One Earth

Gold Standard for the Global Goals
1 ton of CO_2 offset

CellPress

Commentary

Infrastructure investment must incorporate Nature's lessons in a rapidly changing world

Rusty A. Feagin,[1,*] Todd S. Bridges,[2] Brian Bledsoe,[3] Elizabeth Losos,[4] Susana Ferreira,[3] Emily Corwin,[5] Quirijn Lodder,[6] Michael W. Beck,[7] Borja Reguero,[7] Ariana Sutton-Grier,[8] Jens Figlus,[1] Rowan Palmer,[9] Donald R. Nelson,[3] Carter Smith,[10] Lydia Olander,[4] Brian Silliman,[10] Hans Pietersen,[11] Robert Costanza,[12] Rachel K. Gittman,[13] Siddharth Narayan,[14] Nigel Pontee,[15] Mike Donahue,[16] Don McNeill,[17] and Todd Guidry[18]

[1]Department of Ecology and Conservation Biology, Department of Ocean Engineering, Texas A&M University, College Station, TX, USA
[2]Engineering and Research Development Center, US Army Corps of Engineers, Vicksburg, MS, USA
[3]Institute for Resilient Infrastructure Systems, University of Georgia, Athens, GA, USA
[4]Nicholas Institute for Environmental Policy Solutions, Duke University, Durham, NC, USA
[5]Conservation International, Arlington, VA, USA
[6]Rijkswaterstaat, Lelystad, Flevoland, the Netherlands
[7]Institute of Marine Sciences, University of California, Santa Cruz, Santa Cruz, CA, USA
[8]Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD, USA
[9]United Nations Environment Programme, Geneva, Switzerland
[10]Nicholas School of the Environment, Duke University, Durham, NC, USA
[11]Rijkswaterstaat, Houten, Utrecht, the Netherlands
[12]Crawford School of Public Policy, Australian National University, Canberra, ACT, Australia
[13]Department of Biology, East Carolina University, Greenville, NC, USA
[14]Department of Coastal Studies, East Carolina University, Greenville, NC, USA
[15]Jacobs, Bristol, England, UK
[16]AECOM, Ann Arbor, MI, USA
[17]Caterpillar, Inc., Decatur, IL, USA
[18]Dow Chemical, Houston, TX, USA
*Correspondence: feaginr@tamu.edu
https://doi.org/10.1016/j.oneear.2021.10.003

Infrastructure must become more resilient as the global climate changes and also more affordable in the economic and political context of a post-COVID world. We can solve this dual challenge and drive global infrastructure investment into a more sustainable direction by taking our cues from Nature.

Introduction

Several of the major economies of the world plan to stimulate their post-COVID recovery by spending on infrastructure. Among economists and environmentalists, there is a broad consensus that this spending represents a once-in-a-generation opportunity to build a more sustainable global economy.[1,2] The opportunity for transformation abounds in programs as diverse as the European Union and South Korean "Green New Deal" initiatives, the United Nations, United Kingdom, and United States "Build Back Better" programs, and China's 2060 commitment to carbon neutrality and its "Belt and Road" initiative. The future context is enormous—in excess of $81 trillion USD will be required to meet global infrastructure needs over the next 20 years.[3] Without this infrastructure—to include the construction and protection of navigation and transportation routes; the maintenance of sustainable food, energy, and material supply lines; and the provision of clean water and sanitation—human development will suffer in both developing and developed countries. Could this moment be our collective chance to reduce greenhouse gas emissions while also improving the quality of life for billions of people? Can we use this opportunity to develop innovative sectors of green technology?

The unfortunate reality is that the economic and political damage wrought by the COVID crisis will greatly constrain the ability of governments, private entities, and international funding agencies to match infrastructure needs over the next 20 years (Figure 1). Private investment into infrastructure alone fell over 40% in 2020,[3] as people sheltered in their homes and the global economy ground to a halt. The gross domestic product (GDP) of nearly every country has atrophied since the crisis began, reducing the tax base and availability of public funds. At the same time, debt-to-GDP ratios have increased, as governments have had to spend more to address health care and social safety net needs. No country has experienced a greater debt-to-GDP increase than Australia, which saw a 32% rise from 2019 to 2020, with an expected total rise of over 54% by the end of 2021.[4] Within this context, any new spending is less palatable to politicians worried about inflationary risks. For example, in the United States, a game of political brinksmanship has resulted in a risk to the country's credit rating, threatening the investment of ~$1 trillion into infrastructure. And as the COVID crisis abates, another fiscal crisis looms: climate change.

Climate change is already accelerating the deterioration of infrastructure, and the situation will only worsen over the coming decades.[6,7] As average temperatures warm, the seas rise, and weather events become more extreme, the performance of constructed materials and systems will be pushed beyond their design limits and infrastructure will begin to fail.

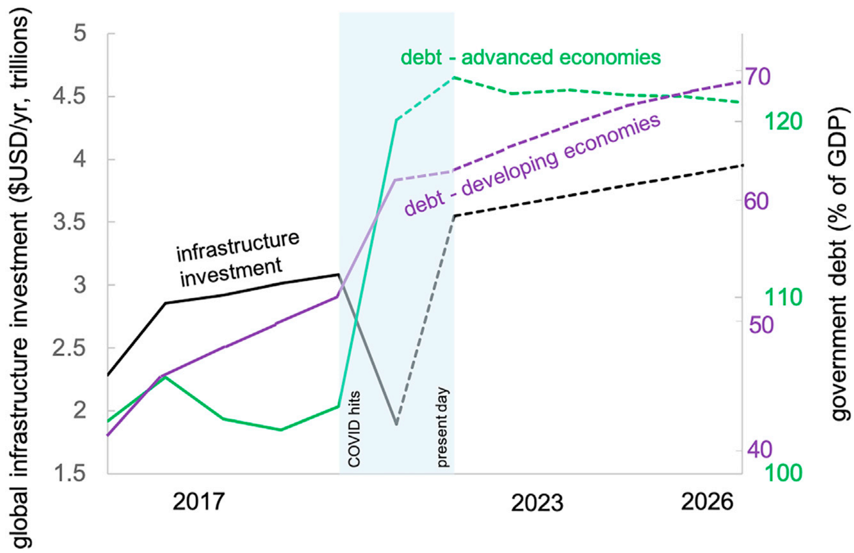

Figure 1. The COVID crisis in 2020–2021 greatly increased government debt and sharply reduced the supply of funds available for infrastructure investment; moving through 2022 and onward, this investment must increase to meet climate adaptation and development needs

Solid lines depict the historical record, dotted lines depict projections. Infrastructure investment data with 40% drop in 2020 and long-term rise due to existing development needs,[3] plus 10% climate adaptation adjustment.[5] General government gross debt data from the IMF.[4]

Governments and international funding agencies will be forced to reinvest sooner to maintain this infrastructure, with annualized costs rising up to 10%.[7] Thus, the investments must not only mitigate and adapt to the changing climatic conditions, but they must also address the looming budgetary shortfalls.

While the global need for infrastructure can be met using conventional "gray" materials like concrete and steel, our investments will be unsustainable if they also increase greenhouse gas emissions and consume too many natural resources. The infrastructure sector is responsible for ~45% of emissions (not including electricity), and the generation and placement of concrete and steel are responsible for ~8% and 7%, respectively.[5] To meet the treaty obligations of the Paris Agreement, these emissions must drop to near zero for many nations. We must stop the cycle of investing into projects that drive further climate change, have little resilience to this change, and then generate long-term maintenance and fiscal burdens. True sustainability will require us to build resilient infrastructure with lower emissions while also saving money in an austere fiscal environment. We contend that Nature provides several novel solutions to help us address this challenge.

Invest in natural infrastructure

A first solution is to reduce the costs associated with conventional gray infrastructure, wherever possible, by investing instead into the natural infrastructure sector. This sector involves actively constructing, restoring, conserving, and re-engineering ecosystems to fulfill economic, social, and environmental needs. This sector is open for competition, primed for innovation, and can employ workers with labor-intensive construction skills.[8] Natural infrastructure solutions can be particularly valuable in countries with little access to debt financing due to their relatively low cost.

Existing natural infrastructure projects have proven the ability of a variety of ecosystem features to cheaply address natural hazard mitigation, for example building sand dunes instead of concrete seawalls to block flooding storm waters.[9] Other projects have delivered climate change mitigation and adaptation benefits, for instance the planting of trees to capture atmospheric carbon and reduce urban temperatures.[10] Still others have enhanced water security and quality by restoring wetlands to reduce sewage treatment costs.[11] In practice, natural infrastructure solutions can be integrated with more conventional solutions, and projects can utilize both gray and green technologies within the same footprint. The common theme is to harness the adaptive capacity of natural ecosystems to meet needs in a rapidly shifting environmental and socio-economic context.

To highlight what Nature's lessons offer for our broader conception of infrastructure, imagine a cartoon-like depiction where an infrastructure solution can be either conventional or natural (Figure 2). A conventional solution, such as a rock seawall for example, is typically developed for a world in which the environmental baseline conditions are considered constant. Its success is measured by performance over its life cycle.[12] If a tropical cyclone strikes and erodes the wall, failure is reached and the life cycle ends. One must then reinvest money to start a new life cycle, within the context of a longer planning time horizon. Alternately, if climate change degrades the wall more quickly, then the life cycle will shorten relative to planning time horizon.

In contrast, the natural infrastructure approach adds adaptive design features that remain in dynamic equilibrium with changing environmental conditions, thereby increasing cumulative resilience over time. A natural solution like planting living mangrove trees may initially prevent less erosion than the wall, but the trees can recover after the tropical cyclone strikes, spread, and build land elevation. Its life cycle is much longer than the wall and may exceed the planned time horizon.

Optimally engineered infrastructure would perform well and exhibit resilience,[12] but this requires it to be adaptive to its environment. Stepping away from the cartoon dialectic of conventional versus natural solutions, a project's adaptive features can be living, non-living, or a hybrid; for example, a computer-controlled traffic light system could adaptively re-distribute excess traffic across a network of roads during rush hour, helping to avoid weight loading and reducing damages. Ultimately, the key lesson from Nature is that the ability to adapt yields both performance and resilience to infrastructure.

Take a long-term view on infrastructure investment

Second, central governments and international funding agencies can increase

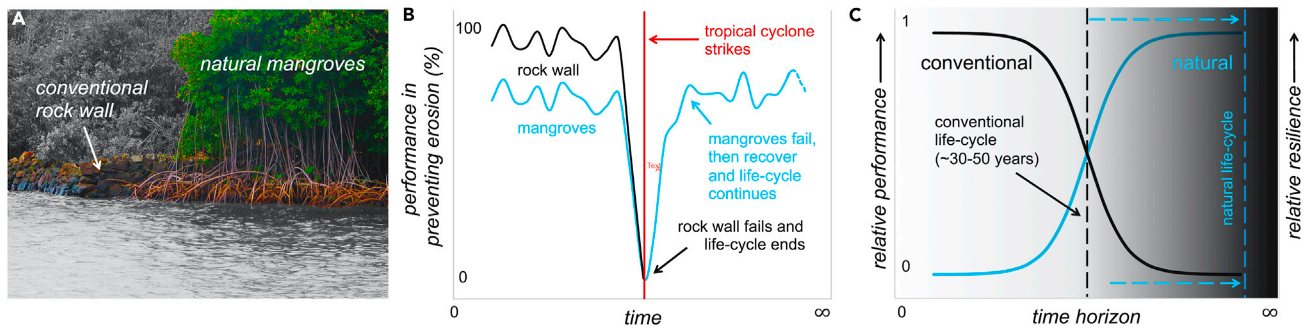

Figure 2. Nature teaches us that the ability to adapt yields both performance and resilience benefits for an infrastructure solution
(A) Example of a hybrid infrastructure project that incorporates both conventional (rock wall) and natural solutions (mangrove trees).
(B) The rock wall performs well at first but fails catastrophically once a tropical cyclone strikes, whereas the mangrove trees are able to recover and replicate well past the life cycle of the rock wall.
(C) Natural solutions often yield performance and resilience benefits that accumulate over a longer time horizon than conventional infrastructure.

resilience and save money by taking a long-term view on infrastructure investment. More precisely, they can modify how they make decisions on infrastructure priorities, with respect to the time horizon and the discount rate.[13] These entities typically fund projects that yield the greatest economic benefits for the least amount of cost, over a time horizon of 30 to 50 years into the future. They then devalue the benefits and costs within this time horizon at a chosen discount rate, compounded annually, to reflect the fact that people care less about the future than the present.

For example, the current US Office of Management and Budget (OMB) guidance for the discount rate on publicly beneficial projects is set by executive order at 7%. After annual compounding, the US federal government is roughly saying that it cares 100% about taxpayer investment into infrastructure today, 33% in 15 years from now, and 11% after 30 years into the future. It can get worse; the World Bank has used a discount rate of 12% at times in the past, rendering 100%, 15%, and 2%, respectively. If decision-makers are asked to heavily devalue a potential project's long-term benefits and costs, then short life cycles with unsustainable outcomes will be the result.

Governments and agencies should thus lower the discount rate for all infrastructure projects, such that it is closer to the real interest rate and lengthen the planned time horizon to at least double the length of the conventional project life cycle. A good guide can be found in an exception to the OMB guidance for water resource-related projects, which allows the US Army Corps of Engineers to use lower rates. The result? More natural and resilient conventional projects have been selected from among the alternatives because they have lower maintenance costs and provide greater benefit streams in future years. By changing how we value time, we can steer taxpayer investment toward more resilient and cost-effective solutions over longer time horizons.

Include project co-benefits

Third, we propose a "moon shot" for the next generation of infrastructure policy—to institutionalize the accounting of co-benefits within benefit-cost analysis. Co-benefits are the additional goods and services provided by a project that go beyond its primary purpose of protecting against the loss of existing capital investment or the direct support of future economic activity. The co-benefit concept is similar to that of ecosystem service value,[14] although broader in that it includes any monetized or non-monetized benefit. For example, the mangrove forest in Figure 2 provides recreational, fishery support, and carbon sequestration benefits in addition to its designed protective benefit. We refer to this goal as a "moon shot" because although there is a large body of literature on how to calculate these benefits, the methods first must be standardized, simplified, and converted into written policy. Once incorporated into the project selection process, co-benefits can increase the net benefit stream over longer time horizons.

Accounting for co-benefits also provides the opportunity to stretch limited public funds further through cost-sharing because multiple societal needs can be met within the same project footprint. By meeting multiple stakeholder goals, taxpayer inputs can be amplified by public-private partnerships, green bonds, common asset trusts, crowd-sourced funding efforts, and ecosystem service-based insurance payouts. In one interesting example, the state of Quintana Roo, Mexico is rebuilding coral reefs destroyed by Hurricane Delta in 2020, using compensation funds received from the insurance company Swiss Re (proving that natural infrastructure can be covered by, and paid for by, insurance payouts[15]). In another example, Dow Chemical has invested $0.5 billion into local projects that have been good for both business and ecosystems. The involvement of multiple stakeholders also enhances social equity and broadens the base of citizen support for project success. Stakeholder interest and support can be critical to avoiding project delays and cost overruns, thus saving money.

Infrastructure must be more sustainable

Today's spending on infrastructure will affect us many years into the future. The world's economies must do more than borrow money to build infrastructure and provide "green" jobs for today. They must also hedge against the inflationary risks and climate-accelerated deterioration costs of the future. If we cannot meet this challenge, then we will find ourselves unable to pay for global infrastructure needs, hindering the quality of life for billions of people. If we also cannot reduce greenhouse gas emissions while meeting these needs, then a rapidly changing climate will render portions of the Earth unlivable.

Governments and international funding agencies can turn this challenge into an opportunity by re-conceptualizing how they spend money on infrastructure projects. The upcoming 2021 UN Climate Change Conference of Parties (COP26) provides the ideal forum to develop nation-specific commitments to (1) investing further in the natural infrastructure sector, (2) taking a long-term view on infrastructure investment by lowering discount rates, and (3) setting rules to measure and include co-benefits when considered among project alternatives. Solutions along these three tracks will enable nations to better meet their Paris Agreement emissions targets and also save money. We must use this opportunity to transform global infrastructure outcomes and build a more sustainable future.

ACKNOWLEDGMENTS

Support to R.A.F. provided by the United States National Science Foundation (1756477). The views expressed in this article are those of the authors and do not necessarily represent the official position of their affiliated organizations.

AUTHOR CONTRIBUTIONS

R.A.F. organized, contributed text, and edited. T.S.B., B.B., E.C., Q.L., A.S.-G., R.P., H.P., and N.P. met virtually, contributed text, and edited. M.D., D.M., and T.G. met virtually and contributed text. E.L., S.F., M.W.B., B.R., J.F., D.R.N., C.S., L.O., B.S., R.C., R.K.G., and S.N. contributed text and edited.

REFERENCES

1. McElwee, P., Turnout, E., Chiroleu-Assouline, M., Clapp, J., Isenhour, C., Jackson, T., Kelemen, E., Miller, D.C., Rusch, G., Spangenberg, J.H., et al. (2020). Ensuring a post-COVID economic agenda tackles global biodiversity loss. One Earth *3*, 448–461. https://doi.org/10.1016/j.oneear.2020.09.011.
2. Andrijevic, M., Schleussner, C.-F., Gidden, M.J., McCollum, D.L., and Rogelj, J. (2020). COVID-19 recovery funds dwarf clean energy investment needs. Science *370*, 298–300. https://doi.org/10.1126/science.abc9697.
3. G20 Global Infrastructure Hub (2021). Forecasting infrastructure investment needs and gaps. https://outlook.gihub.org/.
4. International Monetary Fund (2021). World Economic Outlook (April 2021). https://www.imf.org/external/datamapper/datasets/WEO.
5. Henbest, S., Kimmel, M., Callens, J., Vasdev, A., Brandily, T., Berryman, I., Danial, J., and Vickers, B. (2021). New Energy Outlook 2021. (BloombergNEF).
6. Haasnoot, M., van Aalst, M., Rozenberg, J., Dominique, K., Matthews, J., Bouwer, L.M., Kind, J., and LeRoy Poff, N. (2019). Investments under non-stationarity: Economic evaluation of adaptation pathways. Clim. Change *161*, 451–463. https://doi.org/10.1007/s10584-019-02409-6.
7. United Nations Environment Programme (2018). The Adaptation Gap Report. https://www.unep.org/resources/adaptation-gap-report-2018.
8. Edwards, P.E.T., Sutton-Grier, A.E., and Coyle, G.E. (2013). Investing in Nature: Restoring coastal habitat blue infrastructure and green job creation. Mar. Policy *38*, 65–71. https://doi.org/10.1016/j.marpol.2012.05.020.
9. Odériz, I., Knöchelmann, N., Silva, R., Feagin, R.A., Martínez, M.L., and Mendoza, E. (2020). Reinforcement of vegetated and unvegetated dunes by a rocky core: A viable alternative for dissipating waves and providing protection? Coast. Eng. *158*, 103675.
10. Chausson, A., Turner, B., Seddon, D., Chabaneix, N., Girardin, C.A.J., Kapos, V., et al. (2020). Mapping the effectiveness of Nature-based solutions for climate change adaptation. Glob. Change Biol. *26*, 6134–6155. https://doi.org/10.1111/gcb.15310.
11. Palmer, M.A., Liu, J., Matthews, J.H., Mumba, M., and D'Odorico, P. (2015). WATER. Manage water in a green way. Science *349*, 584–585. https://doi.org/10.1126/science.aac7778.
12. Ayyub, B.M. (2014). Systems resilience for multihazard environments: definition, metrics, and valuation for decision making. Risk Anal. *34*, 340–355.
13. Lueddeckens, S., Saling, P., and Guenther, E. (2020). Temporal issues in life cycle assessment – A systematic review. Int. J. Life Cycle Assess. *25*, 1385–1401. https://doi.org/10.1007/s11367-020-01757-1.
14. Costanza, R. (2021). Valuing natural capital and ecosystem services towards the goals of efficiency, fairness, and sustainability. Ecosyst. Serv. *43*, 101096. https://doi.org/10.1016/j.ecoser.2020.101096.
15. Beck, M.W., Heck, N., Narayan, S., Menendez, P., Torres-Ortega, S., Losada, I.J., Way, M., Rogers, M., and McFarlane-Connelly, L. (2020). Reducing Caribbean Risk: Opportunities for Cost-Effective Mangrove Restoration and Insurance (The Nature Conservancy).