Infrastructure for a sustainable future

Summary

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Cover image source: (Quevedo Gutiérrez et al., 2013)

Introduction

The next twenty years will represent an unprecedented demand for new infrastructure. As developing countries increasingly demand modern infrastructure for growing, urbanizing and industrializing populations, developed countries deal with aging infrastructure in desperate need of replacement. The expected investment in new infrastructure between now and 2040 is higher than the current value of all of the infrastructure in the world (Thacker *et al.*, 2019). This opportunity is a double-edged sword: infrastructure is an expensive and long term investment. Badly developed infrastructure is difficult to replace, and can create debt lasting generations. Unsustainable patterns of development can be locked in by infrastructure that lasts decades.

Climate change will have a significant impact on infrastructure. Existing energy and transport infrastructure will produce emissions far exceeding the targets agreed in the Paris Agreement unless it is abandoned or repurposed before the end of its life (Thacker *et al.*, 2019). Climate change will create conditions that current infrastructure is not designed to withstand and uncertainty that government policies and safety standards are not able to address (Chester, Underwood and Samaras, 2020). Adapting infrastructure to climate change will require more than strengthening and reinforcing current designs; there will need to be a change in thinking about how infrastructure is imagined and used (Shortridge and Camp, 2019). The purpose of this study is to examine case studies of proposed or emerging infrastructure technologies to evaluate how they can contribute to climate change mitigation or adaptation in the coming years.

Case studies were selected on the basis of five predefined search criteria:

1. **Infrastructure**: does the case study involve significant built infrastructure?
2. **Cross-cutting ideas**: does the case study take advantage of opportunity, encompass long term vision or show leapfrogging or repurposing potential?
3. **Internationality:** does the case study promote transboundary cooperation or reduce the risk of conflict?
4. **Stage of development**: is the case study based on or developed from existing technology?
5. **Representativeness:** do the case studies represent a range of infrastructure sectors (adaptation, agriculture, communications, energy)?

From an initial list of ten cases, five were selected for evaluation: floating cities, multipurpose platforms, hybrid coastal resilience, smart undersea cables and gravity storage. The study authors assessed each of these case studies through a review of published literature and reports. They evaluated case studies in terms of three factors: 1) climate change adaptation/mitigation potential; 2) feasibility and cost; and 3) environmental and social impact. Each of these factors was given a score of 1-5, where 1 reflects the lowest potential and 5 the highest potential. Table 1 presents the criteria used in evaluation. In addition, each score is given a certainty ranking from low certainty to high certainty, representing the evidence behind the evaluation.

	Adaptation/mitigation potential	**Feasibility and cost**	**Environmental and social impact**
	Potential for adaptation: risk reduction, resilience improvement, planning, monitoring and evaluation **Potential for mitigation**: carbon sequestration, demand reduction, shift to clean energy	**Technological feasibility**: stage of development, results of trials, evidence from implementation **Cost**: development, construction, maintenance costs relative to benefit, compared to alternatives	**Environmental/social negative impacts**: ecosystem degradation, pollution, displacement, conflict, health impact **Environmental/social co-benefits**: ecosystem services, valuable species
Score			
1	No real potential for adaptation/mitigation Climate benefits outweighed by emissions or other climate impacts	Not technologically feasible now or in the near future Financial costs are prohibitive	Significant, negative and unavoidable environmental and social impact No co-benefits
2	Small potential for adaptation/mitigation Climate impacts cancel much (but not all) of the benefit	Needs significant technical development Financial costs are more expensive than alternatives	Some unavoidable negative environmental and social impacts Minimal co-benefits
3	Moderate potential for adaptation/mitigation Negative impacts low or outweighed by benefits	Technologically feasible, may need testing Costs comparable to alternative technologies	Negative environmental/social impacts can be mitigated or compensated Some co-benefits
4	Significant potential for adaptation/mitigation Any impacts strongly outweighed by benefits	Technology ready for deployment Costs lower than some (but not all) alternatives	Minimal negative environmental/social impact Some co-benefits
5	Transformative potential for adaptation/mitigation No negative climate impacts	Technology works better and at a lower cost than any alternative	Minimal negative environmental/social impact Significant co-benefits

Table 1: Criteria for evaluating case studies

Floating cities

Over the last 70 years extensive efforts have been put on research and development of technologies to build very large floating structures (VLFS) for a wide range of applications such as airports, military bases, offshore energy plants and, more recently, urban settlements (Wang and Tay, 2011).

VLFS are artificially man-made floating parcels on the sea. They may be categorized into two types according to their geometry: 1) pontoon; and 2) semi-submersible (Wang and Tay, 2011). The pontoon-type has a structure similar to a steel ship hull and is used in calm waters, close to the coast with very low or no waves. They have mooring or anchoring facilities to keep the floating structure on site and usually are connected to land through a bridge or a floating road. The Semi-submersible type has a platform raised above sea level using column tubes, is suitable for deployment in high seas with large waves, and is mobile (not anchored) (Lamas-Pardo, Iglesias and Carral, 2015). Depending on the VLFS type, they can range from 1,000m to 10,000m, they can displace from 10^6 tons to 10^7 tons, and they can last from 50 to 100 years.

Factor	Score	Comments
	4 Low certainty	Though there is little evidence linking floating cities to mitigation, they may have significant adaptation value for certain locations, particularly as a response to flooding of low-lying urban areas, as long as they can be designed to withstand extreme climate events.
	2 Moderate certainty	Significant development challenges remain before floating cities can be considered a viable solution to sea level rise. Coastal pontoon type VLFS have lower maintenance and manufacturing costs, but still range between \$5,000 million and \$15,000 million.
	3 Low certainty	While some studies suggest little environmental impact from floating cities themselves, there has been little investigation of the impact of the additional protective infrastructure necessary to make floating cities possible. Floating cities could provide social benefits by alleviating the need for massive relocation of populations.
Combined scores	9 Low certainty	This technology has medium potential for addressing climate change with minimal or avoided negative environmental impacts. The lack of application of VLFS to urban purposes indicates that there is a considerable need to conduct further research before sound conclusions on their feasibility and environmental and social impacts can be made.

Floating platforms for food and energy production

Continued population growth and corresponding increasing demands for food and energy has boosted commercial interests in the ocean as well as research on floating infrastructures that integrate aquaculture and energy production (Aryai *et al.*, 2021). Commonly, these structures are framed as multi-purpose floating platforms (MPFP), which can have very diverse designs, combinations and purposes, and can operate in shallow waters as well as open seas. The economic, environmental and technical feasibility is case-specific and cannot be easily generalized.

Smart floating farms (SFF) are one type of MPFP that integrate solar energy, hydroponics and aquaculture on a single multi-storage floating platform (www.smartfloatingfarms.com). SFF consists of pontoons that support a three-floor building/structure. At the lower level, a recirculating aquaculture system (RAS) is installed to produce fish (Bregnballe, 2015). On the second floor, a hydroponics plant is operated, where fish excrement extracted from the RAS is used as nutrients for crop production. Finally, on the rooftop, solar panels are installed to supply the energy needs of the aquaculture and hydroponics facilities. SFF are designed for shallow waters, near the shore, using mooring systems.

Factor	Score	Comments
	3 Moderate certainty	SFF alone has low to moderate adaptation and mitigation potential from improving agricultural efficiency and reducing land use, but some forms of MPFP that include renewable energy have a higher potential.
	3 Low certainty	There is still a need for significant research and development before MPFP is shown to be feasible, but approaches that have been assessed show promise to be cost effective. There are many variables that factor into feasibility: whether existing platforms are being repurposed, the location of the platform and the purposes incorporated.
	3 Moderate certainty	While environmental risks vary among applications, for some applications there is a chance of significant adverse impacts on the marine environment and local fishers. Where RAS is used, some impacts can be mitigated.
Combined score	9 Moderate certainty	This technology is still in its infancy and there is need for research to confirm its technical and economic feasibility, as well as the appropriate combinations of renewable energy and aquaculture systems to mitigate potential environmental risks or even produce a positive effect on the marine ecosystem. It also shows the need to work out regulatory questions related to permitting associated to the multiple purposes integrated in the platforms.

Hybrid coastal resilience approaches

Climate related storm surges and sea level rise pose a significant threat to coastal communities, which make up a large part of the global population. Hard infrastructure responses, such as seawalls, dykes and breakwaters are expensive and often environmentally damaging, while nature-based solutions using ecosystem restoration may not be feasible or sufficient in all cases. This has led to increasing interest in hybrid approaches, which combine hard infrastructure with green approaches and components (Sutton-Grier, Wowk and Bamford, 2015).

Hybrid approaches exist along a spectrum between grey and green infrastructure, and can encompass:

1. hard infrastructure designed to imitate or support ecosystem functions and connectivity, such as seawalls designed to provide habitat for living organisms;
2. a combination of hard infrastructure and living ecosystems, such as salt marshes cultivated in front of seawalls; and
3. use of hard infrastructure to seed, frame or instigate growth or restoration of protective ecosystems, such as use of artificial structures to attract reef-building species.

Factor	Score	Comments
	3 Moderate certainty	Hybrid infrastructure has the potential to provide greater coastal protection than either natural or built infrastructure alone, and can provide limited mitigation through incorporation of carbon sinks. It is difficult to quantify the relative effectiveness of hybrid infrastructure due to a lack of comprehensive data.
	5 Moderate certainty	The cost of hybrid approaches varies with location, but is typically less than the cost of achieving equivalent protection with grey infrastructure alone (estimated at $70 billion/year). Maintenance costs are lower due to the ability to self-repair of the living component of hybrid infrastructure. Notwithstanding, there is little statistical data on the relative costs and benefits of hybrid infrastructure compared to hard or soft infrastructure.
	5 Moderate certainty	Hybrid infrastructure is designed to mitigate many of the environmental impacts created by hard infrastructure. It can also create social and economic co-benefits in the form of recreational opportunities, water filtration and increased fish populations. However, careful consideration and design must be taken to achieve these environmental and social effects.
Combined score	13 Moderate certainty	Hybrid coastal resilience infrastructure are among the most promising technologies for achieving climate adaptation benefits at lower cost than existing alternatives and with several environmental co-benefits. Due to their relatively recent development, there is an urgent need for additional research, particularly on how the interaction between hard and soft components contributes to effectiveness and the relative costs and benefits compared to hard or soft infrastructure.

Smart undersea cables

The global lack of data on deep ocean processes impedes accurate modeling of climate events and trends. Obtaining high quality data, particularly from the deep ocean and the poles, can be difficult and expensive. One proposed solution is incorporating sensors into existing telecommunication cable networks to scale up ocean observation at a reasonable cost.

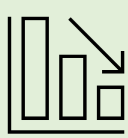
Cables have been used for ocean monitoring for decades: in the 1990s undersea cables were used to detect earthquakes and tsunamis off Japan; since then several countries have created dedicated cabled observatories such as the VENUS and NEPTUNE observatories in Canada, DONET and S-net in Japan and the Ocean Observatories Initiative in the US (Baggeroer *et al.*, 2018). In 2012, a UN Joint Task Force (JTF) was established to consider options for scaling up ocean observation by taking advantage of the extensive undersea telecommunications cable infrastructure. The JTF has developed the concept of Science Monitoring and Reliable Telecommunications (SMART) cables, which integrate sensors for monitoring pressure, temperature and seismic activity into new telecommunications cables. It is working on a demonstration project, to incorporate sensors with short-distance submarine cables in the South Pacific, with support from the ADB (Howe *et al.*, 2019).

Factor	Score	Comments
	4 High certainty	Smart cables have significant potential to generate data relevant for disaster risk reduction (DRR), CO2 processes in the oceans and essential ocean variables. This information is essential for adaptation planning and for building more accurate early warning systems.
	4 High certainty	SMART cables could be included in most routes in the near future (5 to 10 years). The yearly cost of SMART cables deployment at global scale is moderate. However, there are still some technical and legal questions to be solved before SMART cables become a reality.
	4 High certainty	There is little information on the potential environmental and social impact of SMART cables. Based on the impacts of existing communications cables, it seems unlikely that the additional sensors would significantly increase the impact. This technology will create significant environmental co-benefits by contributing to knowledge and understanding of deep oceans and its biodiversity.
Combined score	12 High certainty	Smart undersea cables have a significant potential for adaptation to climate change, they are almost ready for deployment and they could provide more accurate and difficult to access data than other technologies at comparable costs, with minimal foreseeable negative environmental and social impacts and positive environmental co-benefits.

Gravity storage

Gravity storage has been suggested as an efficient, cost-effective, low-impact means of increasing available energy storage and facilitating scaling up of renewable energy. The most established form of gravity storage, pumped hydro storage (PHS), is a mature technology, and currently makes up 98% of global energy storage (Mongird *et al.*, 2019). It functions by pumping water from a lower reservoir to a higher one using excess energy during times of high supply or low demand, and then releasing the water to power a turbine and generate energy when it is needed.

New innovations in gravity storage take different forms intended to be more convenient, cheaper, or more environmentally friendly than conventional PHS. Underground pumped hydro storage (UPHS) systems are based on the same principle as PHS, but locate one or both reservoirs underground. To avoid the cost and impacts of excavation, UPHS can take advantage of existing infrastructure, such as abandoned mine shafts. UPHS projects have been proposed in deep gold mines in South Africa, old slate mines in Belgium and closed coal mines in Spain and Germany (Menéndez, Fernández-Oro and Loredo, 2020). Other proposed gravity storage systems use heavy weights or pistons in underground shafts, which can be suspended by cables (dry gravity storage) or float in water (hydraulic gravity storage) (Botha and Kamper, 2019).

Factor	Score	Comments
	5 High certainty	Energy storage will be essential to scaling up renewable energy generation by capturing excess power, smoothing out fluctuations in energy supply and respond to peaks in demand. Gravity storage alone will not be enough to meet the green economy demands, but there is significant evidence that this technology can play a role in reducing use of fossil fuels in energy production at the level of the grid. It could also support adaptation by increasing resilience of the electric grid in case of extreme weather events.
	4 High certainty	PHS is a relatively efficient storage option (70-85%) with a short response time, long lifetime and low operation and maintenance costs. It requires a high upfront investment, but it has a very low lifetime cost per unit of electricity compared to other options.
	4 Moderate certainty	New types of PHS have minimal environmental and social impact, particularly compared to impacts of alternatives, like lithium-ion batteries. Modern PHS systems use a closed loop minimizing direct impact on aquatic ecology. UPHS may have even a lower impact if they repurpose existing excavations.
Combined score	13 High certainty	Gravity storage has transformative potential in terms of climate change mitigation. The technology has been tested and is ready for deployment at costs lower than existing alternatives. Environmental and social impacts are significantly lower than alternatives.

Summary

Each of the infrastructure technologies assessed in this report has a potential role in climate change mitigation and adaptation. It is difficult to directly compare them because they are designed to serve different purposes and achieve different goals. Where hybrid resilience and smart cables can be seen as an important and beneficial modifications of existing infrastructure, multipurpose platforms and floating cities are ambitious new technologies that may or may not serve a purpose in a climate change world.

Different technologies can work together. Multipurpose floating platforms can be designed to incorporate hybrid elements of grey and green infrastructure, and can be integrated in a grid with gravity storage options to maximize efficient use of wind or solar energy output.

Investment in research and technological innovation would be helpful for each of the five technologies. For those that are ready to deploy, like hybrid resilience, additional research can help build the case for adoption. For gravity storage and smart cables, research and testing is needed to enable deployment in the short term. For floating cities and multipurpose platforms additional investment could bring these ideas into the world of reality and ensure that they are sustainable and effective.

				Combined scores
Floating cities	4 Low certainty	2 Moderate certainty	3 Low certainty	**9** **Low certainty**
Multipurpose platforms	3 Moderate certainty	3 Low certainty	3 Moderate certainty	**9** **Moderate certainty**
Hybrid resilience	4 Moderate certainty	5 Moderate certainty	4 Moderate certainty	**13** **Moderate certainty**
Smart cables	4 High certainty	4 High certainty	4 High certainty	**12** **High certainty**
Gravity storage	5 High certainty	4 High certainty	4 Moderate certainty	**13** **High certainty**

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