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Sustainable Infrastructure

Principles into Practice

Second edition

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Chapter 1
The sustainability challenges for infrastructure

1.1. Characteristics of infrastructure

Infrastructure assets, such as roads, bridges, railways, power plants, residential and commercial buildings, pipelines, and water and energy utilities, have several things in common. They are specific to the geographic location within which they must operate and represent capital goods that are typically long lasting (sometimes for centuries). Transportation, power and water systems rely on complex networks to deliver their functions and can benefit from economies of scale. Other types of infrastructure – such as flood protection systems – have the characteristics of public goods, because it is hard to exclude people from benefiting from the protection they provide and the benefit received by one person does not detract from the benefit received by others. Infrastructure systems also minimise human impact on the environment through wastewater treatment and waste collection, recovery and disposal systems that enable people to live in cities.

These physical assets provide the basic services and interlocking components that allow modern communities and global society to function. They are regarded as being desirable by society, but would be under-produced in a free market, and this requires some form of public intervention to provide for the needs of all (Thacker *et al.*, 2019). However, while these services underpin our economies and meet our human needs, engineers have often achieved them using unsustainable practices that have contributed to climate change, loss of biodiversity, resource depletion, social upheaval and distress. The construction and operation of buildings, transportation and power generation infrastructure account for approximately 70% of global greenhouse gas (GHG) emissions (Saha, 2018) and cause direct and indirect losses of biodiversity and ecosystem services (Brondízio *et al.*, 2019). The construction industry is the largest consumer of raw materials derived from natural resources (Luangcharoenrat *et al.*, 2019) and creates very significant amounts of waste. For example, 63% (120 million tonnes) of the total waste stream in England (189 million tonnes) in 2016 was attributed to construction, demolition and excavation waste (GCB, 2020). The industry also displaces people and can expose people to hazardous working conditions.

Poorly planned infrastructure can often prevent marginalised groups from gaining access to and benefiting from the services it is intended to provide. A common characteristic of large-scale infrastructure projects is their linear nature, which can cause impacts to people that don't receive any benefit and can lead to the displacement and fragmentation of whole communities. They also take many years to develop.

The design life of infrastructure assets is often measured in decades and sometimes centuries, therefore tending to lock in any impacts – both positive and negative – over the longer term (UNEP, 2021). Decisions and actions taken now will influence the future for years to come. The longevity of engineered systems means that there is a danger that engineers create path dependencies for problems that are, by their nature, dynamic and therefore deliver outcomes that cease

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without access to electricity fell from 1.2 billion globally in 2010 to 759 million in 2019, the unfortunate fact is that gains in energy access are being reversed in the wake of the Covid-19 pandemic (IEA *et al.*, 2021). Unless efforts are stepped up significantly, an estimated 660 million people will remain without access to electricity in 2030 and 2.4 billion people will be left with no access to clean cooking solutions (IEA *et al.*, 2021).

Not all the SDGs will be met at the same rate, either globally or across geographic regions, with the emphasis up to 2030 being on catching up, bringing services where none existed before. Success has been hampered by the Covid-19 pandemic, which not only stopped work towards some of these goals but also shifted the immediate focus of national agencies such as the UN and World Health Organization towards dealing with the threats of the coronavirus – a legacy that is likely to last for some time. It is looking as if the ability to deliver the SDGs has been severely compromised, such that many may not be achieved by 2030. Unfortunately, as new inequalities and imbalances emerge between regions, successfully completing the SDG agenda may be set back indefinitely. Nevertheless, the SDGs provide a useful internationally accepted framework to guide future engineering actions and test the efficacy of infrastructure provision. In other words, they provide a mandate for integrated infrastructure planning to ensure long-term sustainable development.

1.4.2 Engaging with the SDGs

Familiar building rating tools such as BREEAM (see Section 12.3) have been mapped onto the 17 SDGs, with the Building Research Establishment showing how each of the goals is supported in a detailed infographic [UR 8]. This shows how assessment tools such as BREEAM and CEEQUAL (see Chapter 12) enable significant contributions to the infrastructure-related goals identified above, together with SDG 3 (Good health and wellbeing) SDG 13 (Climate action) and SDG 15 (Life on land).

Once priority goals and targets have been identified for each project, progress can be monitored using some of the 300 or so different indicators (or metrics) that measure progress on the 169 SDG targets [UR 9]. The UN Global Compact and the World Business Council for Sustainable Development have jointly created *The SDG Compass* [UR 10] to help organisations select relevant indicators for measuring progress against the SDGs.

Ignoring the wide-ranging issues raised in the SDGs will lead to badly planned infrastructure, which can have harmful impacts on people's health (SDG 3: Good health and wellbeing) through air pollution, soil and water contamination and disease transmission, as well as impacting on terrestrial and aquatic ecosystems (SDG 14: Life below water and SDG 15: Life on land). In addition, the allocation, design of and access to infrastructure can impede SDG 5 (Gender equality) and more broadly limit SDG 10 (Reduced inequalities) (Thacker *et al.*, 2019).

In responding to the need for engineers to do more in addressing the SDGs, ICE launched a plan for the engineering community to engage better with the SDGs (ICE, 2019) [UR 11]. This plan was intended to harness the engineering community to accelerate delivery of the SDGs and help to bring about the necessary transformations needed to deliver sustainable infrastructure, with a focus on

- measuring, monitoring and reporting to help embed the delivery of the SDGs into everyday engineering practice and recommending suitable indicators of progress

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Chapter 2
Five ways for engineers to respond

2.1. Interlinking scales – from global issues to project-level actions

It is clear from the challenges set out in Chapter 1 that there are both environmental and socio-economic aspects of sustainability. All people have the right to social and economic development, to have an acceptable quality of life and, in meeting SDG 1, finding a way out of poverty. A good measure for this is the UN's Human Development Index (HDI), which combines information on health and education (society) and GDP/capita (economy) performance into a single score out of 1000. This applies country by country, but is also a regional and local issue. A good measure for assessing the environmental pressures we create is our 'ecological footprint', which is a standardised measure of the demand for natural capital, expressed as an equivalent land area per person, expressed in 'global hectares'. It represents the amount of biologically productive land and sea area necessary to supply the resources consumed by the human population and to assimilate their associated waste.

Figure 2.1 shows the combined assessment of many countries against their HDI and ecological footprint, and the scale of the improvements needed, for the world to achieve sustainable development. The sustainable 'target' for all countries is the box in the lower right-hand corner (the global sustainable development quadrant). The poorest countries (on the lower left) need quality of life improvements of up to 250% to get to the target HDI of 0.8 without increasing their ecological footprint beyond 1.6 global hectares per person. The most developed and environmentally damaging countries (on the upper right) need 'eco-efficiency' improvements of up to 80% without unacceptable losses in their HDI in order to reduce their ecological footprints to the global average capacity of 1.6 global hectares per person. Perhaps the most striking feature of this diagram is that since a similar diagram was published in the first edition of this book in 2014, there has been movement *away* from the global sustainable development quadrant and not towards it, with no countries now shown as being inside or on the boundary of the quadrant. This is a worrying trend and the global backdrop to the sustainability challenges set out in Chapter 1.

These issues can appear so overwhelming and distant it can be hard to see how actions can be taken at the scale of a small everyday engineering project. However, some of the questions that can be asked and the approaches that can be dealt with are addressed in this chapter. Small incremental choices and decisions will make a difference. Everyone can play their part.

Development is frequently interlinked at different spatial and temporal scales. For example, impacts from construction activities rarely stop at the site boundary. The impacts created by some of the materials and resources used can be felt in distant parts of the world. Similarly, engineering decisions taken now should not restrict future living standards or options available to future generations. Choices of solutions and project specifications made today against uncertain knowledge about the future may create a technical lock-in, restricting the ability to move to other options as circumstances change over time.

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Table 11.1 How the tools described relate to the absolute principles

Tool	A1: Respect planetary limits (environmental sustainability)	A2: Improve human wellbeing (socio-economic sustainability)	A3: Regard the future (intergenerational stewardship)	A4: Understand system interactions (complexity)
Chapter 11 Methods for sustainability practice				
System dynamics and systems thinking				✓
LCA	✓		✓	
Carbon management in infrastructure (PAS 2080)	✓		✓	
Measuring infrastructure resilience	✓			✓
Backcasting, forecasting and scenario planning			✓	
Multi-criteria decision-making		✓		✓
Measuring natural capital and valuing green infrastructure	✓	✓		
Adaptive management and adaptation pathways			✓	✓
Measuring social value in infrastructure		✓		
Chapter 12 Established procedures				
Environmental impact assessment and strategic environmental assessment	✓		✓	
Environmental management systems	✓	✓		
Building rating systems and civil engineering awards schemes	✓	✓		✓
Corporate social responsibility and sustainability reporting		✓		
Whole-life cost accounting	✓	✓	✓	

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Systems dynamics was first developed in the 1950s by Jay Forrester, who believed that the biggest impediment to progress comes not from the engineering side of industrial problems but from the management side. Forrester reasoned that social systems are much harder to understand and control than physical systems, and this is at the heart of our approach to delivering infrastructure,

Specifically with regard to criticisms of the AHP, some have pointed to possible flaws in the verbal (versus numerical) scale often used in AHP pairwise comparisons. It is also possible that innocuous changes to an AHP model can introduce order where, in reality, no order exists. Also, if criteria are added whereby all the alternatives perform equally against them, the final priority order can be affected. In some circumstances, the AHP has been found to be unsuitable for complex problems and, in certain situations, even for small problems. If new alternatives are added to the analysis, this can lead to a rank reversal of the final result because of the rebalancing that ensues. The AHP can also produce rank order reversal when eliminating irrelevant data (i.e. data that does not differentiate alternatives). It is an axiom of some decision theories that when new alternatives are added to a decision problem, the ranking of the old alternatives must not change – such that rank reversal must not occur.

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11.7. Measuring natural capital and valuing green infrastructure

11.7.1 Summary

Recognising the additional services provided by some types of infrastructure can change the balance in asset investment decision-making if their wider non-use services can be valued. Similarly, understanding the value of natural environments that may be lost as a result of constructing new infrastructure can also radically change how such projects are viewed. Therefore, the case for assessing ecosystem services, and then valuing them, is that this contributes towards better decision-making on infrastructure projects by ensuring that policy and project appraisals fully take into account the costs and benefits to the natural environment. Otherwise, projects may actually generate wider benefits, and/or cause environmental losses, that go unmeasured. Taking both into account can radically affect the project 'balance sheet' and change decision-making.

Ecosystems such as wetlands, forests or estuaries can be characterised by the physical, chemical and biological processes that occur within them. These ecosystem functions can provide services such as the provision of wildlife habitat, carbon sequestration and water and nutrient recycling, as well as maintaining wilderness qualities and natural landscape features, which have high amenity value and are valued in many recreational pursuits. These functions can be considered to deliver

- *provisioning services*, which produce products such as food, materials, biochemicals and genetic resources from ecosystems
- *regulating services*, such as air quality maintenance, climate and water regulation, erosion control, protection from natural hazards such as storms and floods, and removal of pollutants from waste

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