to assets; CapEx and OpEx costs for repairs; revenue loss due to disruption to operations and services; reduced demand due to changes in consumer behavior; financial and market risk, such as financing cost, cost of debt, and cost of insurance; and sourcing costs, such as the price of raw materials. For governments, this includes broader impacts to people, economies, and ecosystems, ranging from productivity losses, import and export reductions, and GDP loss to direct impacts on households, people, and their livelihoods (for example, due to an increase in poverty, less access to health care and jobs and an increase in malnutrition). Also, environmental impacts such as loss of biodiversity need to be considered.

By understanding the cost of inaction, companies can begin investing in their own A&R. This is particularly important for companies that provide public goods and services, such as roadway operators (see case study 1). Unlocking private finance for such efforts requires a company to design A&R projects that are financially attractive. Such projects come in different forms, including the following:

- Projects that are cash-flow generating or “bankable” (for example, toll-fee revenue charged by companies co-invested with the public sector in resilient roadway infrastructure)
- Projects that have the potential to be cash-flow generating (for example, with support from the public sector through blended finance or tax incentives)
- Projects that do not generate cash flow but provide the benefit of helping a company avoid asset damage, increased CapEx and OpEx costs, and loss of revenue due to disruptions to operations and services (for example, protect assets by financing flood measures to reduce roadway damage during storms)

⁴⁶ Green-Gray Community of Practice (2020).

⁴⁷ Ibid.

CASE STUDY 1

Local government assessing cost of inaction to advance private interest and bankability for A&R in infrastructure projects

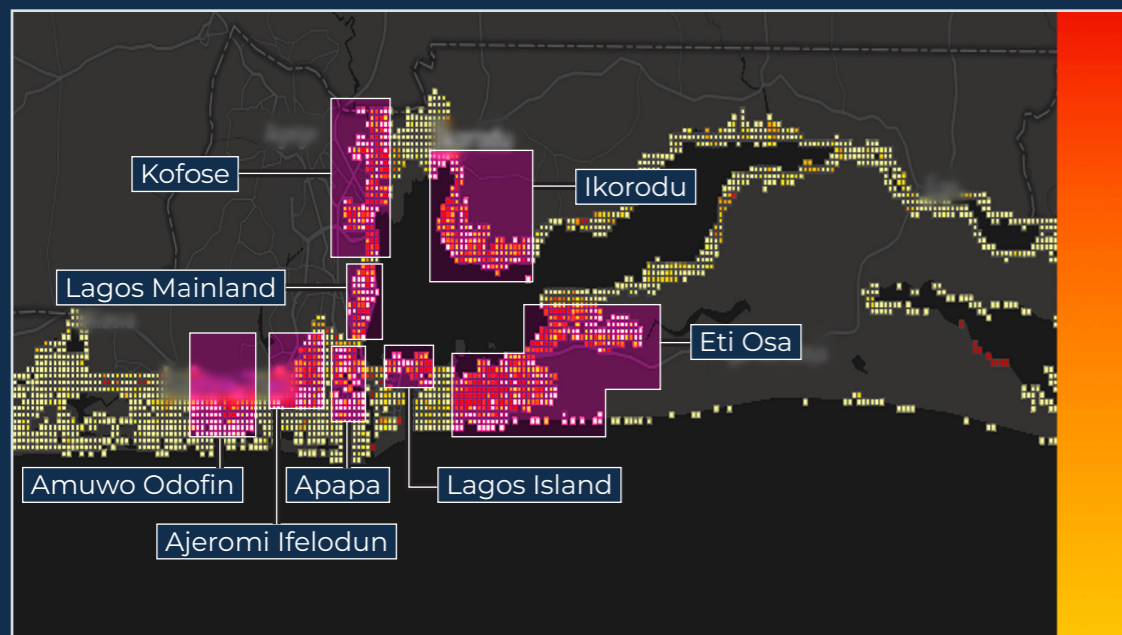
Lagos, Nigeria's smallest but most populous state, is home to Lagos City, the country's largest city and the most populous urban area in Africa with nearly 30 million inhabitants. It is home to more than 12% of the Nigerian population, and constitutes the seventh largest African economy, generating more than 20% of the country's GDP. However, the city faces substantial climate risks, particularly from sea level rise, extreme heat, and precipitation. A number of geographic features are responsible for this exposure; for example, the coastal topology is such that much of the city is less than two meters above sea level, posing considerable risk to highway and road networks.

To address these concerns, Lagos State found itself in need of a comprehensive strategy, including financing of an initial pipeline of 20 A&R projects, including for LTI and nature-based solutions, such as mangrove restoration. This strategy is crucial for facilitating conversations with financiers and securing funding for priority initiatives. The approach included an analytics-driven risk assessment, including deployment of a risk index heat map, which showed that 11% of the transport network was at risk. As a next step, the cost of inaction was quantified, indicating that, for infrastructure, this could be 12 times the total annual budget of \$5 billion. An overview of the comprehensive project pipeline for A&R across sectors identified the need for an \$8 billion investment (estimated \$270 million for roads alone). In order to succeed with stakeholder engagement and build necessary capacity, Lagos built a project pipeline management plan with an investor-ready project assessment to ensure bankability.

Thanks to this investor-ready action plan, Lagos is in a position to boost investor traction with a robust basis for moving effective bankable projects from the design stage to the procurement and construction phases. Its top three projects were selected and are being prepared to progress to the construction phase.

More details on this case can be found [here](#).

Risk level exposure map estimate for sea-level-rise-induced flooding levels



CASE STUDY 2

Road Operator Implementing A&R Strategy through Assessment of Climate Exposure

Italy's largest toll road operator, Autostrade per l'Italia (ASPI), operates 3,000 km of roads and 420 km of tunnels throughout 60 provinces. Recognizing the importance and effects of climate change, the company decided to implement a forward-looking A&R strategy to protect assets against exposure to climate hazards, including the most important east/west transport connection in northern Italy. Additionally, ASPI strives to be compliant with TCFD standards and to maintain its CDP climate scoring.

ASPI approached the challenge by conducting climate risk mapping for its priority assets with a focus on extreme precipitation, floods, landslides, and hail as primary triggers. As a next step, it assessed vulnerabilities to priority assets. Based on the vulnerabilities of the priority assets, a risk map for all ASPI's assets in Italy was built to provide detailed insights on potential exposure per climate scenario on a 15-year basis.

As a result of these efforts, ASPI established a clear pathway for deployment of the climate assessment methodology and for scaling the pilot across its asset network. The resulting data contributes to a tailored A&R strategy, creating a basis to select A&R measures and projects that can manage risk. The company was able to anchor and validate specific A&R measures of its 2038 investment plan, including waterproofing of tunnels as well as reinforcement of bridge foundations, roadways, and tunnel walls and is also set for the future to review those as necessary with changing climate scenarios and more refined data.

More details about this case, including perspectives from ASPI, are available [here](#).

Managed road network across Italy



Similarly, governments can leverage an assessment of the cost of inaction to design A&R projects that maximally address impacts to their people, economies, and ecosystems while being structured in a way that attracts public and private financing from a range of actors such as MDBs, DFIs, etc. (see case study 2). This is particularly important for non-cash-flow-generating projects where making the indirect benefits of projects visible can result in innovative financing structures that bring in investors (for example, corporates through tax increment financing). Such benefits and opportunities can range from economic considerations, such as carbon market revenues by A&R solutions with carbon capture potential, to societal improvements, such as health advancement. In Mexico City, the introduction of a bus rapid transit system reduced passenger exposure to hazardous gases by 50% and resulted in 110,000 tons of greenhouse gas emissions savings per year.⁴⁸

As this mindset gains traction and finance needs to be mobilized faster and at scale, it is increasingly important to have a standardized methodology that helps infrastructure developers quantify the direct and indirect benefits of A&R and structure projects appropriately. Ongoing work such as the Physical Climate Risk Assessment Methodology (PCRAM) Guidelines for Integrating Physical Climate Risks in Infrastructure Investment Appraisal aim to define exactly this.⁴⁹

⁴⁸ OECD.
⁴⁹ CCRI (2021).

IV. A&R IMPLEMENTATION IN PRACTICE

Given the scope of the challenges and opportunities comprising A&R in LTI, it is important to understand the current status of A&R in practice. While it is clear that current A&R efforts are significantly falling behind, with projects stuck at the previously described bottlenecks—such as lacking awareness and overcoming the financing gap or capacity constraints—there are positive signals of global action. Considering that this year will be the first Global Stocktake, it is important to examine current progress. Thus, analyzing real-world project examples provides insight into the challenges facing communities in different parts of the globe, and how those communities are taking A&R action to confront these challenges head-on.

Current Focus of A&R Activities Varies across Life Cycle and Enablers

Current A&R Activity Metric:

The focus of current A&R activity at each individual life cycle stage

Our in-depth analysis of 100+ A&R projects in LTI around the globe offers many insights into which stages in the life cycle and which cross-cutting enablers are currently seeing the most action. It should be noted that the selected examples come mostly from public sources; thus, they showcase best practices that are not representative of overall global A&R efforts. However, this analysis allowed us to generate an A&R activity metric that looks at where current A&R action is focused for the selected project examples and thus identify where even those advanced projects are lacking and more awareness should be created. Note that these considerations are neither a statement of the sufficiency of global A&R activity nor an evaluation of the quality of individual actions; rather, they shed light on which aspects of the life cycle are considered in a selection of current A&R projects.

The first step in our analysis involved identification of relevant case studies from public sources (for example, World Bank reports) and expert interviews. Upwards of 100+ projects were selected to provide a global perspective and represent both public and private sector undertakings. The assets are ~60% road and ~40% rail, with roughly 55% in advanced economies and 45% in emerging and developing economies.⁵⁰ Approximately 75% are public sector projects, with the remaining quarter in the private sector. In addition, we have further supported and aligned our analysis with the perspectives of relevant stakeholders in the field through expert interviews and roundtable discussions.

From our in-depth view of selected best practice A&R project examples across the public and private sector, as well as road and rail stakeholders, we identified five key trends regarding current A&R activity across the life cycle:

- **Activity decreases as the life cycle progresses.**
One of the most revealing insights is that, in general, we see a high focus of activities in the strategy phase of current A&R projects, where measures are undertaken comprehensively across all categories. However, the level of activities tends to decrease as the life cycle progresses into project execution - with the exception of operations & utilization.
- **Activity is low in capacity and constraints planning.**
Surprisingly, despite the constraints in capacity that come on top of the financing needs to implement and scale A&R projects, there is a low focus of current projects on activities related to capacity and constraints planning—and likewise, when it comes to ensuring a resilient supply chain.

⁵⁰ Following IMF (2023) country classification.

- **Advanced economies have a higher focus of activities on operations & utilization and setting standards.**⁵¹

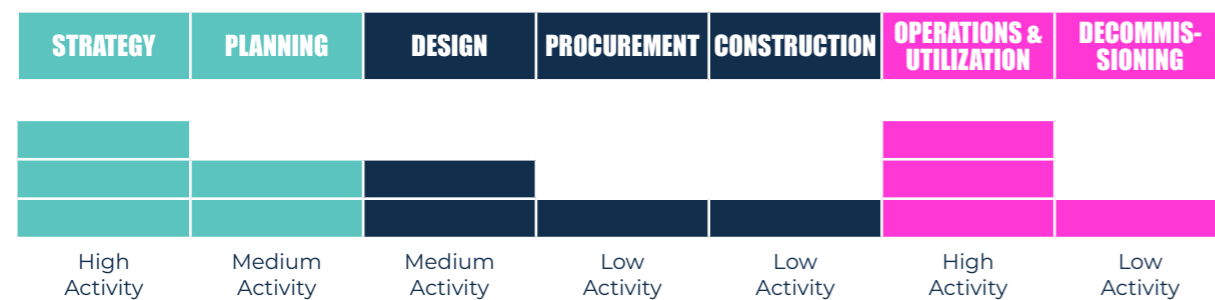
Players in advanced economies, especially in the private sector, focus more activities toward operations & utilization, as they operate under an expectation of high standards of reliability and service quality. They also make stronger use of internal standards and guidelines for design and construction, as well as integrate knowledge building in current projects.

- **Emerging and developing economies have a higher focus of activities on local stakeholder alignment.**⁵²

A&R projects in emerging and developing economies set a stronger focus on including local communities in projects and developing local capacities (for example, through trainings). The transport stakeholder landscape can be quite complex and fragmented (for example, including informal service providers), thus making extended public consultation key.

- **The private sector drives exchange with stakeholders.**

The private sector takes the lead in developing efforts toward establishing platforms for exchange and ensuring aligned communication, including with public stakeholders.



Focus Along the Life Cycle for Selected Case Examples

Strategy

Our analysis reveals comparably high activity in the strategy phase in the landscape of current A&R projects. This is partially due to countries starting to engage in national adaptation plans and hence taking immediate steps to develop a strategy and first stages of planning. Many investors, such as development banks, also have made climate risk assessments mandatory in order to grant financing of infrastructure projects. However, despite this high focus of activity, stakeholders do not consistently manage to prioritize projects with an integrated view and often lack public consultation—both key steps to ensuring project success. Even though this assessment has proved that steps are being taken in the right direction, A&R needs to be integrated even earlier and more broadly across all infrastructure plans and projects.

Planning

Current A&R projects show medium activity in the planning phase, with projects considering their finance options and often setting up a governance structure as the basis for a functioning project. However, additional focus on building capacity to overcome constraints and setting up clearer project timelines and plans with milestones could help reduce project implementation delays and improve supply chain capacity. The overall demand for infrastructure projects and A&R action will only increase with time, thus making it more and more important, especially as many projects are prevented from moving into the delivery phase by the financing bottleneck.

Procurement, Construction, and Decommissioning

When it comes to procurement, construction, and decommissioning, current A&R activities tend to be particularly low in the examples analyzed. In procurement, for example, there are activities related to either developing **procurement** regulations that foster technical progress and reward risks appropriately or introducing contracting models (for example, by establishing contingency contracts to avoid long tendering processes in emergency situations). The tendency toward lack of action on a resilient supply chain strategy shows the magnitude of needed action to overcome A&R implementation constraints (for example, lack of engineers with A&R expertise and constraints to construction industry capacity to realize the demand in A&R infrastructure projects). In the sample of A&R projects analyzed, there was also no particular focus on how to build under extreme weather conditions and align **construction**-phase activities with climate. As climate risk assessments start to get mainstreamed and climate hazards increase in frequency and magnitude, **decommissioning** will gain more importance. Currently, however, it is mostly disregarded by stakeholders due to the mindset that infrastructure assets last forever.

Operations & Utilization

A notable exception, the comparably high activity in the **operations & utilization** stage in current A&R projects, derives principally from a stronger focus by private sector stakeholders in advanced economies, with the aim of maintaining high standards of reliability and service quality. Here, the activities focus on both monitoring assets to optimize maintenance and reacting in disaster situations. However, the use of network and operations models should be further scaled to consider network interdependencies and ensure the goals of network resilience are achieved. In an overall perspective, A&R efforts need to be heavily scaled across infrastructure projects here as well.

Focus on Cross-Cutting Enablers for Selected Case Examples

Analysis of current A&R projects that include efforts to build cross-cutting enablers reveals that most have medium activity, with Policy & Regulation as the only cross-cutting enabler with low activity.

Policy & Regulation

Efforts by public stakeholders to drive the development of A&R Policies & Regulation have seen low activity based on the information available from the selected project sample, with only some examples of laws or official standards being set up.

Finance

Finance is one of the largest challenges hindering A&R implementation. While there have been advancements in new financial products for A&R in infrastructure (for example, EBRD's Climate Resilience Bonds and The Urban Resilience Fund), they are still few and nascent. A&R considerations are also not yet mainstreamed in broader capital markets and project financing activities, thereby limiting the scale of flows for critical A&R projects.

Knowledge & Capacity

There is medium focus of current A&R activity on building and sharing knowledge (for example, via capacity building efforts, masterclasses, or collaboration with universities). Additionally, local capabilities and building up A&R capacity are often considered in current A&R projects. However, overcoming capacity constraints and building A&R expertise is still a significant barrier to be overcome.

Technology, Innovation & Data

Current A&R activity focuses on collecting data on climate hazard-related disasters and weather forecasts and developing tools for early warning, asset management, monitoring, and maintenance, but is not included in all projects, and less focus has also been given to accessibility of data and new technology. Overall, it should be noted that the lack of data—along with a lack of knowledge around its interpretation and use—is a considerable impediment to initiating and delivering A&R projects.

⁵¹ Following IMF (2023) country classification.
⁵² Ibid.

Partnerships & Inclusivity

In current projects, local communities are often considered and platforms for exchange are available to align communication, often driven by private sector efforts. By contrast, there is low activity related to accelerating innovation and there is little to no active consideration of marginalized groups in the selected project sample.

Various Barriers Pose Obstacles to Global A&R Action

A&R efforts are difficult, and numerous challenging factors work against successful execution. The risk factors vary significantly by context. Depending on the geography, the ecosystem, and the stakeholders involved, A&R initiatives can be impeded by a wide variety of risk factors. Some of these risks exist at the macro level, threatening building a successful integrated A&R plan. Others tend to emerge in association with particular stages of the infrastructure life cycle, while still others can undermine the essential cross-cutting enablers that support successful A&R efforts.

Obstacles to an Integrated A&R Plan

Some risk factors pose obstacles to integrated infrastructure A&R planning at the overarching level, potentially interfering with the ability to develop unified efforts. One of these is stakeholder fragmentation, both horizontally and vertically. Vertical fragmentation refers to disconnects between and among the rungs of hierarchical systems (for example, local, state, and federal governments); meanwhile, horizontal fragmentation takes the form of gaps among stakeholders within the same or similar hierarchical levels (for example, various municipal authorities across different towns and cities).

Another risk (interconnected with fragmentation) is lack of clarity between national and subnational asset ownership and thus responsibilities. Likewise, siloed thinking precludes a joint network view that takes a holistic consideration of the network and supporting infrastructure. This type of fragmented context is fertile ground for the emergence of competing objectives, which are compounded by tensions over access to limited funding. The end result is priorities become subjective and short-term needs (for example, due to climate hazard-related disasters and the materialization of risks) might well take precedence over long-term goals and holistic planning—both of which are essential to successful A&R action.

One further risk to integrated infrastructure A&R plans is the constrained environment in which such investments take place, with lack of finance, human resources, A&R expertise, complex project planning, and delivery, as elaborated in chapter II.

Obstacles by Life Cycle Stage

Some risks emerge in close association with particular stages of the infrastructure life cycle.

Strategy

Without a definition of resilience and a set of metrics to measure progress, target setting is hindered. The strategy stage also faces potential risk from insufficient pre-investment to afford the kind of exposure and vulnerability assessment necessary to inform solution selection and effective planning. Fragmented stakeholders present risks to project support at the strategy stage; moreover, they can create delays in decision-making. Also, quantification of the socioeconomic benefits as part of business cases is complex and no standard approach has been established.

Planning

At the planning stage, a gap between the long-term benefits of A&R initiatives and the relatively short time horizons for investment might hamper funding. Infrastructure projects tend to include high levels of upfront investment with potentially long-term payback horizons, which might not align with the risk-return profiles of many funders. Making a clear business case with a robust calculation of the cost of inaction is paramount to secure private funding. In general, extended planning processes can risk missing important targets by “arching over” the very A&R timelines they’re designed to address.

RISK FACTOR CASE STUDY:



Fragmentation in a European Country

A European country faced heavy flooding, resulting in significant regional damage. **Lacking an integrated source of truth and coordination** across federal levels, the country was unable to deploy assistance in a timely manner. Lack of clarity on responsibilities and flawed communication meant federal efforts had to wait for state-level authorizations during the emergency.

RISK FACTOR CASE STUDY:



Fragmentation in an African City

When a populous city in a West African nation was developing an A&R strategy, a **lack of clarity** between national and subnational ownership of a road leading to an airport resulted in the road being excluded from the city’s adaptation strategy.

RISK FACTOR CASE STUDY:



Strategy Stage – Lost Opportunity in an African City

When a West African city did not consult the public about a large-scale road project, the project lost investors due to **public protests** against the project.

Design

One of the principal risks at the design stage is simple disregard for increasing climate hazards. Because financial constraints often limit options on solutions, low-cost (but insufficient) options can become necessities. Another significant risk emerges when there is a lack of A&R expertise and/or engineering capacity, which reduces the ability to design solutions optimized for climate risk, including a disregard for effective nature-based and green-gray solutions. Finally, an insufficiently holistic network view (“siloed” thinking) risks selecting sub-optimal solutions that disregard the inter-connection between climate change and socioeconomic impacts.

Procurement

When design specifications important for A&R efficacy are missing from contracts—or insufficiently integrated into them—mismatches can occur between the original A&R design and the delivered project. Another procurement risk lies with inadequate (or missing) long-term supply chain strategy. This can result in insufficient market capacity for increasing A&R needs.

Construction

The principal risk at the construction stage lies with insufficient construction industry capacity at the regional or national level. As explored in the second chapter, there are several challenges that impede the sector from investing in innovation to develop the required expertise for A&R.

RISK FACTOR CASE STUDY:



Ops & Service Stage—Rail Network Rendered Unusable in Africa

As a West African city's economic growth presented a need for greater transport, its **insufficiently maintained freight rail network** was rendered unusable after heavy rains. As freight switched to roads not properly designed for freight capacity, the roads deteriorated under heavy use.

RISK FACTOR CASE STUDY:



Ops & Service Stage—Aging Road Infrastructure in American Country

A North American country is connected by a complex road network largely composed of **aging legacy infrastructure**. With ~40% of it in poor condition, maintenance needs are high and a focus on backlogged maintenance precludes focus on forward-looking A&R investment.state-level authorizations during the emergency.

RISK FACTOR CASE STUDY:



Ops & Service Stage—Inadequate Flood Preparation in Africa

Increasingly intense flooding began to affect an East African nation. Inadequate preparation for the flooding included **underestimating its financial impact** and underbudgeting for it. The nation faced weeks of disruption before recovery could be completed.

RISK FACTOR CASE STUDY:



Lack of Resilience Data in European Country

When a country's Ministry of Transport aimed to develop an A&R strategy, it needed KPIs to track progress. The **lack of data** presented a challenge to measuring resilience. As a result, the resilience status of the road network was unclear and specific targets could not be set.

RISK FACTOR CASE STUDY:



Data/Impact Disconnect in European Country

While risk data existed regarding the potential for heavy flooding, there was no clear, practical translation of the data into actual potential impact. As such, the **warnings were highly technical and not widely understood**, and thus did not trigger action

Operations & Utilization

A broad range of risks emerge during the extended operations and utilization life of infrastructure projects. Lacking maintenance can put assets at risk, and the prevalence of legacy infrastructure not designed for current climate scenarios compounds maintenance costs. When alternatives to primary links (for example, major roads or rail lines) are insufficient or non-existent, a major risk to network resilience emerges. Finally, inadequate preparation and disaster response disrupt connectivity in crisis situations.

Decommissioning

The risks at the decommissioning stage come from unclear ownership. When ownership is unclear, responsibility for decommissioning work is likewise unclear, thus making for difficult decision-making. This is compounded by the fact that these tasks often involve costly dismantling or transforming legacy assets—and oftentimes, these actions are not been planned for. Further complicating the situation is that with increasing climate hazards, some existing assets might be rendered unusable sooner than originally expected, which could impose substantial unexpected costs.

Risks to Cross-Cutting Enablers

It's essential to have cross-cutting enablers that can support A&R action. When they are absent or insufficient, those gaps introduce serious risks, as a lack of resources and capacity can hinder project planning and delivery. If funding via diverse finance instruments is insufficient for A&R projects, implementation cannot happen.

Moreover, limited access to data and tools inhibits proper risk assessment. Even when access is granted, lack of data granularity brings the practical usefulness of these tools into question. Additionally, even a wealth of data is meaningless without sufficient expertise to decipher it. If it is presented in an excessively technical manner, it is unlikely to be translated into practical efforts.

Best Practices Can De-risk and Accelerate A&R

The good news is that despite these numerous risks, there are a range of best practices that can both de-risk and accelerate A&R efforts. The following global map of case studies illustrates myriad approaches, both at the integrated A&R planning level as well as for particular life cycle stages and cross-cutting enablers.

New York, United States

Increasing flood frequency and its impact on New York City's metro system called for the creation of a climate adaptation task force to intervene in crisis situations. The taskforce takes action during emergencies such as sealing tunnels and station doors, along with other measures to protect equipment and control rooms, enabling better disaster response.

Pulido, Darido, Munoz-Raskin & Moody (2018).

White Plains, United States

To improve resilience of public transportation, in White Plains, New York, school electric buses with vehicle-to-grid (V2G) technology have been piloted for three years. The buses have two functions: transporting children to/from school and serving as an emergency repository for grid peaks and in disaster situations, thereby increasing the resilience of the transport network and electricity grid

Consolidated Edison Company of New York (2020).



Guayaquil, Ecuador

Coastal floods threaten Ecuador's urban infrastructure in the city of Guayaquil, which has prompted several A&R design decisions, including the use of permeable pavement, streetscape redesign to include bioswales, and reclaiming of streetscapes to allow for long green flood protection embankments that can be strengthened with mangroves as a nature-based solution. This options-based approach used green and gray infrastructure to boost resilience and create new public green spaces

Green-Gray Community of Practice (2020).



National Highways, United Kingdom

To reduce the increasing impact of floods and extreme heat on assets, National Highways has updated its design and construction manuals with higher resilience standards, is digitally monitoring pavement and asset conditions, and is engaged in collaborations with universities to develop resilience knowledge (for example, for improved asphalt pavements). This enables the company to be more proactive in design, construction, and maintenance. At the same time, for design, the company is piloting a project for natural flood management as a nature-based solution.

National Highways (2022).

London, United Kingdom

Facing rising summer temperatures for its metro, especially in deeper lines such as Bakerloo and Central Line, the London Underground introduced several heat management measures. In order to use the piston effect to move hot air, there is a big focus on maintenance with the introduction of new trains, a relay of tracks, updated signaling, and installation and renewal of vents and fans. To reduce heat production by trains, it has also introduced regenerative braking with gentle approaches to stations and uses groundwater as a cooling solution for platforms and train tunnels.

Douglas (2010).



Uganda

When 271 km of Uganda's Kampala-Malaba Meter Gauge Railway needed rehabilitation, a collaboration with the World Wildlife Fund fostered the design and finance of complementary nature-based solutions, such as planting trees along the railway. This resulted in a rehabilitation project that increased resilience and was aligned with Uganda's Vision 2040 National Strategy and East African Community's Vision 2050.

GCA (2022)

Saudi Arabia

In Saudi Arabia, a proactive approach to A&R was established by centralizing asset management. Including A&R considerations into asset management processes allowed the Roads General Authority to optimize fund allocation in the long term. Additionally, technology, such as survey vehicles and drones, and new digital systems are being implemented (for example, for maintenance scheduling including monitoring of assets and notification to contractors for maintenance needs).

Expert interview Roads General Authority.



Bangladesh

Sea level rise and coastal flooding pose serious risks to Bangladesh. By considering nature-based solutions in the design phase, the country decided to introduce mangroves to improve flood protection for its LTI. This design decision also allowed the country to realize further economic co-benefits (for example, revenue opportunities for shrimp farming).

Expert interview Resallience.

Kuala Lumpur, Malaysia

Facing increased urban flood risk, Kuala Lumpur utilized a public-private partnership to build a tunnel that can divert and store flood waters as well as be used for vehicle passage. Co-investment from the government reduced upfront risk for private investment and improved the business case, while a toll-based system generates revenue to support private investment. The successfully financed project has already improved resilience and has the potential to reduce congestion, travel time, and emissions.

Special Unit for South-South Cooperation (2012).



South East Asia

With four of the world's top 15 countries most at risk from natural disasters, Southeast Asia is a global hotspot for climate challenges. To drive A&R action in the region, the SEACAR Alliance was formed in 2023 as a result from COP27. The SEACAR Alliance prioritizes collaborative action and emphasizes nature-based solutions, climate analytics, and AI to enhance resilience in cities and communities across six crucial themes: natural ecosystems, infrastructure, trade, water, agriculture, and health.

Based on BCG project experience.



Timor-Leste

Through nature-based solutions, such as vegetated embankments and soil bio-stabilization, rural road infrastructure in Timor-Leste was heavily developed and expanded. These efforts included the local population by training them and boosted resilience against floods, landslides, and coastal erosion.

AECOM (2015).

Philippines

In the process of developing a National Adaptation Plan to drive integrated A&R action, the Philippines facilitated consultation among fragmented stakeholders at both the national and subnational levels. Through collaboration and communication, cross-sector A&R action clearly prioritized and broadly agreed upon.

Based on BCG project experience.

South Tarawa, Kiribati

South Tarawa, Kiribati's capital, is connected via a single main road and four causeways, totaling 46 km, 60% of which has not received maintenance in the last 20 years. To ensure network connectivity, a recent project involved restoration of the main road, including drainage systems and drinking water transport infrastructure. The project also deployed a coastal vulnerability assessment to identify areas requiring protective structures, set up performance-based contracts for long-term road maintenance, and supported design and piloting of emergency response systems for rapid repairs after storms.

AECOM (2015).

Minderoo Foundation, Australia

The Minderoo Foundation, which supports Australia's fight against wildfires and floods, has created a Fire and Flood Resilience program, committing to building a system to share national fire and flood resilience data for decision-making. The foundation also supports efforts to accelerate innovation, including a large prize competition for innovative firefighting technologies involving space-based fire detection and autonomous wildfire response

Minderoo Foundation (2023).

- Integrated A&R plan examples
- Lifecycle stage examples
- Enabler examples
- Nature-based solution



Eco friendly car parking. Modern innovative solution for environmental problems. Green grass growing through concrete blocks allowing excess precipitation absorption. Nature finds a way.

V. THE WAY FORWARD

The scale and complexity of the challenge to ensure a resilient LTI network is daunting—even more so with the rising devastating physical, socioeconomic, and environmental impacts and mounting costs of inaction that emerge from erosion and breakdowns of that network and its operations at the local, regional, national, and international levels. While some positive signs of resilience implementation can be observed, there is an urgent mandate for scaled action.

Eight Calls for Immediate Global Action

It is essential that both public and private sector stakeholders begin (or, such as the case may be, continue and expand) their A&R efforts immediately. The following eight calls to action need an urgent response:

- 1 Introduce common taxonomy for climate-resilient infrastructure.**
Common language is important to unified efforts. Thus, the global community must agree on a common definition and taxonomy for climate-resilient transport infrastructure as the basis for target setting and investment acceleration.
- 2 Set global targets.**
The world needs widely understood goals to make efforts effective. That requires the international community to define clear global targets for A&R in transport infrastructure, along with a unified methodology for measuring progress that can be tied to the SAA outcomes and thus support their operationalization.
- 3 Accelerate A&R finance flows.**
Projects can only move from strategy and planning to implementation once funding is secured. Current LTI A&R investment needs are largely unmet, and they exist on top of already large investment needs for infrastructure. Without action, the gap in funding will only increase. Solving it requires involving the private sector and translating national integrated plans into prioritized, localized, and financially attractive A&R projects. Thus, public authorities must devise new regulation and policies to create a conducive investment environment for A&R (for example, by developing accounting and reporting mechanisms for A&R flows and by supporting financial structuring of projects to be aligned with multi-funder project settings).
- 4 Include integrated infrastructure A&R plans in national adaptation plans and translate locally.**
National Adaptation Plans should include a particular section on integrated infrastructure A&R planning that is based on a network view of vulnerabilities—including supporting infrastructure—to ensure economic, societal, and environmental resilience. Public authorities, owners/operators, and other stakeholders at all levels need to create plans that are translated from the national plans and that take into consideration the levels above and below them—crucial for truly integrated LTI A&R plans that will avoid the high cost of inaction for society, the economy, and the environment with early action by avoiding potential disruptions.
- 5 Standardize business case methodology.**
A robust business case methodology should include a holistic view of the cost of inaction as well as co-benefits of A&R as a standard. This should be data-driven and integrate climate risk assessments, including economic, environmental, and societal impacts beyond the physical and financial impacts. A subsequent aspect to consider is whether to establish a standard methodology of said assessments to enable comparability and prioritization of different investments based on common measures of impact, costs of inaction, and potential co-benefits.

6 Set standards for A&R in engineering.

Engineering associations and other standard-setting agencies must rapidly update engineering standards for design and construction of existing and new infrastructure to integrate climate scenarios. This is key to avoiding catastrophic failures, implementing new design approaches such as risk-absorbing infrastructure, ensuring that network interconnectivity and criticalities are considered, and establishing new ways of thinking, such as options-based design.

7 Embed A&R in engineering curricula.

Universities must deeply embed A&R focus and new design approaches and concepts into engineering education. This includes changing the thinking of infrastructure design and building to be more flexible and adaptable to changing climate conditions and understanding how to incorporate results of climate risk assessment in the selection of the best technical option for LTI projects.

8 Develop a market for A&R technologies, materials, and services.

To be able to implement A&R in LTI, technologies, materials, and services need to be available. However, there is a gap between their demand and supply. To address this, public and private stakeholders need to take measures to create a conducive market environment for the development of technologies, materials, and services, including construction industry capacity.

It Can Be Done, If We Act Now

The magnitude and urgency of the A&R challenge require a strong global platform—and, fortunately, this exists through the SAA that was launched by the COP27 presidency and the UN Climate Change High-Level Champions in 2022. The SAA is rallying action from public and private stakeholders across key sectors of the economy under one agenda, which sets global outcomes needed to increase the resilience of 4 billion vulnerable people by 2030. One of the outcomes, under Resilient Infrastructure Systems, hopes that, by the end of the decade, “Transport infrastructure is resilient to climate hazards through adoption of new technology, design and materials.”⁵³

The goal is not only to build resilience of LTI assets themselves, but also to generate wider economic, societal, and environmental benefits. This report supports the efforts of the SAA and aims to complement the findings of the first Global Stocktake to take place at COP28 by providing clear-eyed insight about the scope of A&R challenges, revealing the numerous gaps in action that must be closed and providing case studies that prove success can be achieved with concerted efforts. Whereas the SAA has rallied behind an outcome of resilient transport infrastructure, which the world should aspire to, it is now crucial to develop specific targets to ensure this outcome.

The challenge of implementing A&R in LTI lies with the combination of its broad scope, immense scale, and significant investment needed—and compounding all this, the very real urgency to act. Given the rapidly increasing impact of climate-driven transformations facing our world, there is no time for delays. With the increasingly likely scenario of overshooting 1.5°C warming, the Intergovernmental Panel on Climate Change (IPCC) reports an expected scenario of 2.2°C to 3.5°C warming with current announced policies.⁵⁴ This would increase the frequency and severeness of climate hazards significantly and accelerate climate change, with devastating impacts to LTI networks. It is crucial for us to prepare for these scenarios and the uncertainties bound with them. We must embrace a long-term and global perspective to drive action so as to ensure not only LTI A&R but also socio-economic and environmental resilience.

⁵³ UN Climate Change High-Level Champions (2023).

⁵⁴ IPCC (2023).

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About Boston Consulting Group

Boston Consulting Group partners with leaders in business and society to tackle their most important challenges and capture their greatest opportunities. BCG was the pioneer in business strategy when it was founded in 1963. Today, we work closely with clients to embrace a transformational approach aimed at benefiting all stakeholders—empowering organizations to grow, build sustainable competitive advantage, and drive positive societal impact. Our diverse, global teams bring deep industry and functional expertise and a range of perspectives that question the status quo and spark change. BCG delivers solutions through leading-edge management consulting, technology and design, and corporate and digital ventures. We work in a uniquely collaborative model across the firm and throughout all levels of the client organization, fueled by the goal of helping our clients thrive and enabling them to make the world a better place.

About UN Climate Change High-Level Champions

The UN Climate Change High-Level Champions hold a unique mandate by the Parties to the UN Framework Convention on Climate Change (UNFCCC): To mobilize climate action by non-state actors, enhance ambition and accelerate action in support of Parties to reach the goals of the Paris Agreement. Each High-Level Champion acts on behalf of their respective President of the COP to facilitate the successful execution of existing efforts and the scaling-up and introduction of new or strengthened voluntary efforts, initiatives and coalitions. The two serving High-Level Champions are H.E. Razan Al Mubarak and Dr. Mahmoud Mohieldin.

