THE ROLE OF FUNDING, FINANCING AND EMERGING TECHNOLOGIES IN DELIVERING AND MANAGING INFRASTRUCTURE FOR THE 21ST CENTURY

Executive Summary and Recommendations from the EPSRC-NSF Infrastructure Workshop

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UNIVERSITY OF CAMBRIDGE
CSIC Cambridge Centre for Smart Infrastructure & Construction
CORNELL UNIVERSITY FOUNDED A.D. 1865
CPIP Cornell Program in Infrastructure Policy

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EXECUTIVE SUMMARY

Infrastructure provides the basic building blocks – in the form of critical public services – necessary for the functioning of any modern society. Services provided by infrastructure include safe and reliable transportation, widely available communications, low-cost clean water, dependable heating and cooling, affordable electric power, education and criminal justice, among others within the many definitions of infrastructure. Such services should be universally accessible. Their construction and operation should be administered with sustainable practices and carbon-emission reductions in mind. A vast array of infrastructure facilities, including roads, bridges, tunnels, dams, levies, cell towers, airports, seaports, schools and courthouses ensure that critical services are available, and help define a modern society.

Despite its paramount importance, many countries find it increasingly difficult to provide these services in an efficient and cost-effective way. Common challenges and exigencies include inadequate funding from traditional sources, equitable funding, large backlogs of deferred maintenance, slow adoption of proven technologies, large amounts of carbon emissions, infrastructure modernization to increase climate resilience, adaptation of infrastructure to meet societal needs and demographic change, and projects that are often over cost and over budget during the delivery phase. One overarching infrastructure challenge is the funding gap. The global infrastructure funding gap is estimated to be about USD $15 trillion, and USD $18 trillion if we also include investments needed to achieve UN Sustainable Development Goals.

Additionally, the increasingly complex interdependencies of our infrastructure systems means that we need to move away from traditional siloed approaches to infrastructure management, delivery and regulation to a system-of-systems approach. Challenges like reducing carbon emissions to net zero and making society resilient to the physical effects of climate change are systemic and require systems-based solutions to ensure that we are able to continue to deliver the services that society relies on.

To help address those challenges, the UK Engineering and Physical Science Research Council (EPSRC) and the US National Science Foundation (NSF) supported a Workshop entitled, *The Role of Funding, Financing and Emerging Technologies in Delivering and Managing Infrastructure for the 21st Century*. The Workshop was held in New York City from the 11th to the 15th of July 2022. It included 30 participants invited by US members of the organizing committee, and 25 invited by UK members as well as online participants.

The Workshop assembled a multidisciplinary group of international experts from academia, policy, and practice to explore how to improve infrastructure delivery through innovative funding and financing as well as emerging technologies. This Report captures the discussion and narratives arising from the Workshop and presents recommendations for policy, industry and future research. The Workshop focused on the interconnections between resilience, net-zero carbon and social equity within the context of infrastructure funding and financing. However, each challenge is examined separately in this Report for clarity. The complex interconnections across those issues are acknowledged throughout, with emphasis on the systems and systems-of-systems nature of those challenges.

Although this Report addresses challenges related to infrastructure delivery and resilience, and to historical inequities of infrastructure provision and services, challenges related to climate change are considered the most urgent and affect all of the others. Time is running out to address carbon emissions. The window of opportunity to keep an increase in global temperature to 1.5C in reach and to avoid the worst impacts of global warming is closing fast – at best we have less than seven years to halve current global emissions[1]. The built environment is estimated to contribute from 39% (UN, 2017) to 70% (WRI, 2021) of carbon emissions depending on how emissions are allocated by sector. Infrastructure clearly has a significant role in reducing carbon emissions to acceptable levels.

[1] https://climateclock.world/

New technologies related to materials, sensing, communication and computing are emerging at an accelerated pace compared to prior decades. Emerging technologies are being increasingly applied in infrastructure systems; they increase the timeliness and reliability of information about the current state of infrastructure. They support decision making and increase long-term infrastructure performance and return on investment. The data and insights generated from these technologies can empower decision-makers to improve design approaches and system resilience, decarbonize existing infrastructure networks and achieve more equitable service outcomes.

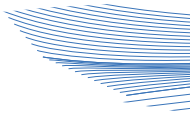
This Report contains a set of specific and actionable recommendations for policy makers, industry practitioners, and researchers. There are six recommendations for improving infrastructure funding and financing, seven related to emerging technology, ten for improving resilience, fifteen for achieving net-zero infrastructure, and ten for improving equity in infrastructure delivery.

Resilience, net-zero carbon, and equity are only achievable if adequate funding and financing mechanisms are in place to support and incentivize critical investments in infrastructure. Key recommendations include: (*i*) considering the adoption of funding mechanisms that correlate closely with infrastructure use and that vary with the value of the facility at that time; (*ii*) bundling together facility design, construction and operation into one long-term contract to reduce incentives to defer maintenance while enhancing incentives to adopt new technologies and improve life-cycle asset maintenance; (*iii*) adopting measures that support resilience by recognizing the need to plan for plausible events, not just the most likely ones; and (*iv*) incorporating stakeholders into decision-making about design and funding.

Adopting frameworks, such as the UK Task-force on Climate-related Financial Disclosures (TCFD), can drive thinking about possible future scenarios across a number of different variables, and improve and increase reporting of climate-related financial information. The use of scenario planning and modelling is a powerful means of exploring a range of possible futures and designing resilience solutions that can be adapted as the future plays out.

Key recommendations regarding infrastructure and the reduction of carbon emissions are:

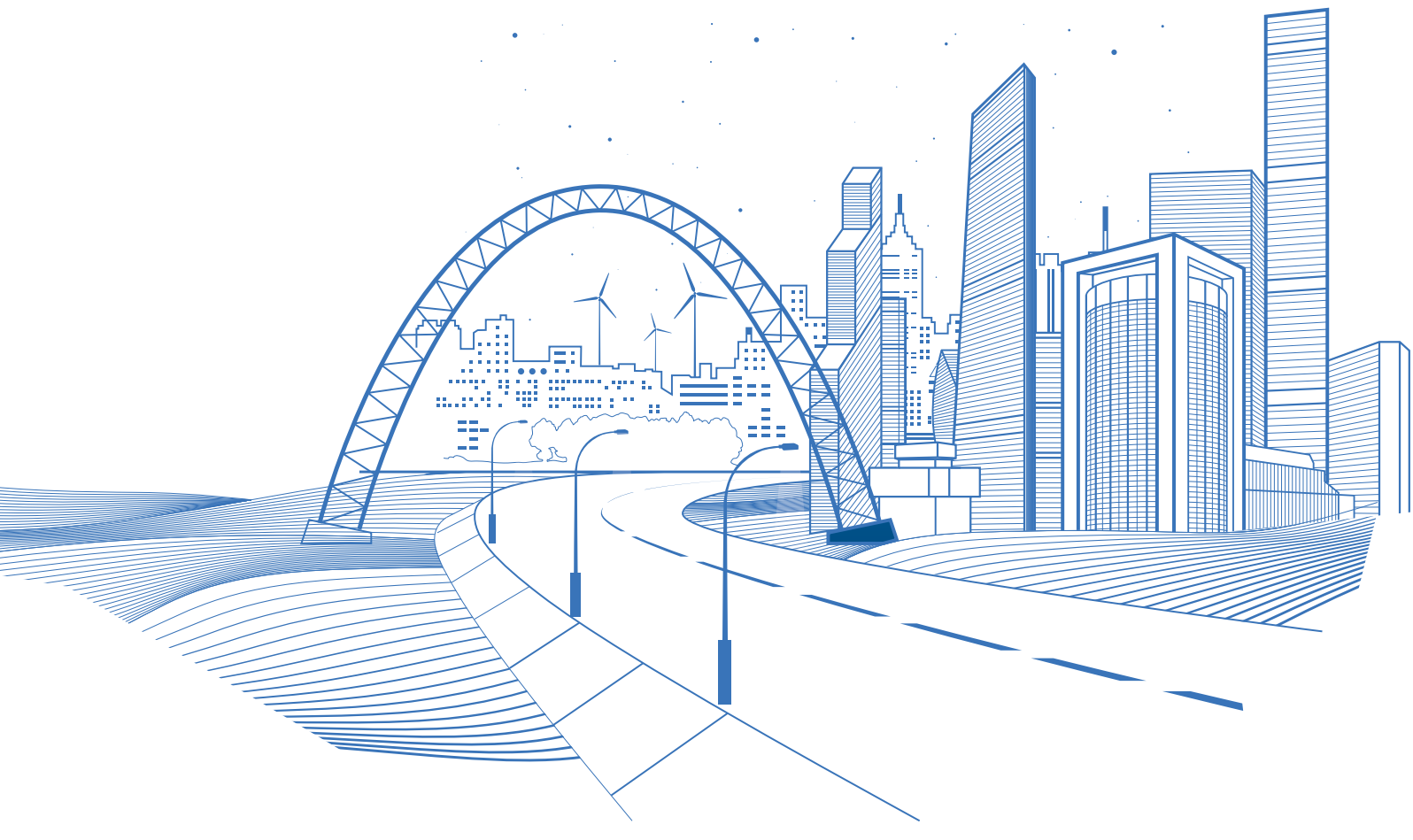
- Every capital project proposal should be reviewed to ascertain whether reducing demand for infrastructure services or refurbishing existing infrastructure are viable and have carbon reduction as a key outcome within the options identified and proposed for implementation.
- Processes should be developed for capturing and analyzing carbon data and integrating with existing digital technologies and processes (e.g., BIM models, digital twins) to facilitate the advancement of accurate carbon measurement.
- All actions made or controlled by government at every level should be required to demonstrate how they support local communities and are consistent with UN Sustainable Development Goals while improving the performance and resilience of infrastructure assets and systems.
- Design codes should be reviewed and revised to reduce conservatism and the resultant over-use of material.
- Industry benchmarks and best practice to measure whole-life carbon need to be developed, refined and adopted in order to provide evidence to set targets and establish financial incentives for carbon reduction.
- Incentives for whole-life, risk-based management approaches need to be identified, with risks allocated to those best able to manage them. These should be embedded in contracts to drive adoption of monitoring approaches and motivate better-informed asset management decisions to reduce carbon emissions from operation and maintenance.



There is a need to regularly reassess the value of critical infrastructure because the value and highest/best use of infrastructure evolves over time. High-quality, system-level targets and metrics (and data) are needed to better understand the true impact of these systems and to benchmark existing performance. A whole-system approach should be taken at all stages of the project lifecycle, with a focus not only on the four traditional priorities (scope, cost, risk and time) but equally on the four new priorities (biodiversity, social value, resilience and carbon & environment). These eight whole-system priorities should be considered when capturing requirements, setting the desired outcomes and benefits, and developing, designing and delivering projects through operation, maintenance and end of life. They should be included (on a comply or explain basis) in business cases, strategies and procurement documents. Balanced scorecard reporting throughout the asset lifecycle should reflect all eight priorities equally, with front page space given to each. To underpin this whole-system approach, good-quality data is needed across all eight priorities. These data will enable a better understanding of the true impact of these systems and benchmarking of existing performance.

Guidance, tools and incentives are needed to enable engineers and planners to link desired outcomes and project appraisal processes with locally relevant solutions. Decision makers should account for the importance of equity in relation to economic viability – ensuring all communities have infrastructure that enables people to be productive and contribute to the future. One overarching Workshop focus was on distinguishing between the funding of infrastructure and its financing. Although adequate financing is an important issue, many critical infrastructure issues stem from inadequate funding, or the absence of underlying resources available for operation and maintenance as well as design and construction.

Overall, this Workshop Report reflects the urgency of addressing key infrastructure industry, policy and research challenges. The analysis and recommendations contained in this Report should be of interest to scholars, practitioners and policy makers with different backgrounds and perspectives. It should serve as a framework for prioritization of efforts in infrastructure studies and policies over the next five years, setting up a foundation for a new normal for infrastructure sustainability and resilience.



SUMMARY OF RECOMMENDATIONS

This section provides a summary of recommendations for policy, industry and research that have been developed on the basis of the Workshop. The recommendations are listed according to the main Workshop topics. Funding and Financing, Emerging Technologies, Resilience, Net Zero and Social Equity are listed as FFR, ETR, RR, NZR and ER, respectively. The main focus of each recommendation is shown with a colored box that links the recommendation with policy, industry, and/or research.

	Recommendation	Policy	Industry	Research
	Funding and Financing			
FFR1	Consider adopting funding mechanisms that correlate closely with infrastructure use and that vary with the value of the facility.	■		
FFR2	Bundling together facility design, construction and operation into one long-term contract can reduce the incentives to defer maintenance while enhancing incentives to adopt new technologies and improve life-cycle asset maintenance.	■	■	
FFR3	Including an equity component in the financing structure of a PPP can provide an equity cushion that allows private investors to absorb risk while financing larger upfront amounts relative to debt-only financing structures. This is standard practice in the United Kingdom.	■		
FFR4	Bundling or wrapping many relatively small but similar projects together into one large contract can attract international partners who have the expertise, capital and incentives to complete the project on-time and on-budget.	■	■	■
FFR5	Innovative approaches such as value capture and asset recycling can incentivize public asset owners to assess and extract value that may be latent in infrastructure after decades of traditional operation and management techniques. Value-capture projects that include environmental benefits such as methane capture and use should be a key focus.	■	■	■
FFR6	Public-sector-only executive education can help ensure that innovative approaches such as PPPs, TIFs, value capture and asset recycling are in the public interest and can support public owners in the pursuit of new, socially beneficial approaches.	■		■
	Emerging Technology	**P**	**I**	**R**
ETR1	Intelligent sensor and autonomy systems must be designed for long lifespans or be adaptable for replacement.		■	■
ETR2	Autonomy in infrastructure construction and operation should be developed within the framework of a common data environment (CDE) with standardized data so that efficiencies in infrastructure systems can be achieved.	■	■	■
ETR3	Using the framework of sociotechnical digital twin, infrastructure asset modelling should be linked to social behavior to understand human interaction with physical infrastructure systems.	■	■	■
ETR4	There is a need for machine learning and artificial intelligence to address prediction accuracy and prediction reliability of infrastructure system performance.		■	■

ETR5	Through innovations in materials and construction/maintenance processes, future infrastructure systems must be designed to generate their energy or rely exclusively on renewable energy, realizing a net-zero or negative carbon system.			
ETR6	There is a need to develop a commonly shared approach to evaluate emerging technology contributions for improved delivery, resilience, net-zero carbon, and equity objectives of infrastructure systems. The framework needs to be used to enhance communication between infrastructure owners and technology developers.			
ETR7	A large market for smart infrastructure should be created and developed by innovative policies and financial incentive mechanisms.			
	Resilience	**P**	**I**	**R**
RR1	Adopting frameworks such as the Task Force on Climate-related Financial Disclosures (TCFD) can drive thinking about possible future scenarios across a number of different variables and improve and increase reporting of climate-related financial information.			
RR2	Use scenario planning and modelling and a whole-system approach to explore a range of possible futures and design resilient solutions that can be adapted as the underlying data and boundary conditions become clearer.			
RR3	Use lessons learned alongside better data and information from emerging technologies to update design standards and develop policies to ensure adherence to the updated standards.			
RR4	Utilize nature-based solutions to deliver improved resilience with increased biodiversity and public amenities, building in valuation of these co-benefits as part of the business case.			
RR5	Develop effective community engagement strategies that help communities to understand risk and resilience, alongside equity, financing and other issues. This would enable collaborative evolution of appropriate responses to potential events, through research and consultation.			
RR6	Engage with stakeholders using simulation and social media to help citizens and asset managers visualize a potential event and develop response strategies, provide feedback to authorities and receive services from authorities prior to, during and after events.			
RR7	Government at all levels should be required to demonstrate how decisions made in relation to infrastructure support local communities, are consistent with the UN Sustainable Development Goals, and improve the performance and resilience of infrastructure assets and systems.			
RR8	The capacity for managing resilience in operating organisations needs to be strengthened to become a core capability. This will entail more collaborative approaches within and between sectors that help to mitigate risk at a system-of-systems level.			
RR9	There is a need to equip resilience professionals with the right tools and skills that allow them to be adaptive in the face of unexpected challenges. A broader-based body of knowledge for future infrastructure resilience professionals should be defined.			
RR10	There is a need to reassess on a regular basis the value of critical infrastructure because the concept of value and highest/best use of infrastructure will evolve over time. Good quality system-level metrics (and data) are needed both to understand the true impact of these systems and for benchmarking existing performance.			

	Net Zero	P	I	R
NZR1	Review every capital project proposal to ascertain whether reducing demand for infrastructure services or refurbishing existing infrastructure are viable and reduce carbon options.	■	■	
NZR2	Procurement should focus on low- or zero-carbon solutions as well as refurbishing waste materials. Include residual value/residual carbon to encourage use of novel materials.	■	■	
NZR3	Review and revise design codes to reduce conservatism in design and resultant overuse of material.	■	■	
NZR4	Academic and industry research into low- and zero-carbon materials, such as improved cements, should be scaled up and accelerated to deliver replacement products as rapidly as possible. Reuse of products such as steel beams should be encouraged. It is important to understand how these materials may age and to manage residual risk in adopting these new materials and to scale up supply chains.		■	■
NZR5	Processes should be developed for capturing and analyzing greenhouse gases, including carbon-based data and the integration of this information with existing digital technologies and processes (e.g., BIM models, digital twins).		■	■
NZR6	Require maintenance, refurbishment and renewal projects to demonstrate substantial reductions in operational energy as well as carbon-based use throughout the system.	■		
NZR7	Develop financial incentives such as grant schemes to support carbon-efficiency retrofit programs.	■	■	
NZR8	Deploy asset heath monitoring and assessment widely across the asset base to facilitate condition-based and risk-based approaches to asset maintenance and capacity assessment to enable life extension of assets and targeted deployment of maintenance resources. Develop O&M contracts that avoid lock-in to specific technologies, by using outcome-based specifications to encourage innovation during the contract.		■	
NZR9	Develop a one-stop-shop service to support householders and small businesses to retrofit their buildings for energy efficiency.	■		
NZR10	Industry benchmarks and best practice need to be developed, refined and adopted to measure whole-life carbon and provide the evidence to set targets and establish financial incentives for carbon reduction. Identify incentives for whole-life, risk-based management approaches, with risks allocated to those best able to manage them. Embed such incentives in contracts to drive the adoption of monitoring approaches and motivate better-informed asset management decisions.		■	■
NZR11	Implement an accounting system for carbon and prices that will appropriately value the impact of carbon on the environment both now and in the future (natural capital accounting). Consider developing a carbon metric label for materials and products.	■		
NZR12	Adopt a scheme such as the Gross Replacement Carbon footprint (GRCf) toolkit to account for the embodied carbon of existing assets in option selection.	■	■	
NZR13	Recognize, prioritize and protect the role of nature as a complex and interconnected natural system and develop frameworks which favor nature-based solutions over hard engineered solutions when possible.	■	■	■

NZR14	Continue to invest in circular economy research and innovation initiatives to develop technologies, processes and a marketplace for material reuse and repurposing.			
NZR15	Evaluate the effects of military operations on carbon released to the atmosphere. Estimate delays in carbon reduction milestones and provide plans either to adapt or estimate the cost associated with carbon reduction milestone delays.			
	Equity	**P**	**I**	**R**
ER1	Guidance, tools and incentives are needed to enable engineers and planners to link desired outcomes and project appraisal processes with locally relevant solutions.			
ER2	Decision makers should take into account the importance of equity in relation to economic viability – ensuring all communities have infrastructure that enables people to be productive and contribute to the future.			
ER3	Real-time accounting and appraisal systems are required to better understand equity needs as well as outcomes, and to ensure that the changing dynamics shaping our societies are captured.			
ER4	To achieve equitable outcomes from infrastructure investments, develop effective partnerships between governments, society, and private-sector organizations, to facilitate the adoption of support mechanisms.			
ER5	Inclusive, integrated, and long-term planning is needed at local, municipal, subnational and national scales, together with effective regulation and monitoring systems.			
ER6	Equity considerations should be included in systems perspectives and should be implemented in planning and delivery of infrastructure and services.			
ER7	To ensure infrastructure meets the needs of the communities it seeks to serve, citizen engagement should be sought from the outset, and this requires a shift in focus to the citizen. Equity considerations need to be community-specific and outcome-driven.			
ER8	Develop guidance and policy for early citizen engagement in developing equity-related initiatives and associated metrics.			
ER9	Planners need to use digital tools which can help to engage citizens in decision-making at an early stage, while also addressing persistent access barriers.			
ER10	Infrastructure sponsors would benefit from the development of digital tools for monitoring environmental and social outcomes of interventions, and guidance regarding the ethical requirements surrounding such tools.			

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