Investing in Climate, Investing in Growth
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Chapter 3

Infrastructure for climate and growth

Infrastructure investment is vital to underpin economic growth and development, but current levels of investment are inadequate. Meeting the Paris Agreement's mitigation and adaptation objectives will also require a radical shift in the world's infrastructure base. This chapter considers the current gap in infrastructure investment, the infrastructure and technology transformations needed to shift onto low-emission, climate-resilient pathways, and the incremental capital costs involved. It then looks at the energy sector as an indicative assessment of progress in aligning infrastructure investment plans for the transition, before exploring how governments might better align short-term investment strategies with long-term decarbonisation and resilience goals.

Choices made today about the types, features and location of infrastructure will heavily influence the extent of the impacts of climate change and the vulnerability or resilience of societies to it. Creating low-emission, climate-resilient pathways compatible with the Paris Agreement, as described in Chapter 2, requires a radical shift in our infrastructure bases, mainly for energy, mobility services and buildings. Sustainable infrastructure – infrastructure that is socially, economically and environmentally sound – is a key foundation for economic activity and for reaching the Sustainable Development Goals (SDGs). Since the financial crisis, however, infrastructure of all kinds has suffered from chronic underinvestment.

The first section of this chapter documents the current gap in infrastructure investment required to sustain growth and development. The inconsistencies between current investment trends and climate goals, and the infrastructure investment and technology transformations needed to shift G20 governments onto low-emission, climate-resilient pathways are then addressed. The chapter then focuses on the energy sector as an indicative assessment of progress in aligning infrastructure investment plans for the transition, highlighting the risks of locking in emissions and stranding assets that come with continued investment in fossil-fuel infrastructure. Finally, the chapter concludes with guidance to G20 countries on how they could better align short-term investment strategies with long-term, low-emission decarbonisation goals, and the need to enhance resilience to climate impacts.

Scaling up infrastructure investment to sustain growth and development

Infrastructure in sectors such as energy, transport, water and telecommunications is the backbone of our economies, essential for sustained, inclusive growth and for meeting the SDGs. But current levels of investment in infrastructure are generally too low to sustain growth, and often of insufficient quality. Ensuring affordable and reliable access to basic services remains a major challenge in lower and middle-income countries, while advanced economies are struggling with chronic underinvestment in their ageing infrastructure. Infrastructure investment in the G20 countries needs to be significantly scaled up to fill this gap.

Current levels of infrastructure investment are insufficient to sustain growth and development

Effective energy and transport infrastructure underpins almost all economic activity. Many studies have underscored the positive relationship between high-quality public infrastructure and economy-wide productivity in the long run (e.g. Berg et al., 2012; Ghazanchyan and Stotsky, 2013; Calderon and Serven, 2014). Infrastructure investment is also a way of stimulating demand in the short term: after the financial crisis, many G20 countries devoted a major share of their fiscal stimulus to infrastructure investment (see Chapter 4). On average, emerging and developing economies devoted 40% of their stimulus packages to infrastructure spending, while advanced economies devoted 21% (ILO and IILS, 2011).

Infrastructure investment can also have an impact on promoting inclusive development and fighting income inequality. Inclusive growth, human well-being and poverty reduction depend critically on the type, extent and quality of the infrastructure that supports key services: food, energy, water supply, safe and resilient cities, and sustainable industrialisation (Bhattacharya et al., 2016a). For example, SDG7 (*"Ensure access to affordable, reliable, sustainable and modern energy for all"*) requires considerable investment in energy infrastructure in urban and rural areas. Investments in sustainable infrastructure can boost growth and employment and contribute to *"promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" (SDG8)*. Transport infrastructure – such as roads, railways, ports and airports – connects home to work, and rural areas to domestic and regional markets, contributing to economic development and the goal of "*ending poverty in all its forms everywhere*" (SDG 1). Infrastructure choices also affect our natural environment and the sustainable use of natural assets such as air, water, terrestrial ecosystems and forests (SDGs 13, 14 and 15).

Despite the links between infrastructure investment and growth and development, underinvestment in infrastructure has been chronic over the past decades. The stock of public capital relative to GDP decreased by 15% globally in the past 30 years (Bhattacharya et al., 2016b; IMF, 2014). Over the past two decades, global infrastructure investment has averaged 3.5% of world GDP (Woetzel et al., 2016).

In advanced G20 economies, public investment fell from 5% of GDP in the late 1960s to 3% in the mid-2000s. Despite increased infrastructure investment following the recent financial crisis, spending remains at a historic low, resulting in an ageing and poorly maintained infrastructure stock in many G20 countries. In the United States, for instance, the National Association of Manufacturers rates transport-related land-based infrastructure as mediocre to poor, with US bridges on average 42 years old, and 1 in 9 structurally deficient. In addition, 65% of roads in 2013 were in "less than good condition", a significant factor in 30% of road fatalities (National Economic Council and the President's Council of Economic Advisers, 2014).

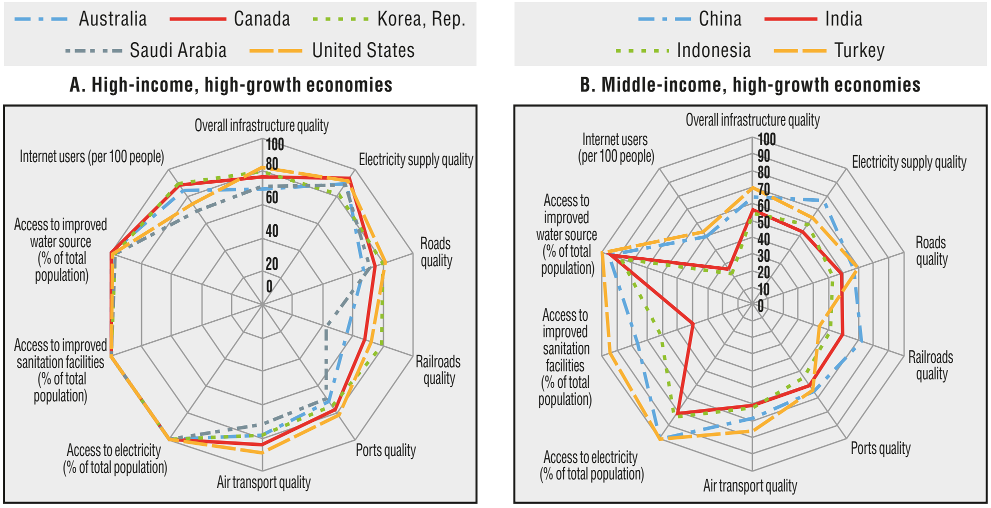
In emerging and low-income economies, public investment fell from 8% of GDP in the late 1970s to 4-5% in the mid-2000s, rising again to 6-7% in 2012. This increase has been led by China, which in 2014 accounted for USD 1.3 trillion of the USD 2.2 trillion invested in infrastructure in developing and emerging economies. This is not only more than all other developing countries, but also more than all developed countries combined (Bhattacharya et al., 2016b).

The quality of infrastructure is critical for development. Many middle-income economies – such as Brazil, India, Russia and South Africa – are left with infrastructure bases of low quality, which constrains medium- and near-term growth. In South Africa, for instance, only 46% of households had piped water of good quality in 2012 and only 71% of households had access to sewerage networks. One-fifth of South African firms identified unreliable electricity supply as a major constraint to doing business (Development Bank of Southern Africa, 2012). Even in China, despite sustained investment in the past decades, the quality of urban infrastructure is not always adapted to the challenges faced by rapidly growing cities (Pan, 2016). Some suggest that China has in fact overinvested in infrastructure and highlight a need to reallocate investments towards more productive infrastructure (Ansar et al., 2016).

Unprecedented levels of infrastructure investment are needed to *i)* maintain and upgrade ageing infrastructure in high-income countries; and *ii)* achieve universal access to basic services in middle-income economies. G20 countries face different priorities in improving infrastructure quality and access (Figure 3.1). Rapid rates of urbanisation and population growth require an expansion of transport and electricity infrastructure, especially in developing countries. By 2050, the global population is expected to increase to 9 billion people, 66% of which will be urban, compared with 54% in 2014. Demand for urban mobility is expected to nearly double between now and 2050, with most of this growth concentrated in developing countries (OECD/ITF, 2017). One in 8 people still live in extreme poverty, nearly 800 million suffer from hunger, 1.1 billion live without electricity, and water scarcity affects more than 2 billion (UN, 2016). Countries that are caught in a low-growth trap could use this opportunity to boost their growth in the short-term, capitalising on the current environment of low interest rates, or optimise the taxation-spending balance to increase infrastructure spending (see Chapter 4).

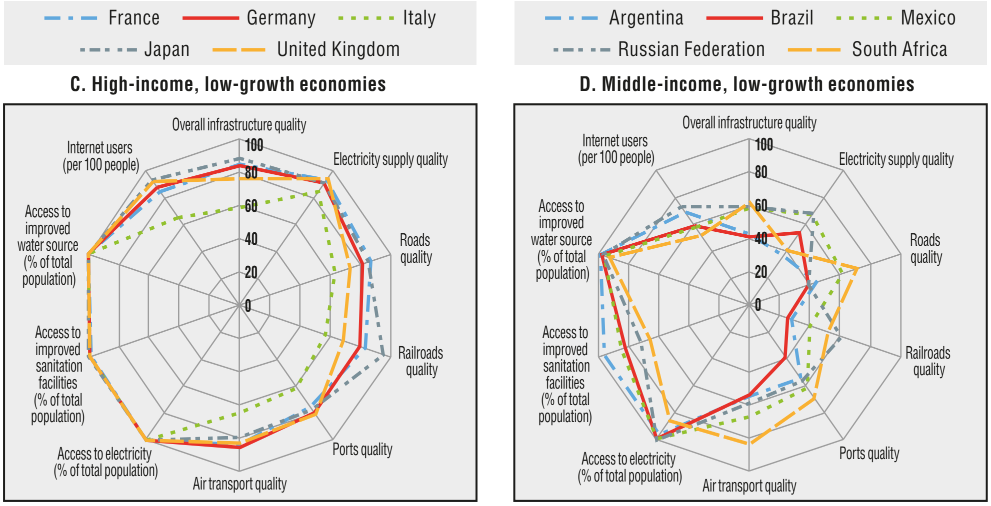
The importance of infrastructure quality for sustainable growth and well-being can be seen by looking at both access to basic services and at a measure of the quality of the underlying infrastructure (Figure 3.1). For example, while many high-income and middle-income countries boast near-universal access to electricity, in many cases the quality of electricity supply is mediocre, with important consequences for both economic activity and well-being.

Figure 3.1. **Quality of infrastructure and access to basic services in G20 countries, by income and growth groups**



A. High-income, high-growth economies

B. Middle-income, high-growth economies



C. High-income, low-growth economies

D. Middle-income, low-growth economies

Note: The growth groups are based on the 2010-15 average of GDP growth, population growth and gross capital formation as a share of GDP.

Source: Authors, based on WEF (2015) and World Bank (n.d.a.) (accessed on 28 February 2017).

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The infrastructure investment gap

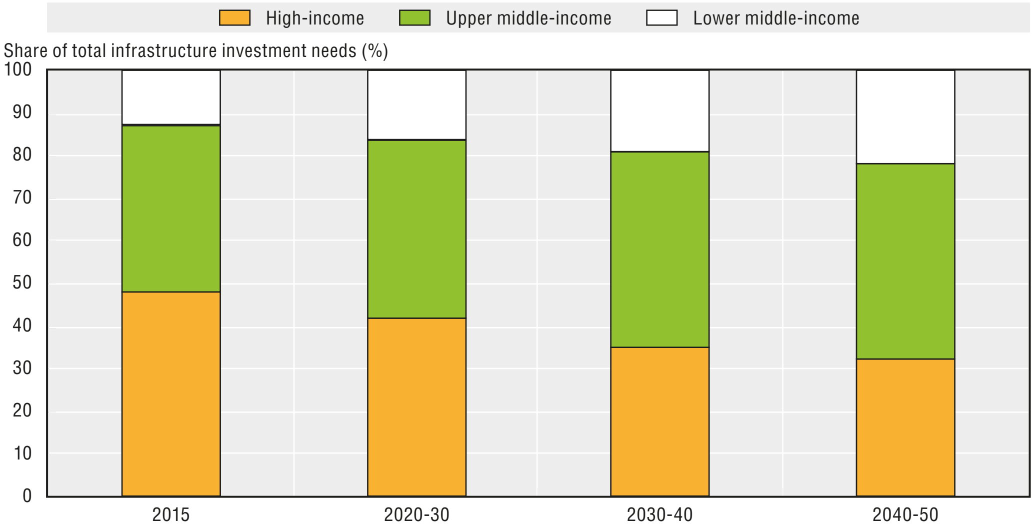
The OECD estimates that around USD 95 trillion of investments will be needed between 2016 and 2030 in energy, transport, water and telecommunications infrastructure to sustain growth, or around USD 6.3 trillion per year, even if governments take no further action on climate change (Table 3.1). This number is to be compared with current infrastructure spending of around USD 3.4 to USD 4.4 trillion (IEA, 2017; IEA, 2016b; Woetzel et al., 2016; Bhattacharya et al., 2016b). Middle-income countries are expected to represent around 60% to 70% of future infrastructure needs (Pardee Centre, n.d; NCE, 2016; Bhattacharya et al., 2016b) (Figure 3.2). The majority of infrastructure investments are required in transport and power, two critical sectors that are also at the heart of decarbonisation strategies (Figure 3.3). However, all infrastructure estimates need to be read with caution (Box 3.1).

Table 3.1. **Global estimates of infrastructure investment needs 2016-30, by sector (before taking into account climate considerations)**

USD 2015 trillion		**Annual average**	**Cumulative**
Energy supply	Power and Transmission & Distribution (T&D)	0.7	11.2
	Fossil fuel supply chain	1.0	14.3
Energy demand		0.4	6.6
Transport infrastructure	Road	2.1	31.8
	Rail	0.4	6.4
	Airports and ports	0.2	2.7
Water and sanitation		0.9	13.6
Telecoms		0.6	8.3
TOTAL		**6.3**	**94.9**

Sources: IEA (2017) for energy supply and demand; IEA (2016d) for road and rail infrastructure; OECD (2012) for airports and ports; McKinsey (Woetzel et al., 2016) for telecoms. The water and sanitation estimate is an average of estimates from: Booz Allen Hamilton (2007), McKinsey (Woetzel et al., 2016) and OECD (2006). See technical note on estimating infrastructure investment needs for further details on methodology (http://oe.cd/g20climatereport).

Figure 3.2. **Evolution of infrastructure investment needs by income groups in the G20**



Source: Pardee Center (n.d. accessed February 2017).

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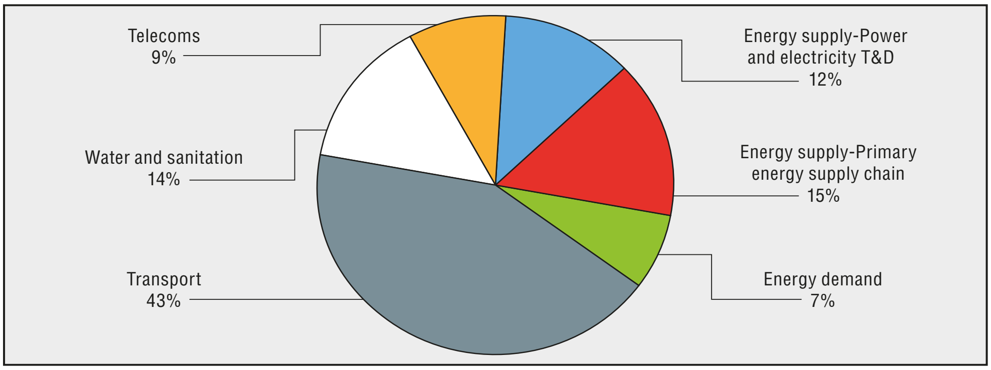
Figure 3.3. **Global investment needs by sector, 2016-30**



Source: As per Table 3.1.

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Box 3.1. **The challenges of estimating infrastructure investment needs**[1]

There have been several attempts to provide estimates on infrastructure investment needs (WEF, 2013; NCE, 2014; Bhattacharya et al., 2016; Woetzel et al., 2016; Kennedy and Corfee, 2012). Each projection is highly uncertain as it combines several distinct sources, each with different underlying assumptions:

- Projections attempt to take as a starting point existing infrastructure investment, but there is a lack of comprehensive data on investments across countries, including G20 countries (AsDB, 2017, Bhattacharya et al., 2016b). There is a need for national and international agencies to gather more comprehensive, better quality data on infrastructure investment.
- Most infrastructure needs assessments are based on projected GDP growth and country-level elasticity of infrastructure spending to growth (Woetzel et al., 2016; NCE, 2016), which results in estimates that are highly dependent on GDP assumptions. Few studies are based on achieving minimum quantitative benchmarks for infrastructure stocks and services (such as those used by Pardee Center, 2014), which is more relevant in particular for low-income countries and in the context of the SDGs.
- Most infrastructure assessments are based on global models, but infrastructure needs and priorities depend on countries' specific circumstances – such as access to energy, quality of current infrastructure, growth rate and inequalities – and should be informed by country-specific long-term development strategies.
- Many assessments do not account for how infrastructure is managed and implemented. Some analysts suggest that better management of infrastructure could lower infrastructure investment needs (Woetzel et al., 2016).
- Many assessments do not integrate incremental investment needs for climate change adaptation and mitigation. When they do, they do not necessarily take a network approach, to account for the interdependency between infrastructure systems. For instance, decreased demand for energy reduces the capital requirements for new infrastructure in oil, gas and coal, potentially freeing up rail and port capacity (Kennedy and Corfee-Morlot, 2012).

The figures presented here offer an up-to-date estimate based on the sources listed in Table 3.1. The new estimate in this report is around USD 4.9 trillion per year for energy, transport, water and telecommunications infrastructure, reflecting a recent reevaluation of investment needed in transport (IEA, 2016d). This estimate is of a similar order of magnitude

Box 3.1. **The challenges of estimating infrastructure investment needs**[1] *(cont.)*

to figures presented in other analyses. The New Climate Economy (NCE) (2014) estimated that the world needed to invest USD 57 trillion (USD 3.8 billion per year) in infrastructure between 2014 and 2030, or around USD 96 trillion (USD 89 trillion in 2010 dollars) including primary energy generation and energy efficiency. More recent estimates by Bhattacharya et al. (2016b) anticipate larger needs: USD 75-86 trillion (or USD 5.4 trillion a year), excluding primary energy and energy efficiency – USD 1.6 trillion more per year than the NCE.[2] McKinsey (Woetzel et al., 2016) estimates cumulative needs of USD 49 trillion (or USD 3.3 trillion per year) for the period 2016-30 (Table 3.2). The Pardee Center (2014) estimates that annual spending in infrastructure will be on average USD 4.3 trillion per year between 2014 and 2050.

Table 3.2. Selected estimates of infrastructure investment needs, 2016-30 – annual averages in 2015 USD trillion per sector

	Energy supply					
	Power and T&D	Primary energy use supply chain	Energy demand/ efficiency	Transport	Water and sanitation	Telecoms
OECD (2017)	0.7	1.0	0.4	2.7	0.9	0.6
Bhattacharya et al. (2016b)	1.5	0.8	1.6	2.0	0.9	1.0
McKinsey (Woetzel et al., 2016)	1.0	not included	not included	1.2	0.5	0.6
NCE (2014)	0.7	0.9	1.7	1.0	1.5	0.5

Note: See technical note on estimating infrastructure investment needs for further details (http://oe.cd/g20climatereport).

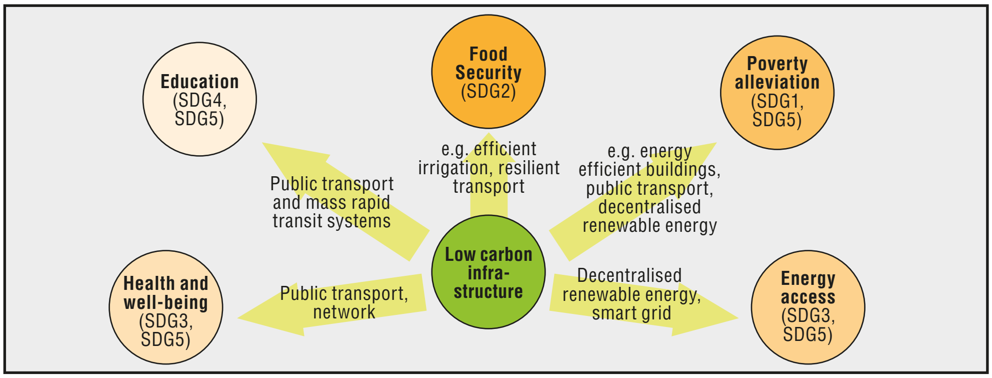
Sources: NCE, 2014; 2016; Bhattacharya et al., 2016b; Pardee Center, 2014; Woetzel et al., 2016.

Shifting infrastructure investment for low-emission, climate-resilient pathways

Low-emission, climate-resilient pathways will require an unprecedented transformation of our infrastructure system. Most existing energy and transport infrastructure was designed and built for a world of cheap and abundant fossil fuels, contributing to economic growth in many regions but also to GHG emissions. As a result, around 60% of GHG emissions are hard-wired into existing infrastructure (NCE, 2016; IPCC, 2014). In an effort to keep average global warming well below 2°C, the Paris Agreement stipulates that a "balance" between anthropogenic sources and sinks of GHGs must be reached by 2050-2100, so that there are zero net emissions to the atmosphere in the second half of the century (see Chapter 2). In many cases, it will be important to shift as much investment as possible towards zero-emission (rather than low-emission) options, given that some difficult-to-decarbonise sectors will still have residual emissions.

In addition to being responsible for more than 80% of energy-related CO_2 emissions (IEA, 2016a), G20 countries represent around two-thirds of global investment needs in infrastructure. This share is expected to raise to 75% of infrastructure needs between 2016 and 2030 (Pardee Center, n.d.). G20 country choices are critical to the world's ability to mitigate climate change and will also dictate the resilience of G20 infrastucture to climate change impacts. The infrastructure required for the low-emission transition is also integral to meeting many of the SDGs beyond SDG13 on climate change (Figure 3.4).

Figure 3.4. **The links between low-carbon, climate-resilient infrastructure and the SDGs**



Infrastructure and technology shifts for low-emission pathways

Achieving low-emission, climate-resilient pathways requires strategies spanning infrastructure, technology development and innovation in the energy, land-use and agriculture sectors. This section examines the implications for infrastructure and technology of the shift to zero net emissions across these different categories (Table 3.3).

Table 3.3. **Examples of infrastructure and technologies needed for a low-emission transition**

	Strategies	Infrastructure needs		Technologies
Transport	Improve carbon intensity of vehicles Shift to more efficient transport modes Avoid carbon intensive mobility when possible	Passenger	Charging infrastructure for electric cars and fueling infrastructure for hydrogen cars Intelligent Transport Systems Smart grids Rail Mass rapid transit systems (light rail, metro, bus rapid transit lanes) Infrastructure for walking, cycling	Electric cars Advanced biofuels and biojet (algae) for air and maritime transport Hydrogen aircrafts Batteries
		Freight	Hinterland rail infrastructure	Electrification of trucks Advanced biofuels, hydrogen for shipping Investment in agriculture research (yields)
Energy	Decarbonise the power sector Electrification of end-uses Energy efficiency	Energy and power generation	Renewable energy (wind, solar, thermal energy, tidal, waves) Smart grids Infrastructure for CO_2 transport and storage	Energy storage (thermal cycle, power to gas, batteries) Tidal, thermal energy CCS (large-scale demonstration)
		Buildings	Retrofitting of the building stock Energy-efficient new build Heat supply	Zero energy or positive energy buildings Alternative material for steel and cement
Heavy industries	Energy efficiency in industrial processes Material efficiency Capture of emissions		Energy efficiency in industrial processes Infrastructure for CO2 transport and storage	CCS (large-scale demonstration of industrial CCS applications) Hydrogen in steel making
Land use	Improve carbon sequestration by land Minimise emissions from food production, including livestocks	Negative emissions	Infrastructure for CO_2 transport and storage	CCS Direct air capture and storage BECCS (deployment at commercial scale) Biochar Ocean liming
		Agriculture	Restoration of degraded grassland	Research on yields improvements Innovative agricultural practices to improve productivity

Source: Authors.

Infrastructure for low-emission energy and transport systems

Energy production and use accounts for around two-thirds of all anthropogenic GHG emissions, mostly in the form of CO_2 from the combustion of fossil fuels (IEA, 2017). Creating low-emission pathways requires radical changes in infrastructure, not only to reduce the carbon intensity of energy supply, but also to create less energy-intensive behaviours and to reduce energy use in transport, buildings and industry. The main elements of infrastructure-related changes needed to reshape energy supply and use are described here, with the main technological breakthroughs needed covered in Box 3.2.

Key to the energy transition is the decarbonisation of electricity, including phasing out inefficient coal-fired power plants and unabated coal, the widespread deployment of renewable energy sources, further development of nuclear power according to country choices, and potentially the development of negative emissions technologies (NETs) such as bio-energy with carbon capture and storage (BECCS) (IEA, 2017). Significant investments in smart grids will be needed to help manage demand and support increased penetration of intermittent renewable energy. On the demand side, reducing energy use in transport and buildings will be key.

Transport produces roughly 23% of global CO_2 emissions and is the fastest-growing source globally. Without further policy action, CO_2 emissions from transport could double by 2050 (OECD/ITF, 2017). Reducing emissions from transport is not only crucial for a low-carbon transition: it also reduces air pollution and congestion. The strategies necessary will depend on each country's circumstances, for example to what extent cities have already been developed around car ownership, and where opportunities exist to use urban planning to reduce the need for personal vehicles (OECD, 2015a). In general, ambitions will only be fulfilled with integrated policy action to:

- *avoid* unnecessary travel and reduce the demand for total motorised transport activity;
- promote the *shift* to low-emission and even zero transport modes; and
- *improve* the carbon intensity and energy efficiency of fuels and vehicle technologies. Significant advances have been made recently, notably in the electrification of transport via battery and fuel cells vehicles that are now on the market.

Building sector energy use was responsible for 9% of CO_2 emissions in 2013 in G20 countries. Increasing energy efficiency in buildings has not been sufficient to offset large increases in energy demand driven by the growth in population, energy-intensive appliances, and heating and cooling of buildings (IEA, 2016c). This is despite the availability of technologies that could lead to widespread decarbonisation of buildings through immediate widespread uptake. In developing and emerging economies, the building sector tends to be dominated by new construction and demolition of older buildings as cities expand. Integrating energy efficiency principles early in construction is therefore more important than retrofitting existing buildings. In mature economies, 75-90% of today's buildings will most likely still be in service by 2050. Many of these buildings are not built to the standards of today's energy efficiency codes and do not benefit from the latest energy-saving technologies; as a result, 30% of current buildings will need to be retrofitted by 2030 (IEA, 2017). Energy demand and efficiency of the appliances contained in buildings also has a major impact (Climate Policy Initiative, 2013). Managing policy decisions in tandem with investment decisions on heating, cooling, and power transmission and distribution infrastructure could enable additional cost reductions.

Box 3.2. Which technological innovations are needed for a low-carbon economy?

Many of the technologies needed to decarbonise the economy are known and available at a commercial scale, even though ongoing R&D will likely see further cost reductions: electric vehicles, renewable electricity generation and advanced building insulation techniques are all examples. However, to achieve pathways consistent with the Paris goals, many new technological breakthroughs will be required. Twenty-one technological innovation priorities were identified for this project that are crucial to achieving a low-carbon economy but have not yet been deployed at commercial scale and therefore still require significant R&D. Some key examples are described here.

Carbon capture and storage (CCS)

Current scenario projections rely heavily on CCS to meet emission targets. In the IEA scenario consistent with a 66% chance of reaching the Paris Agreement's 2°C goal, CCS contributes around 15% of emissions reductions by 2050 (IEA, 2017). In industry, it accounts for one-fourth of cumulative CO_2 emissions savings by 2050 relative to the New Policies Scenario. Furthermore, negative emissions technologies (NETs) such as bioenergy with CCS (BECCS) would benefit from the advancement of conventional CCS. While the components of carbon capture, transport, injection and storage have been demonstrated individually at commercial scale (Florin and Fennell, 2010), large-scale demonstration is an urgent priority to overcome the challenges of whole systems integration across the CCS chain (LCICG, 2014). The main research priorities are: (1) developing advanced adsorption and membrane processes; (2) advanced processes such as Ca-looping; and (3) improved modelling of CO_2 storage, including optimal injection scenarios and expected leakage (IEA, 2012; UKCCSRC, 2015).

The cost of CCS for power generation is estimated at USD 43-80/tCO_2 (IEA, 2012). CCS applied to industrial processes is less well developed and is generally more challenging, but has the potential to be cheaper than CCS for power generation. Each process and site is unique and will likely require bespoke equipment and plant design. Current cost estimates are USD 15-138/tCO_2 for cement and USD 51-64/tCO_2 for steel (Fennell et al., 2012). Research priorities for industrial CCS include: (1) improving heat and flow integration; (2) testing the impact of impurities on the capture process; and (3) developing novel sorbents optimised for industrial operating conditions.

Industrial sector (energy use and process emissions)

The industrial sector accounts for one-third of global emissions. Of this, steel, cement and chemicals together make up over 70% (IEA, 2010). Energy efficiency improvements will not be able to reduce industrial emissions as needed. The other options for achieving low (or zero) emissions from industrial processes are: switching from fossil fuels to biomass or hydrogen; electrification; and CCS. With the exception of biomass usage in certain applications, all these options are still in the concept phase. There is an urgent need to develop breakthrough processes (e.g. steel production based on hydrogen or electrolysis) that could result in a step-change in emissions reductions. Development of alternative building materials to steel and cement could reduce emissions from both industry and the built environment. Alternative cement chemistries (i.e. not based on limestone) could provide a low-carbon solution for cement, but extensive testing would be required to gain wide-scale acceptance in the construction industry.

Aviation sector

CO_2 emissions from aviation amounted to 700 MtCO_2 in 2013, or around 2% of global CO_2 emissions (Elgowainy et al., 2012). With demand expected to rise by around 5% per annum, emissions could be as high as 3 100 MtCO_2 by 2050 (ATAG, 2014). In the medium term, radical new aircraft designs (e.g. the "blended wing" concept) could improve fuel efficiency by 25% compared with the most efficient planes today (DfT, 2007). In the short term, options for low (or zero)

Box 3.2. **Which technological innovations are needed for a low-carbon economy?** *(cont.)*

carbon airplanes are extremely limited. Biofuels present the most viable alternative but are limited to those that meet industry standards and are interchangeable with conventional fuels. New engine designs that can cope with the low aromatics composition of biofuels could open the aviation sector up to cheaper biofuels supply options. Hydrogen-powered planes should not be ruled out. In 2016, the first four-seater hydrogen fuel-cell powered plane took flight (Pultarova, 2016). While this is promising, significant technical challenges need to be overcome for commercial-scale hydrogen powered planes to become a reality. In particular, the low energy density of hydrogen requires a large storage volume, which will require major design modification. A starting point for hydrogen in aviation may be for use during taxiing. EasyJet is exploring this idea (Carrington, 2016).

These alternative fuels for aviation, as well as other sectors, will rely on cost-effective and scaled-up supply chains. Researching and designing new plant strains optimised for biofuel production would increase crop yield and reduce the cost of biofuel supply. Other promising avenues for investigation include cellulosic biomass, algae and halophytes (Epstein, 2014). Hydrogen supply from electrolysis, which requires a large amount of electricity, could be superseded by new technologies such as photocatalytic water splitting (Hisatomi et al., 2014; Moniz et al., 2015) or microbial processes (Magnuson et al., 2009), reducing the amount of electricity required per unit of hydrogen produced.

Negative emission technologies (NETs)

There are five main NETs: direct air capture, the lime-soda process, augmented ocean disposal, biochar and bioenergy with CCS (BECCS), the best known. Cost estimates for NETs are USD 59-155/tCO_2e (Workman et al., 2011). With the exception of BECCS, all NETs are in a very early stage of technical development. BECCS relies on a sustainable source of biomass; given competing pressures for bioenergy across different sectors, it is unlikely that BECCS alone will be adequate. The main research priorities are: (1) developing novel sorbents to reduce the energy input for direct air-capture technologies and the soda/lime process; (2) optimising the design of pyrolysis plants for biochar production (3) integrated testing of CCS with 100% biomass-firing; (4) improving liquefaction processes for artificial trees; and (5) systematic studies of biochar effectiveness, focusing on repeatability and side-effects (Gurwick et al., 2013; Workman et al., 2011).

Electricity storage

Electricity storage is required to accommodate high levels of intermittent renewable generation. Beyond 2050, scenarios limiting global warming to 2˚C have a share of generation from intermittent renewables greater than 50%. A rule of thumb is that for every GW of intermittent renewables, 1 GWh of storage is required (Budischak et al., 2013). The research priorities for electrical batteries include new cell chemistries emerging from the lithium-ion family, such as lithium-air (Grande et al., 2015) and lithium-sulphur (Fotouhi et al., 2016), or other metals such as sodium and magnesium (Erickson et al., 2015). These could improve power and charge density (Zhang, 2013), decreasing the cost per unit of energy stored. Improved manufacturing techniques and efficient management of battery packs could provide evolutionary cost and performance improvements. Capital costs of lithium-ion batteries of around USD 193-254 per kWh of storage capacity are possible (Darling et al., 2014) and new cell chemistries could offer further reductions to reach the USD 150/kWh thought to be the threshold for commercialisation of battery technologies for battery electric vehicles (Nykvist and Nilsson, 2015). Less mature electricity storage technologies, such as redox flow batteries, molten salt batteries, flywheels, and power-to-gas could also play an important role in balancing supply and demand over different timescales (from seconds to months), and different scales (distributed and centralised) (Brandon et al., 2016).

Source: Napp, T. (forthcoming).

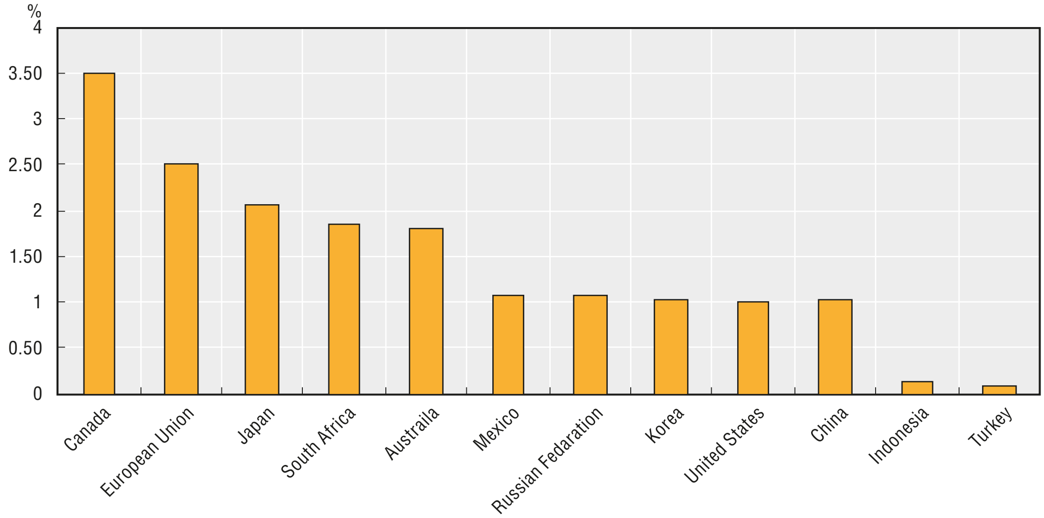
The importance of innovation in land use sectors

Chapter 2 highlighted the importance of agriculture, foresty and land use (AFOLU) for low-emission pathways, accounting for around 25% of global anthropogenic GHG emissions, mainly deforestation (9-10% of emissions) and agriculture (10-12%, mainly methane and nitrous dioxide) (IPCC, 2014). In some countries, proportions are much higher: land use and agriculture were responsible for 48% of emissions in Indonesia, 46% in Brazil, 31% in Argentina, and 27% in Australia (FAO, n.d.). By 2050, land will have to supply 60% more food than it does today to feed a growing population (Alexandratos and Bruinsma, 2012). It will have to do so in a way that does not further harm the climate. AFOLU sectors are expected to play a significant role in low-emission development pathways through carbon sequestration and sustainable approaches to managing land and livestock, and climate adaptation.

While crucial for low-emission pathways, AFOLU sectors differ from other sectors of the economy in the sense that infrastructure is not central to low-emission strategies (Box 3.3), at least in the short term. In the long term, infrastructure investments will be needed to increase resilience of agriculture (for example through access to on site renewable energy sources), to optimise the transport of produced goods, and to further develop ship and rail freight (Box 3.3).

Innovation is central to low-emission, climate-resilient land-use strategies. Although agricultural emissions of methane (CH_4) and nitrous oxide (N_2O) are notoriously difficult to reduce, technological innovation offers possible paths. This includes improving crop and livestock productivity (e.g. by developing crop varieties that are resilient to local hazards and that inhibit the production of nitrous oxides); more efficient fertiliser use; improved soil management; and practices aimed at reducing CH_4 emissions from ruminants, rice paddies and manure management. Better agricultural practices that increase the productivity of arable land in a sustainable manner would also help to halt and reverse deforestation and widespread land degradation, which is estimated to cost USD 100 billion per year (Delgado et al. 2015).

Figure 3.5. **Government spending on agricultural knowledge and innovation systems in 2012-14 in selected G20 countries, as a share of agricultural value added**



Note: a. Government spending on agricultural knowledge and innovation systems includes funding of agricultural research, agricultural education, training and extension services for farmers. b. Exchange rates used in the OECD Producer and Consumer Support Estimates database have been applied here: http://www.oecd.org/agriculture/agricultural-policies/producerandconsumersupportestimatesdatabase.htm. c. Data for other G20 countries are not available.

Source: OECD (2016b).

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Agricultural innovation is not only about technological improvements but also about education, training and organisational improvements. Further investment in research and development and education is hence central to spur agricultural innovation that can improve sustainable productivity growth (Ignaciuk, 2015). Indeed, the level of technological development and innovation in agriculture has a direct impact on its capacity to produce adequate and sustainable supplies of food and feed (OECD, 2014). Given the importance of sustainable productivity growth for achieving ambitious mitigation targets, G20 countries can be encouraged to increase their spending in agricultural knowledge and innovation systems (Figure 3.5).

Box 3.3. **Investing in innovation and infrastructure for resilient agriculture**

Ensuring access to a secure water supply will be one of the main challenges of the land use sector – particularly agriculture – in the years to come. Climate change is expected to reduce crop yields in some areas. Coupled with increased demand for food from a growing population with increasingly rich diets, this will impose serious strains on agricultural systems, threatening food security in the most vulnerable countries.

Strategies to adapt agricultural systems are varied. Much can already be achieved by increasing the sector's reliance on on-site renewable energy sources, as well as optimising the transport of produced goods by shrinking the distance food is transported, and developing ship and rail freight. Technology also has a considerable role to play, via such measures as:

- developing new crop varieties that are drought-resistant and better adapted to higher temperatures; and
- improving water efficiency via the widespread dissemination of pressurised irrigation systems (e.g. sprinklers and drip irrigation), which decrease water demand while increasing the efficiency of water use.

Significant investment in R&D will be required to increase the resilience of agricultural systems to climate change. In OECD member countries, annual adaptation costs in agricultural R&D and in improved irrigation technology are estimated at USD 16-20 billion by 2050. In the short term, most of this investment is likely to come from public sources, although by 2050 the private sector is likely to invest more in this area than the public sector (Ignaciuk and Mason-D'Croz, 2014). Governments could facilitate private investment by lowering investment barriers that impede R&D, ensuring that private knowledge is disseminated, and encouraging public-private partnerships for R&D, where appropriate (Ignaciuk, 2015).

Incremental investment needs: mitigation

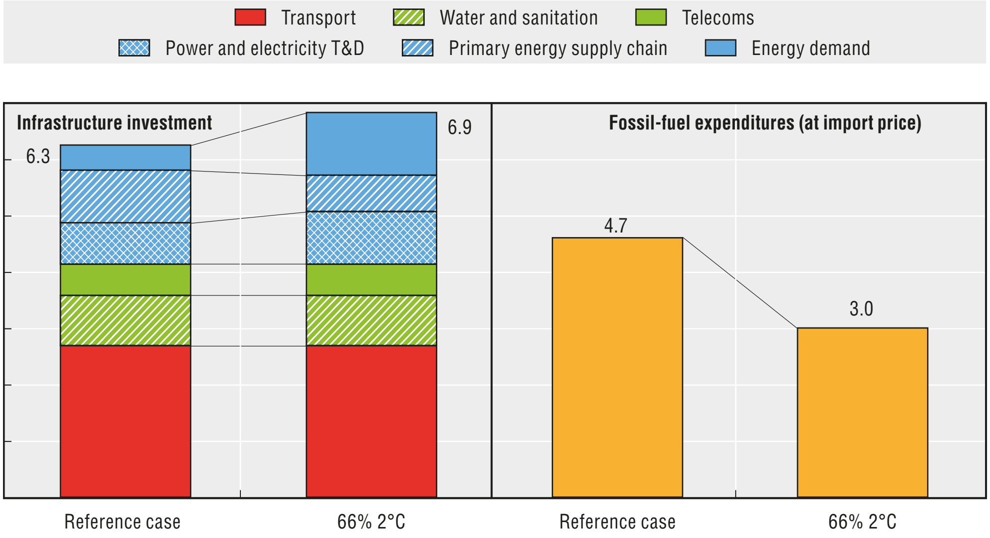
Assessment of the incremental capital requirements for putting the world on track to meet the mitigation objectives of the Paris Agreement depends on a number of factors, including the interpretation of the target (e.g. well below 2°C or efforts towards 1.5°C, likelihood of reaching the target); assumptions concerning decarbonisation strategies chosen (e.g. with or without nuclear, accounting or not for behavioural changes such as modal shifts in transport); and assumptions made on several factors such as the evolution of GDP, population, and technology costs.[3]

Consistent with the global pathways analysis in Chapter 2, this section takes as its core the IEA scenario consistent with a 66% likelihood of keeping the global average surface temperature increase to below 2°C throughout the century (IEA 66% 2°C scenario, IEA 2017).

The OECD estimates that around USD 103 trillion of cumulative investment between 2016 and 2030 would be required for the IEA 66% 2°C scenario, or 10% more than in a scenario where no further action is taken to mitigate climate change. The major shift of energy supply investments towards low-emission alternatives and significant scaling-up of demand-side investments for energy efficiency assumed by the scenario would require 29% more investment in the energy sector alone (IEA, 2017). Annual investment needs in transport, water and sanitation, telecommunications and energy supply and demand would be around USD 6.9 trillion over the next 15 years, versus USD 6.3 trillion a year with no further action (Figure 3.6, left-hand panel).

The incremental capital cost of shifting investments for the IEA 66% 2°C scenario is therefore significant, but not prohibitive; furthermore, incremental costs would be offset by fuel savings of up to USD 1.7 trillion per year through 2030 (Figure 3.6, right-hand panel). Factoring in modal shifts in transport could also lower overall investment needs for low-emission pathways, due to reduction in vehicle ownership and less investment needed in parking space (IEA, 2016d). Finally, provided low-emission infrastructure investment is pursued in an integrated way with climate-consistent, growth-enhancing policies, it could form an integral part of a new growth model for low-carbon growth, offsetting incremental costs entirely (Chapter 4).

Figure 3.6. **Global annual infrastructure investment needs for a 66% scenario 2°C, and fuel savings, 2016-30, USD 2015 trillion**



Notes: Reference case assumes no further action by governments to mitigate climate change.

Sources: IEA (2017) and IEA (2016a) for energy supply and demand; IEA (2016d) for road and rail infrastructure; OECD (2012) for airports and ports; McKinsey (Woetzel et al., 2016) for telecommunications. The water and sanitation estimate is an average of estimates from: Booz Allen Hamilton (2007), McKinsey (Woetzel et al., 2016) and OECD (2006). See technical note on estimate of infrastructure investment needs for further details on methodology (http://oe.cd/g20climatereport).

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The global infrastructure investment needs estimate presented here is higher than in previous exercises, partly because many past estimates were based on a less ambitious scenario with a lower chance of limiting warming to below 2°C. NCE (2016) and Kennedy and Corfee-Morlot (2012), for example, estimated that incremental capital costs could increase by as little as 5% compared to a business as usual scenario in a low-emissions future. The impact on investment needs of increasing the level of ambition is not just incremental and linear: it implies a radical reorientation of investments and measures to decarbonise sectors that are harder and more expensive to decarbonise (transport, aviation, industry). For instance, cumulative global investments increase by 13% in the IEA 66% 2°C scenario compared with a scenario with a 50% chance of meeting 2°C, mainly due to increased investment in low-emission electricity supply and end uses (IEA, 2017).

There are many uncertainties associated with those estimates. Further research is required to understand the impact of the digitalisation of energy on telecommunication infrastructure, for example. Deployment of BECCS may generate significant investments in CO_2 pipelines (Chapter 2). There are also many remaining uncertainties on the impact of a low carbon future on future demand in infrastructure beyond energy. Between 2010 and 2015, fossil fuels represented between 11% and 18% of the value of international trade in goods (UN, n.d.). Fossil fuels accounted for an average of 42% of total maritime traded volumes between 2011 and 2015 (UNCTAD, 2016). In the long term, a world less reliant on fossil fuels is likely to require fewer port capacities, oil and gas tankers, and hinterland railways to transport coal (Kennedy and Corfee-Morlot, 2012). Specific country contexts will also influence investment needs. Encouraging more efficient transport modes from the outset in developing and emerging economies where infrastructure continues to be built could generate significant savings, reducing the need for road and parking spaces, which in many non-OECD countries are more costly than the additional investments required in public transport infrastructure (IEA, 2016d).

Box 3.4. **Investment needs for low-emission urban mobility**

Cities have a major role to play in strategies to decarbonise transport (see Chapter 2). It is essential to integrate transport and land-use planning to reduce overall demand and facilitate the shift from individual cars to mass transit systems. The International Transport Forum undertook a modelling exercise to assess transport investment needs in G20 countries between 2015 and 2050 under three different scenarios for urban development (see OECD/ITF (2017) for more details) (Figure 3.7).

In the baseline scenario (BASE), no additional measures to reduce travel demand and CO_2 emissions are implemented. The combined effects of urban extension, population and income growth will result in a surge in motorised mobility. Road traffic – the sum of car-km and motorcycle-km – will increase globally by 91%. Most of the increase comes from G20 countries, with 7 600 billion additional vehicle-km out of a total of 11 100 billion. In the G20, this increases CO_2 emissions by 10%.

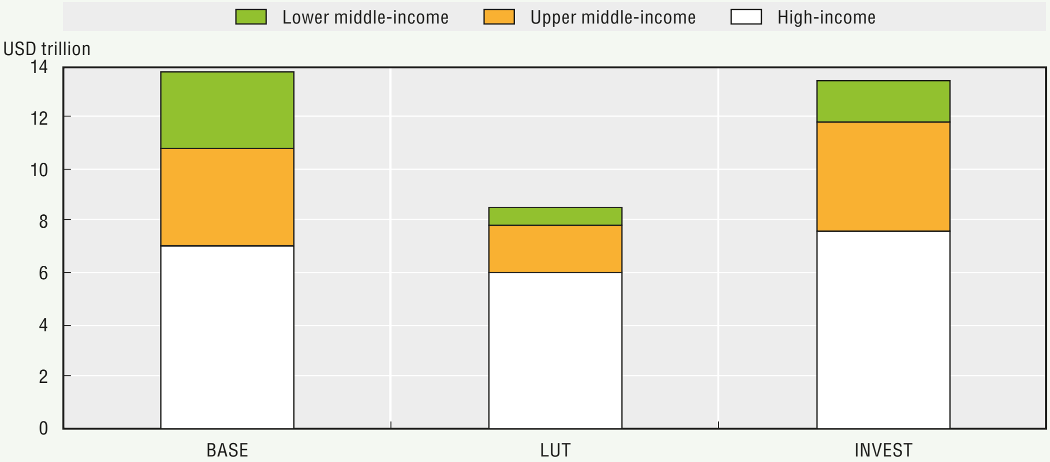
In the Integrated land-use and transport planning scenario (LUT), stringent policies targeting land-use planning, development of public transport and restriction of car use significantly mitigate CO_2 emissions. In G20 countries, transport emissions decrease by 34%.

In the strong investment scenario (INVEST), budgetary constraints on transit infrastructure are removed, increasing investment in mass transit infrastructure – urban rail, underground and tramways – especially in middle-income countries. This leads to a decrease of 50% in CO2 emissions.

Overall, aggregate infrastructure investment needs are smaller in the transit-oriented scenarios (USD 9 trillion in LUT and USD 13 trillion in INVEST) than in the baseline (USD 14 trillion). However, the results differ by income groups. High-income economies need to frontload urban transport investment towards light rail systems in the next 10 years. Middle-income countries can significantly decrease overall investment needs by 2050 by shifting investments in the next 10 years to rail.

Box 3.4. **Investment needs for low-emission urban mobility** *(cont.)*

Figure 3.7. **Investment in urban infrastructure in G20 countries, 2016-50, road and rail – ITF projection**



Source: Based on ITF data (accessed on 28 February 2017).

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Incremental investment needs: adaptation

Estimates of the additional funding required for infrastructure adaptation depend on specific definitions of what constitutes "infrastructure adaptation", including which sectors are included (Box 3.5). In practice, costs are very context-specific, adding to the challenge.

Box 3.5. **Defining adaptation investments**

Adaptation investments can be considered across three areas:

Adaptation investments that create an enabling environment, such as investing in climate information, awareness raising and capacity building, and adapting governance systems to better account for the projected changes and deep uncertainty regarding climate change. If private stakeholders are sufficiently aware of climate risks, some adaptation investments make economic sense without public support.

Adaptation investments that "climate proof" infrastructure, reducing the exposure or vulnerability of an infrastructure asset or network, whether from the outset or as part of a retrofitting process. Such investment can take the form of engineering work with clearly identifiable additional costs, such as building a bridge higher than would otherwise be the case or building to higher design standards. It can also mean considering reduced exposure when siting or designing, often without incurring additional costs, for example siting back-up power generators to avoid them being flooded or modifying operational routines. It can also consist of pursuing a different approach to provide the same service, for example expanding green spaces to absorb rainfall in urban areas, instead of investing in larger drainage pipes.

Adaptation investments that fill gaps in infrastructure provision, particularly in developing countries, where infrastructure can be insufficient even for addressing current climate challenges.

Source: Agrawala and Fankhauser (2008).

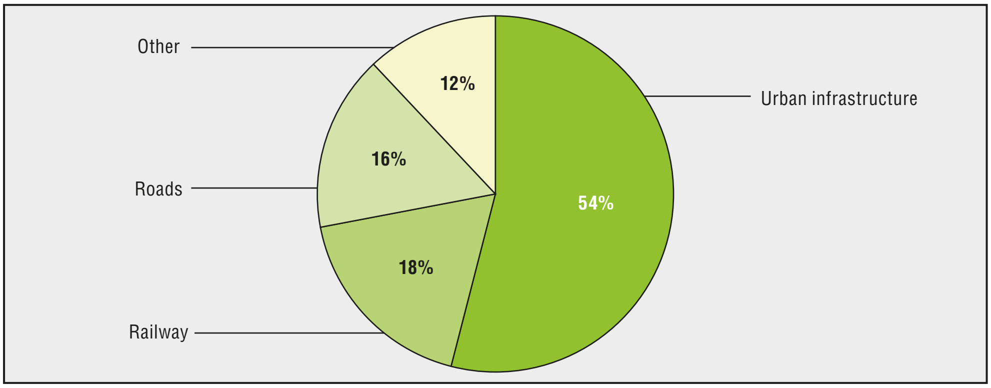
Several estimates of the global costs of adaptation feature a category on infrastructure adaptation. These tend to estimate the costs of "climate proofing" infrastructure by applying an adaptation cost mark-up to future investment plans to take account of future climate change. Such investments are estimated to be small compared with other factors that may influence the future costs of infrastructure. The cost of adapting infrastructure has been estimated at no more than 1-2% of the total cost of providing that infrastructure (Hughes, Chinowsky and Strzepek, 2010).

Other estimates take into account adaptation investments that fill gaps in infrastructure provision. Below are three recent estimates:

- The UNFCCC (2007) estimated that by 2030, the world would be spending USD 8–130 billion more each year on *new* infrastructure than would otherwise be needed in response to impacts associated with climate change, with two-thirds of the investment in OECD countries. This estimate excludes operating and maintenance costs, as well as the costs of adapting *existing* infrastructure, and any additional investment needed in water supply infrastructure (USD 11 billion, 85% of which will be needed in non-Annex 1 Parties) or housing.
- The UNFCCC estimates were criticised for failing to account for the infrastructure deficit in low and middle-income countries (LMICs), the investments in governance and technical capacity needed to maintain infrastructure in those countries, as well as the "residual" losses that cannot be prevented even with adaptation. With these elements taken into account, adaptation infrastructure investments in LMICs are eight times higher than the high-bound UNFCCC estimate (Parry et al. 2009.).
- Infrastructure accounts for a significant share of the USD 70-100 billion in annual global adaptation costs, according to a 2010 World Bank study on the costs between 2010 and 2050 of adapting to an approximately 2°C warmer world. Infrastructure adaptation is estimated to require USD 13-27.5 billion per year, depending on wetter or drier climate scenarios (Figure 3.8). Urban infrastructure (drainage, public buildings) accounts for over half of these costs, followed by railways (18%) and roads (16%), with costs highest in East and South Asia. This amount does not account for coastal zone adaptation, water supply or flood protection.

Figure 3.8. **World Bank estimates of global adaptation investment needs 2010-50**

USD 13-27.5 billion per year



Note: The estimate provided above does not account for adaptation in coastal zone adaptation, water supply or flood protection.

Source: World Bank (2010).

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A transition is under way, but not at the required pace

The estimated global carbon budget consistent with a 66% likelihood of limiting global warming to below 2°C (described in Chapter 2) equates to 15 to 30 years of fossil fuel-related CO_2 emissions at current rates. Given the slow rate of capital stock turnover (Table 3.4), the infrastructure investment choices countries make over the next 15 years will be pivotal in determining the extent of global climate change. If governments continue to invest in fossil-fuel infrastructure, they risk locking in even higher levels of GHG emissions for decades to come, and they will enhance the risk of stranded assets. Long operational lives also make infrastructure vulnerable to the impacts of climate change in the coming decades. Overall, unless global emissions peak by around 2030 and fall to zero by 2100, serious climatic disruption could draw up to 720 million people back into extreme poverty (Granoff et al., 2015).

Information on infrastructure projects is not always complete or available to the level of detail required to allow meaningful analyses on progress in shifting investment in line with the Paris Agreement's goals. Energy is the only sector where information is more complete, as surveys and commercial databases track information on power plant capacity announced, at pre-construction stage, under construction, cancelled or in operation. This section therefore focuses on the energy sector as an indicative assessment of progress in aligning infrastructure investment plans for the transition, using the IEA 66% 2°C scenario as a benchmark.

Table 3.4. **Typical lifespans of selected infrastructure and equipment**

	Lifespan
Water infrastructure (dams, reservoirs, sanitation facilities)	30-200 yr
Transportation (port, bridges)	30-200 yr
Buildings, housing (insulation, windows, buildings)	30-150 yr
Power plants (coal-fired, gas-fired, nuclear)	20-60 yr
Cars	15-20 yr
Building appliances	10-20 yr
Industrial boiler	10-30 yr
Cities, urbanisms, land use planning	> 100 yr

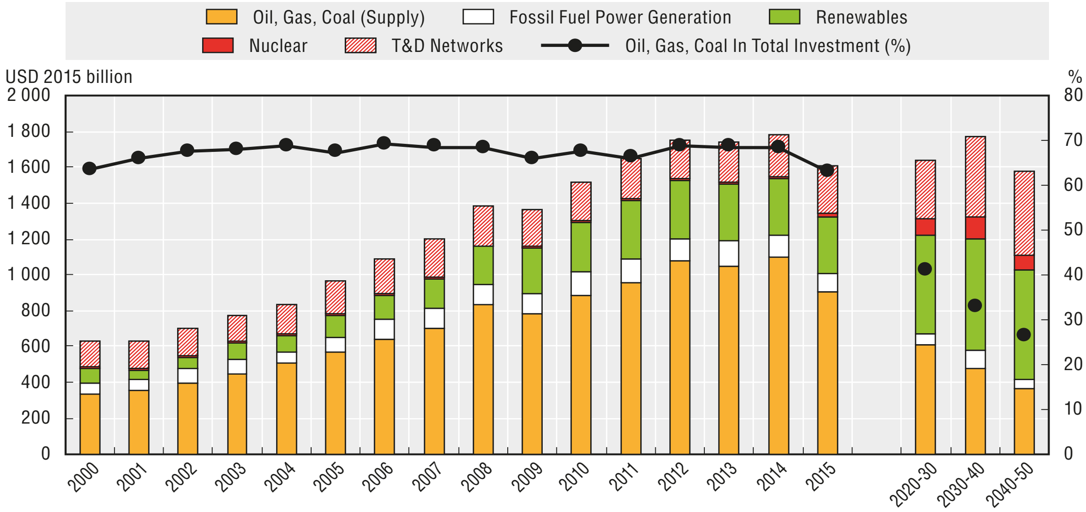
Source: Corfee-Morlot et al. (2012).

Investment is shifting towards cleaner infrastructure – but slowly

Fossil fuels have held the lion's share of energy supply investment in G20 countries. Fossil fuels continued to represent 63% of total supply-side investments, or USD 1 trillion in 2015. This share needs to drop to 26% by 2050 to be consistent with the IEA 66% 2°C scenario (Figure 3.9).

The transition is under way, however, with investment flows slowly shifting from fossil fuels to low-emission technologies in particular sectors. In power generation, G20 countries invested USD 290 billion in renewable energies in 2015, three times more than in 2000. Capacity investments have increased for wind, solar and hydropower generation in particular (IEA, 2016b). Since 2011, these technologies have captured approximately 40% of total annual investments in power generation (IEA, 2016b). This increase in total renewables capacity investment is even more impressive given that the cost of production of the technologies has decreased in the past few years: since the end of 2009, solar PV module prices have fallen by around 80% and wind turbine prices by 30-40% (IEA, 2017).

Figure 3.9. **G20 investment in energy supply 2000-15, and investment needs in the 66% 2°C scenario**



Sources: IEA, 2017; IEA, 2016b.

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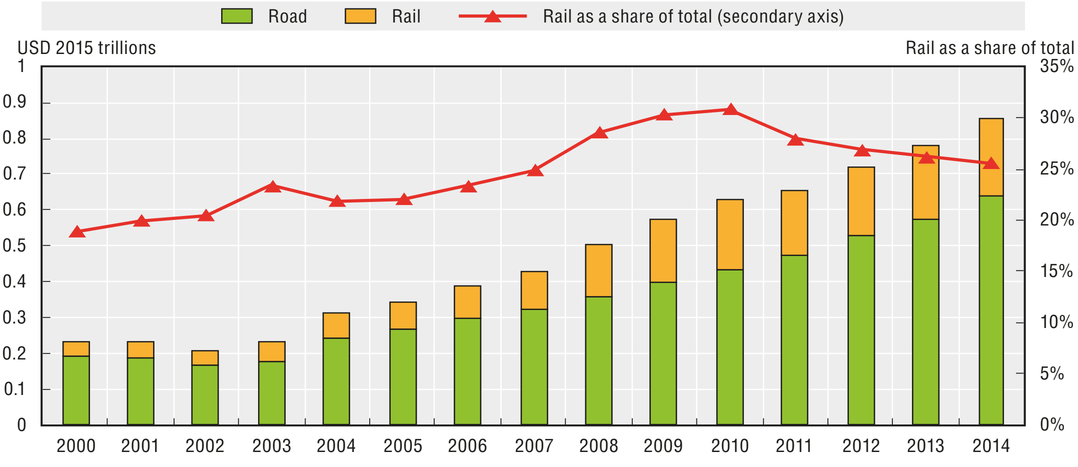
In the transport sector, most of the investment in G20 countries has targeted road transport since 2000, but the share of rail infrastructure investment – important to help promote the shift from emissions-intensive road transport – has been growing steadily, from 20% in 2000 to 26% in 2014, with a peak at 31% in 2010 (Figure 3.10). From a low of USD 250 billion in 2003, investment has more than doubled in size to reach USD 650 billion in 2014 (OECD/ITF, 2017). Investment in rail needs to increase significantly in the coming years to help fully decarbonise the economy.

Figure 3.10. **Road and rail infrastructure investment in G20 countries, 2000-14**



Source: OECD/ITF, 2017.

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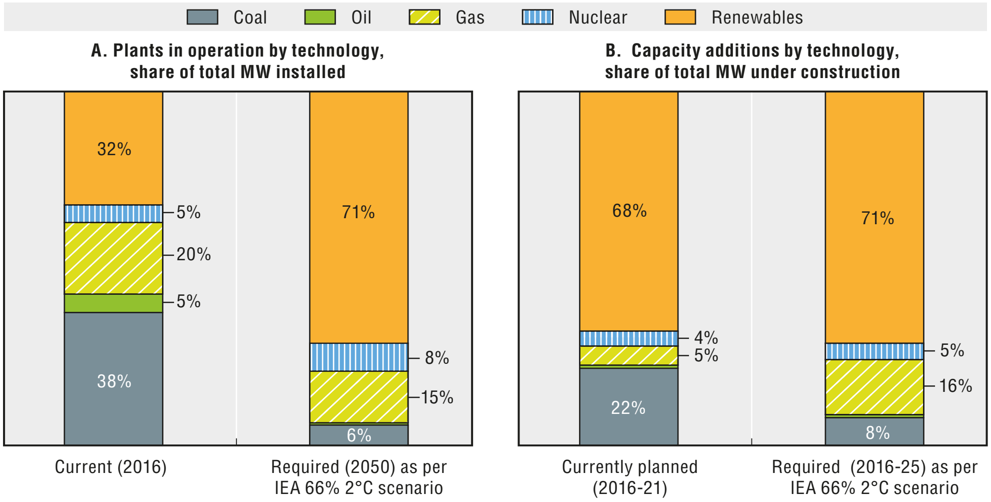
Investment plans are not yet aligned with the Paris Agreement's objectives

How, then, do current investment patterns and national energy sector infrastructure plans match up with the trajectory needed to achieve Paris objectives? In the power sector, the current capacity mix in G20 countries is still far from that required by the IEA 2050 scenario (Figure 3.11, left-hand panel). However, the plants under construction and planned for the next five years paint a different picture. The right-hand panel of Figure 3.11 compares this pipeline with required additions up to 2025 in the IEA 66% 2˚C scenario. The share of zero-carbon capacity additions is close to that required under the scenario (72% renewables and nuclear, versus 76% required). Solar and wind represent 84% of renewable generation capacity under construction, versus 36% for the plants in operation (Figure 3.12). However, the share of coal is much greater than the required level (22% of planned additions, versus 8% required). So, across the G20, the real challenge facing the power sector is accelerating the phase-out of coal-fired power generation.

Figure 3.11. **Current capacity and current pipeline of power plants relative to those required in a 66% 2°C scenario**



Note: Results are presented as share of total gigawatts and refer to power generation in operation in G20 countries in 2016, the energy mix in 2050 in the IEA 2°C 66% scenario, capacity additions in G20 countries for the period 2015-21, and global capacity additions in the IEA 2°C 66% scenario in the period 2016-25.

Source: Authors' analysis from *i)* Platts WEPP (2017) for oil and gas under construction; *ii)* the Global Coal Plant Tracker (2017) for coal under construction; *iii)* IAEA (2016) for nuclear under construction; *iv)* IEA (2016c) for renewable energy under construction; and *v)* IEA (2017) for capacity additions in the IEA 2°C 66% scenario.

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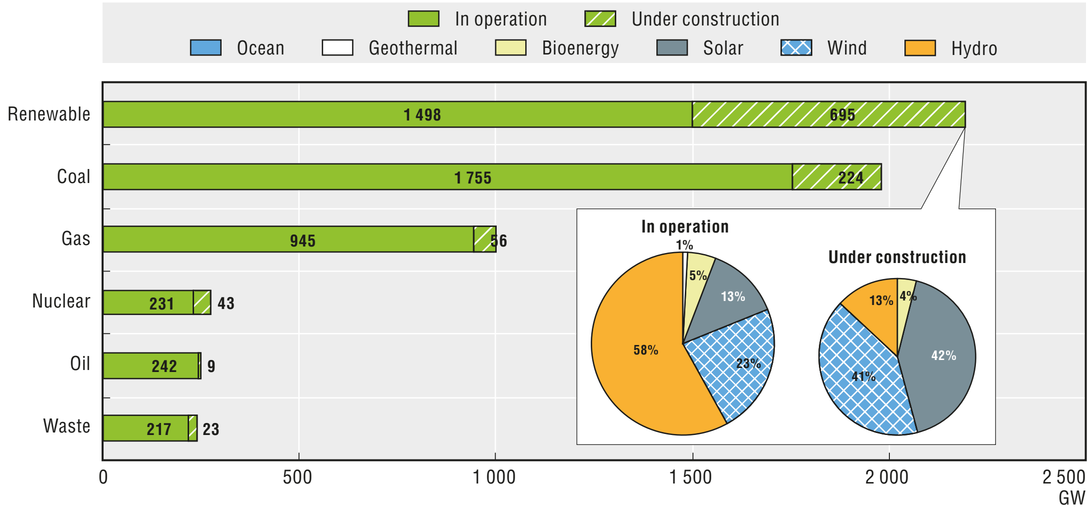
Figure 3.12. **Power plants in operation and under construction in G20 countries, by technology (in GW)**



Source: Authors' analysis from *i)* Platts WEPP (2017) for oil and gas under construction (accessed March 2017); *ii)* the Global Coal Plant Tracker (2017) (accessed on 28 February 2017) for coal under construction; *iii)* IAEA (2016) for nuclear under construction (November 2016); and *iv)* IEA (2016c) for renewable energy under construction.

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The level of coal plants in the pipeline is high despite recent falls in global capacity under development, mainly due to shifting policies and economic conditions in China and India – which account for 86% of coal power built globally between 2006 and 2016 – together with a reduction in overall power demand (Box 3.6). Pre-construction activity decreased by 48% from January 2016 to January 2017. Construction starts dropped 62%, and ongoing construction decreased by 19%. Coal plant retirements are taking place at an unprecedented pace, with 64 GW of retirements in the past two years, mainly in the European Union and the United States (Shearer et al., 2017). Nevertheless, the proportion of overall G20 capacity investment that is coal based could increase in the future, as 416 GW of coal plants are in pre-construction, and 543 GW are "on hold" (Figure 3.13).[4] Considerable further efforts are therefore needed. These efforts will not only be domestic. G20 economies also influence the type of infrastructure that is built outside of their borders, and especially in developing countries through development finance and export credits (Box 3.7)

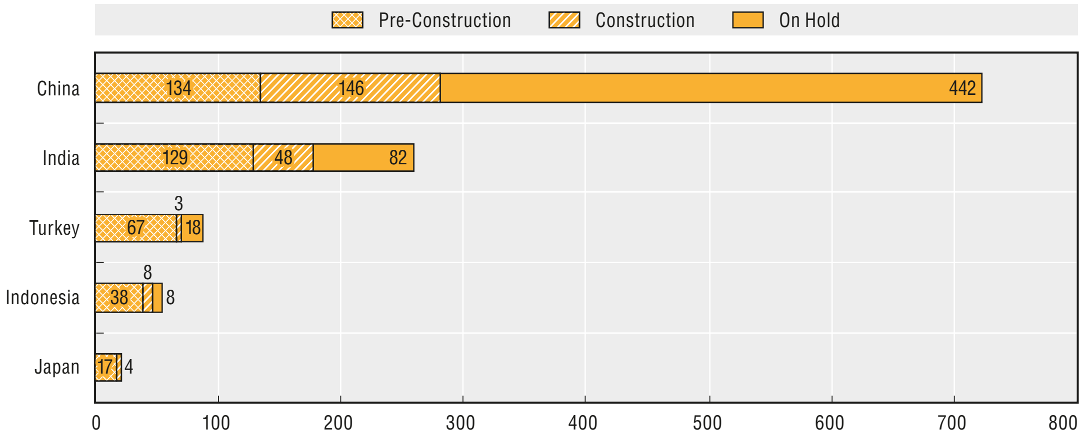
Box 3.6. **Recent reductions of the coal project pipelines in China and India**

In China, over 300 GW of projects in various stages of development were put on hold in 2016 until after the 13th Five Year Plan (2016-20), including 55 GW of projects that were already under construction. According to a survey by Greenpeace, the amount of new coal power capacity authorised for construction in 2016 in China was 22 GW, a decline of 85% from the 142 GW authorised in 2015.

In India, the draft National Energy Plan, released in December 2016, states that no further coal power capacity beyond that currently under construction will be needed until at least 2027; but there is already 177 GW in the pipeline before that date. Moreover, India is in the midst of a solar power revolution, with bids as low as Rs 2.97 (USD 0.044) per kilowatt-hour, and government proposals to install 215 GW of renewables (biomass, small hydro, wind, distributed solar PV, and utility scale solar PV) by 2027. Although some policy and financial challenges need to be addressed to reach the ambitious goals set by the government, the combination of the current low capacity utilisation rate of several coal power plants and the declining cost of renewables has caused many financial backers of coal projects to withdraw support. Construction activity is now on hold for 31 coal plant units at 13 sites totalling 12 725 MW of capacity, mainly due to frozen financing.

Source: Extract from Shearer et al. (2017).

Figure 3.13. **Coal power plants under construction, 2015-21, top five G20 countries**



Source: Authors' analysis based on the Global Coal Plant Tracker (2017) (accessed on 5 April 2017).

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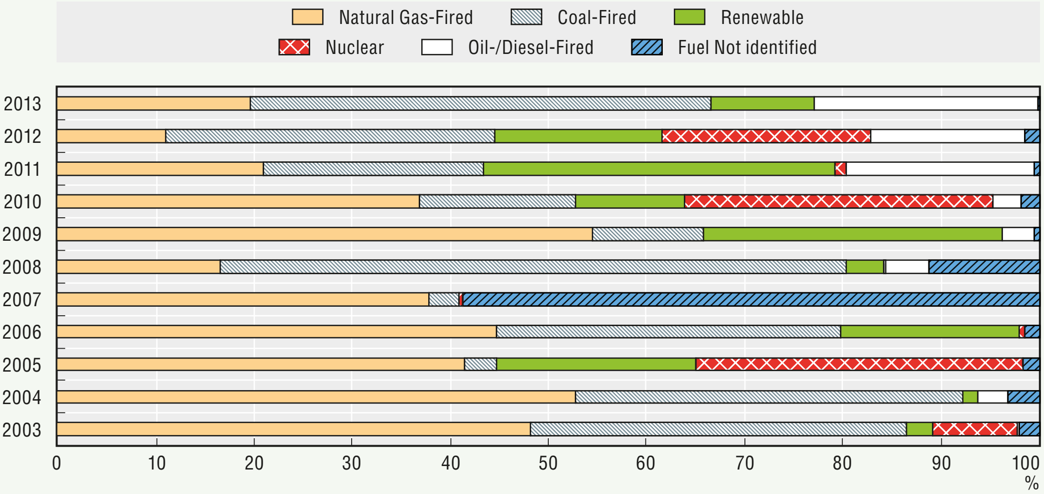
Box 3.7. **Aligning ODA and export credits for infrastructure investment with the Paris Agreement's objectives**

The G20 includes the biggest aid providers globally – roughly 77% of ODA and ODA-like flows come from G20 countries, according to the OECD-DAC statistical system – and while aid supports only a small share of infrastructure investment overall, it plays a critical role in low-income countries where it is difficult to mobilise domestic and external finance. Export credits – commercially motivated support linked to a country's trade strategy – also play an important role in financing infrastructure. For example, 20% of external finance for infrastructure projects in Sub-Saharan Africa is provided by China EXIM Bank alone (Gutman, Sy and Chattopadhyay, 2015).

An analysis of export credits in support of power generation from G20 countries that report to the OECD shows that the overwhelming majority of these credits supported fossil fuel technologies over the last decade (Figure 3.14). Export credits provided by G20 countries for coal power generation specifically amounted to USD 13.1 billion. Most signatories to the OECD's Arrangement on Export Credits have agreed to begin limiting export credits related to coal.

Figure 3.14. **Official export credits for power generation projects**

(Share per sector, G20 members reporting to the OECD Working Party on Export Credits and Credit Guarantees)



Note: G20 countries that report to the export credit committee are Canada, France, Germany, Italy, Japan, Republic of Korea, the United Kingdom and the United States.

Source: OECD (2015a).

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Minimising the risk of stranded assets

Limiting global warming in accordance with the Paris Agreement will lead to some infrastructure being replaced before the end of its economic life, especially in energy supply and demand activities, as low-GHG solutions replace more GHG-intensive ones. The longer infrastructure investment plans are misaligned with the agreement's climate goals, the more extensive the value of the assets at stake. Locking in long-lived assets that risk later being economically stranded when policy constraints finally catch up will lead to higher costs if the global carbon budget is still to be met, and is sub-optimal from a global welfare perspective.[5]

Stranded assets are a common feature of market economies that spur reallocation of capital as some firms are outcompeted by others (Caldecott et al., 2017). A range of approaches has been used to define and quantify the climate-related risk for assets (Box 3.8). Similar assets may also face different financial risks depending on their contribution to their country's emission profile, making the identification of the exact magnitude of assets at risk more challenging. A natural gas power plant, for example, can play a positive role if it replaces low-efficiency coal or balances variable sources of power generation, or a negative role if it slows the penetration of renewables.

Box 3.8. Climate-related risks for assets: clarifying the terms of the discussion

Many different definitions have been used in the debate on the impact of climate policy and climate change on assets.

- **Stranded assets:** Assets whose investment cannot be fully recouped as the result of climate policy (e.g. a coal power plant closing before it has recouped investment as its electricity is no longer competitive, whether because of a carbon price, other forms of support to low-carbon generation, or on pure financial grounds). More precisely, if the revenues of an asset are lower than its capital expenditure minus operating costs, the difference is the estimate of the stranded asset.
- **Assets at risk under climate change:** Infrastructure at risk of being destroyed or made unusable as the result of local climate changes (flooding, sea-level rise, typhoons, droughts). Dietz et al. (2016) provide a first estimate of value at risk, estimated at 1.8% of global financial assets in their central estimate (USD 2.5 trillion), rising to 16.9% in a 99% percentile scenario (USD 24 trillion).
- **Foregone revenues:** Revenues lost as lower volumes of fossil fuels are sold, and sold at a lower price than would otherwise be the case without climate mitigation policies (also known as the "carbon bubble"). IEA argues that the foregone revenues can be larger than stranded assets as the former include profits, even if these are discounted.
- **Capital value loss:** The capital value that a company loses as its activity is impaired by climate policy (and possibly climate change damages), as used by IRENA for its upstream fossil fuel estimates of stranded assets (IRENA, 2017b). There is much overlap between foregone revenues and the capital value of an energy company, although much depends on how the company is managed, and how quickly it can diversify its portfolio (e.g. a company that produces oil exclusively versus an oil and gas company with a renewable energy branch and ownership in electricity distribution).
- **Unburnable carbon:** Fossil fuel resources that are not used due to climate mitigation policies, but that would be burned if there were no constraint on emissions, usually expressed in energy amounts (Carbon Tracker Initiative, 2013).

IEA (2017) and IRENA (2017a) represent the latest estimates of energy-related assets at risk; both use the notion of stranded assets, although their metholodgy, sectoral coverage and assumptions about the future energy mix differ. Assuming an orderly transition to meet the Paris Agreement objectives, the IEA 66% 2°C scenario estimates stranded assets at USD 852 billion between 2014 and 2050, distributed as follows:

- USD 320 billion for power (96% of which are coal-fired power plants), with about half of the stranded assets occurring before 2030.

- USD 532 billion for production facilities, including coal mines, oil and gas wells and processing plants, that fail to recover their capital investment as a result of climate policy (USD 120 billion for gas, USD 400 billion for oil and USD 12 billion for coal).

A less orderly transition – for example, a delay followed by abrupt action – is likely to have more deleterious effects. The IEA considers a "disjointed transition case", in which climate policy would change abruptly in 2025, shifting from weaker action to a more ambitious trajectory, allowing the world to stay within the carbon budget of the 66% 2°C scenario. This would mean a change in investors' and market expectations, with investments previously committed to fossil fuel-based production that would eventually be stranded following the change in policy. Stranded assets would then amount to USD 2.1 trillion, with the brunt of the additional assets in oil (USD 1 trillion) and gas (USD 300 billion). The "delayed action" scenario in Chapter 4 builds on these numbers.

IRENA provides a different set of estimates of asset risks based on a renewable energy-driven low-carbon transition scenario, REmap (IRENA, 2017a). In terms of sectoral coverage, IRENA differs from the IEA in including heavy industry and buildings, in addition to oil and gas.[6] Among other differences, while the same emission budget as the IEA is used, IRENA projects renewables to provide 65% of total primary energy by 2050, against 47% for the IEA scenario.[7] Results for the delayed action case are indicated in parentheses, confirming the much higher financial impact of an abrupt adjustment in mitigation policy:

- The capital value loss for the oil, gas and coal sector is estimated at USD 3.8 trillion (USD 7 trillion in a Delayed Policy Action case).
- Stranded assets in power generation are estimated at USD 200-300 billion for a low assumption of plants economic lifetimes and USD 1.2 trillion with longer lifetimes (USD 1.9 trillion in a Delayed Policy Action case).
- Stranded assets in industry are estimated at USD 220 billion (USD 740 billion in the Delayed Policy Action case).

A combination of IEA and IRENA estimates indicate that stranded assets could amount to USD 1.06 trillion for the energy supply and industry sectors – using IRENA's low range for industrial assets economic lifetime – a number that would nearly triple under a delayed action scenario. These amounts are significant for sectors at stake. However, they appear manageable when compared with the global infrastructure investment needs over the same period to 2050 – i.e. USD 244 trillion, particularly if exits are well planned and impacts on the work force are mitigated (Chapter 6).

Possible ripple effects through the financial system also need to be taken into account. Stranded assets can be viewed as the primary effect of what may be broader effects on the financial situation of companies and sectors in the low-carbon transition. As the value of physical investment in energy production assets that will not be recovered becomes visible to investors, they should reassess publicly listed companies' value, taking into account future earnings. How companies would anticipate, and adapt to, a more stringent climate policy environment is highly uncertain at this stage, and estimates of capital value losses therefore carry more uncertainty than stranded assets. In general, because capital value loss casts a wider net than stranded assets, capital value loss ought to be higher, unless the company has diversified its activities or changed business model, which cannot be evaluated ex ante. Financial stability concerns add to the case for swift action (Carney, 2015).

Stranded assets are not only about energy. A changing climate also weighs on crop yield productivity, which calls for sustainable agriculture investment to taper volatility of future earnings (Morel et al., 2016). The risk of stranding is particularly high in countries like Brazil and Malaysia where deforestation gives way to agriculture (Rautner et al., 2016).

Aligning short-term infrastructure investment plans with long-term, low-emission, climate-resilient development strategies

Barriers to accelerating investment in low-emission and resilient infrastructure include a lack of long-term infrastructure planning that integrates climate mitigation and resilience from the outset, and a lack of a pipeline of bankable and sustainable projects that internalise positive and negative externalities over the lifetime of infrastructure. In order to overcome these barriers, G20 countries should first develop clear infrastructure investment plans that consider mitigation and adaptation as part of their work on developing pathways to 2050.

This section looks at how countries have framed long-term plans, before considering how governments might improve the transparency of infrastructure project pipelines, both to improve the alignment of short-term infrastructure investment with long-term, low-emission, climate-resilient development strategies and to enhance investment flows to that end. The other barriers to accelerate low-emission and resilient infrastructure investment are discussed in Chapter 5.

Develop long-term low-emission strategies to reconcile short-term actions and long-term decarbonisation goals

The Paris Agreement invites parties to communicate by 2020 long-term, low-emission development strategies to 2050 as one of its mechanisms to support strengthening of the international response to climate change. In addition to helping to scale up the ambition of the NDCs, which remain inadequate to reach the Paris Agreement's goals (Chapter 2), such strategies are vital to assist countries in reconciling short-term actions with long-term climate goals. Aligning short-term infrastructure investment plans with long-term, low-emission development strategies will help minimise the risk of both emissions lock-in and stranded assets. Long-term infrastructure investment planning is equally important to ensure flexible, forward-looking investments in resilience, to minimise future impacts from climate change and related economic damage and social hardship.

Post-2030 decarbonisation pathways require different infrastructure, technologies and industrial bases. Countries need to prepare in the next 15 years the technologies and infrastructure necessary to overcome the fossil fuel bias of our economies. In addition, what is considered to be "low-carbon" may differ across countries and over time. Not all "low-carbon" infrastructure is necessarily consistent with the trajectory to a carbon neutral society by the second half of the century; what could be considered as low-carbon in the next five years in some places may not be considered low-carbon elsewhere or on a different timescale.

To date, six countries have submitted mid-century long-term plans to the UNFCCC: Bénin, Canada, France, Germany, Mexico and the United States (Box 3.9). Many other countries are in the process of developing such plans; it is vital that they follow suit. China, India, Russia and the G7 countries have all indicated their intent to develop such strategies before 2020. The 2050 Pathways Platform initiative launched at the UN Climate Change Conference in Marrakech (COP22) represents an important complementary initiative (see Box 2.9).

G20 leaders recognised at the 2014 G20 Summit in Brisbane a lack of a clear pipeline of bankable infrastructure projects as one barrier to infrastructure investment. The lack of information on the pipeline of infrastructure projects makes it difficult to match investment needs and investors, including for low-emission, climate-resilient infrastructure. Providing detailed, comprehensive information on infrastructure projects is key to sending the right signals to private stakeholders to invest in the transition. The lack of information also makes it difficult to carry out a cross-country assessment of consistency of infrastructure plans with long-term mitigation and adaptation goals.

This challenge is particularly important for transitional or "bridge" technologies. Switching from oil or coal to natural gas, for example, will reduce GHG emissions and help countries achieve their 2030 targets and NDCs. But in the mid-term it may generate infrastructure that is costly to replace as further decarbonisation is necessary. There would then be a choice either to let the asset become stranded or to lock in its emissions and accept a continued dependence on fossil fuels that could prevent countries from achieving 2050 targets.

Retrofitting infrastructure post-construction, or stranding assets before the end of their economic life, can be very costly – more costly than designing infrastructure from the outset to take into account climate considerations (Corfee-Morlot et al., 2012; NCE, 2016). To minimise the scale of such problems, each country needs to define now which low-emission options and technologies are consistent with its low-emission pathway to 2050 and beyond, as well as the timing with which new and existing assets need to be deployed and/or phased out. Given the uncertainties associated with the deployment of technologies that are necessary for low-emission pathways (e.g. BECCS), there is a need for a continual reassessment of ambition, as set out in the Paris Agreement.

How do strategic infrastructure plans match up with long-term mitigation and adaptation goals?

At the 2014 G20 Summit in Brisbane, G20 leaders recognised that "tackling global investment and infrastructure shortfalls is crucial to lifting growth, job creation and productivity" and endorsed the Global Infrastructure Initiative (GII), a multi-year work programme to improve the quality of public and private infrastructure investment. In 2015, the G20 Investment and Infrastructure Working Group (IIWG) conducted a voluntary survey to compile information on countries' investment strategies, including the main challenges being addressed, policy priorities, and the policy context of these strategies. This section draws on that work, which remains in progress, in reviewing the extent to which current investment plans and pipelines of infrastructure projects are consistent with climate goals in G20 countries (Table 3.5).

Box 3.9. **Examples of mid-century long-term plans under the Paris Agreement**

France has committed to reducing carbon emissions by 40% by 2030, compared with 1990 levels, and by 75% by 2050. This means that annual emissions reductions must accelerate from 8 megatonnes of carbon dioxide equivalent (MtCO$_2$eq) per year to 9-10 MtCO$_2$eq. Sectoral targets are spelled out for three "carbon budget" periods – 2015-18, 2019-23 and 2024-28 – followed by a long-term target to be achieved by 2050. The national low-carbon strategy is founded on two pillars: including carbon footprint reductions as a key consideration in all economic decisions; and redirecting investments to support the energy transition, through interventions such as environmental quality labels, guaranteeing public funds, and gradually increasing carbon taxes without increasing the overall tax burden.

The United States has committed to reducing its GHG emissions by 26-28% below its 2005 levels by 2025, making every effort to reach a 28% reduction (including LULUCF). It considers this target to be in line with a straight-line emission reduction pathway from 2020 to deep, economy-wide emissions reduction of 80% or more by 2050. To reach these targets, the government has set out three pillars for action:

- shifting to a low-carbon energy system, while putting a particular emphasis on *i)* increasing the energy efficiency of buildings, vehicles and plug-in appliances, *ii)* decarbonising electricity, and *iii)* shifting to clean electricity and low-carbon fuels in transport, buildings and industry;
- carbon sequestration and removal, taking advantage of the country's natural land resources and their capacity to continue to act as a net carbon sink;

Box 3.9. **Examples of mid-century long-term plans under the Paris Agreement** *(cont.)*

- reducing emissions from non-CO_2 gases, notably via the introduction of *i)* stringent standards and incentives to limit CH_4 emissions from oil and gas production and from landfills; and *ii)* new technologies and best practices for livestock agriculture.

Germany's Climate Action Plan 2050 (adopted in November 2016) sets out to obtain extensive GHG neutrality by 2050, which implies reducing total GHG emissions by 80-95% from 1990 levels. The strategy includes a mid-term target of 55% emissions reduction by 2030, and provides several strategic measures, including:

- sector-specific emissions reduction targets for 2030 that will undergo an impact assessment and possibly be revised in 2018;
- a road map towards an almost climate-neutral building stock;
- a commission for growth, structural change and regional development, which will bring together stakeholders from different levels of government, business, industry and various regions, in order to develop strategies for implementation of the Climate Action Plan by the end of 2018.

Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy sets out to cut GHG emissions by 80% by 2050 from 2005 levels. The strategy is not policy prescriptive, but seeks to inform the Pan-Canadian Framework on Clean Growth and Climate Change, and more generally the conversation on how Canada can achieve a low-carbon economy. It describes modelling analyses that illustrate various scenarios towards deep emissions reductions and outlines potential GHG abatement opportunities. Furthermore, it identifies the areas in which emissions reduction will be more challenging, thus requiring an increased policy focus. The Pan-Canadian Framework has four pillars: *i)* pricing carbon pollution; *ii)* complementary measures to further reduce emissions across the economy; *iii)* measures to adapt to the impacts of climate change and build resilience; and *iv)* actions to accelerate innovation, support clean technology, and create jobs.

Sources: FMESDE (n.d.); GFMoENBN (2016); Government of Canada (2016); Government and Provinces of Canada (2016); White House (2016); UNFCCC (2015).

Table 3.5. **Overview of infrastructure plans in the G20 countries**

COUNTRY	Adaptation strategy incl. in infrastructure plan	Mitigation strategy incl. in infrastructure plan	ENERGY						TRANSPORT												WATER						AFOLU					
			Fossil fuels			Renewables			Rail/road			Electric v.			Airports			Ports			WSS			Flood			Agriculure			Forests		
			P	B	T	P	B	T	P	B	T	P	B	T	P	B	T	P	B	T	P	B	T	P	B	T	P	B	T	P	B	T
Argentina			🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩				🟩		🟩	🟩	🟩								🟩	🟩	🟩			
Australia*	✓	✓	🟩	🟩				🟩	🟩	🟩					🟩	🟩		🟩	🟩		🟩	🟩										
Brazil	✓	✓	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩
Canada*	✓	✓					🟩			🟩				🟩		🟩			🟩			🟩			🟩							
China	✓	✓						🟩																					🟩			🟩
France		✓			🟩			🟩						🟩																		
Germany*		✓						🟩	🟩	🟩	🟩			🟩				🟩	🟩	🟩				🟩	🟩							
India*	✓	✓			🟩			🟩		🟩				🟩		🟩			🟩									🟩				
Indonesia*	✓	✓	🟩	🟩	🟩			🟩	🟩	🟩					🟩	🟩		🟩	🟩	🟩	🟩	🟩										
Italy		✓						🟩			🟩									🟩												
Japan	✓	✓						🟩			🟩			🟩												🟩						
Korea		✓						🟩						🟩																		
Mexico			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩						
Russia		✓		🟩	🟩			🟩																								
Saudi Arabia					🟩			🟩		🟩	🟩																					
South Africa	✓	✓	🟩		🟩			🟩	🟩		🟩				🟩			🟩					🟩			🟩	🟩					
Turkey					🟩			🟩			🟩						🟩			🟩					🟩				🟩		🟩	
UK	✓	✓	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩				🟩	🟩		🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩						🟩
US**																																

Notes: a. The table does not provide an overview of the countries' emissions reduction targets, as stated in the NDCs. These are reflected in Annex 2.A1. This table provides a snapshot of the coverage of national infrastructure plans in G20 countries, and the extent to which adaptation and mitigation are mainstreamed into those plans. b. Abbreviations: WSS: Water supply and sanitation ; AFOLU: Agriculture, forestry and other land use; c. Shaded cells indicate the availability of an infrastructure plan (P), associated budget (B), and target (T); d. Infrastructure plans (P) must include details on the location, type (new construction vs renewal), and the action(s) to be performed in each project (e.g. capacity strengthening, efficiency measures or safety enhancing measures) to be captured in the table; e. Outcome-based targets (T) included are those expressed as, inter alia, kilometres (road and rail), megawatts (energy), number of units (EVs), a percentage (the share of renewable energy in total energy supply or the share of roads that will be upgraded), or hectares (afforestation). Sectoral emissions reduction targets are not taken into account in the table, as these alone provide no information about the kind of infrastructure measures that will be implemented. * These are federal states, where infrastructure projects to a large extent are planned at a state level. The table reflects national plans only; ** The US has stated that it will issue an infrastructure plan during 2017; however, this was not available at the time the information for this table was compiled.

Mainstreaming climate mitigation and adaptation in infrastructure plans

Low-emission growth and economic development are often presented, erroneously, as competing priorities. While there will always be trade-offs and competing objectives between different goals for infrastructure investment, many climate-friendly infrastructure options also provide relief from problems like congestion, air pollution and access to energy in rural locations that have to date lacked easy answers (Box 3.10). This can be a boost to mainstreaming of climate considerations into infrastructure plans. As with any large-scale investments, the essential task is to ensure that all the costs and benefits are considered coherently at the outset, taking into account the time frames during which the infrastructure will be operated.

Table 3.5 shows that only 9 countries – less than half of the G20 – have integrated both mitigation and adaptation considerations into infrastructure planning. An additional four countries only mention mitigation. Five mention neither climate mitigation nor adaptation. In addition, only seven G20 countries have made available a detailed plan of infrastructure projects covering at least three of the four economic sectors of primary concern from a climate perspective (e.g. transport, energy, water and AFOLU, addressed below). The majority cover only one of these areas, or have not communicated infrastructure plans in these areas at all. There is therefore considerable scope for G20 countries to heighten their efforts to both align infrastructure plans across key economic sectors with climate mitigation and adaptation goals, and communicate those plans.

For transport, five G20 countries have provided detailed plans for road, rail, ports and airport infrastructure. Five more have an overall target specific to road and rail. Many countries that do not have a detailed plan tend to either have specific targets (e.g. Turkey) and/or allocated a budget for infrastructure (e.g. India). While these are promising signs, there is a need to better shape and define the future nature of transport in these countries for the transition. China, Russia and the United States are yet to communicate targets, budgets and plans for transport infrastructure. Infrastructure to facilitate the deployment of electric vehicles – such as public charging stations – is also important to the transition in the transport sector. However, to date, G20 infrastructure plans make no mention of concrete charging station infrastructure.

For energy, 17 G20 countries have defined renewable energy targets. Most, however, have not communicated a pipeline of projects for the years to come. Further, Table 3.5 also indicates that fossil-fuel related energy is still prevalent in many governmental plans. Ten G20 countries have targets for fossil fuel energy.

Water and AFOLU receive little attention in national infrastructure plans. For water supply and sanitation, only five countries have defined infrastructure plans. One additional country has set aside an envelope of funding for this issue. As for AFOLU, three countries have defined a pipeline of projects in agriculture. A further three have either established a budget or a target but are yet to provide information on the specific projects involved. In terms of forestry, information is even more scarce: targets exist in only three G20 countries, and one country has identified a budget to invest in this sector. Given the importance of these two sectors in transiting to low-emission, climate-resilient economies, there is scope for G20 countries to develop more robust plans, budgets and targets in their strategies in these areas.

Box 3.10. **Examples of co-benefits between low-carbon infrastructure and other SDGs**

Air pollution

Improved air quality is one of several co-benefits of climate action that have positive implications for human health. The OECD estimates that in 2010, 3 million people died prematurely because of outdoor air pollution. Unless policies become more stringent, projections suggest 6-9 million people will die prematurely each year by 2060. These deaths are largely projected to take place in densely populated regions with high concentrations of PM2.5 (particulate matter 2.5 micrometers or less in diameter) and, to a lesser extent, ozone (especially China and India) and in regions with aging populations, such as China and Eastern Europe.

In addition, increasing concentrations of PM2.5 and ozone are projected to lead to substantially more cases of illness. This will imply more hospital admissions, greater health expenditure, a higher number of lost working days and limitations on normal daily activities. Air pollution-related healthcare costs are projected to increase from USD 21 billion in 2015 (using constant 2010 USD and PPP exchange rates) to USD 176 billion in 2060, reflecting both a large number of additional cases of illness due to air pollution, and a projected increase in healthcare costs per illness. While a reduction in the burning of fossil fuels is likely to decrease the risk of heart and lung diseases, such as lung cancer, as well as neurologic disorders, other measures also provide clear benefits for human health. For example, replacing cars by more active forms of transport such as walking and cycling can reduce obesity, lung disease, heart disease, breast cancer and depression (Armstrong, 2012).

If climate change mitigation and air pollution policies are integrated, air quality could improve to a point where 40% of the global population currently exposed to dangerous PM levels would breathe air that meets World Health Organisation clean air quality guidelines. At the same time, expenditure on air pollution control will be reduced by EUR 250 billion in 2050. According to the estimates provided by the study, one-third of the total financial co-benefits by 2050 will occur in China, while annual cost savings of EUR 35 billion are estimated for the European Union, provided the current air pollution legislation and climate policies are adopted in parallel (Rafaj et al., 2012).

Reducing congestion

A number of governments have implemented Bus Rapid Transit (BRT) systems to reduce local air pollution and improve health. National railway systems have also reduced congestion, while improving access to remote, small or low-income communities, and supporting economic development and trade (Ang and Marchal, 2013). By improving connectivity and reducing congestion, these policies can boost the contribution of urban centres to productivity growth (OECD, 2015b).

Sources: OECD (2015b; 2016a); Armstrong (2012); Rao et al. (2016); Rafaj et al. (2012).

Improving the transparency of infrastructure project pipelines

Infrastructure development plans and project pipeline information that are inaccessible, incomplete or poorly aligned with long-term climate mitigation and adaptation goals are likely to hinder the flow of infrastructure investment in support of climate goals. Several mechanisms are available to help governments improve the transparency of infrastructure project pipelines.

The Global Infrastructure Hub (GI Hub) launched by the G20 in 2014 could prove a useful tool to increase transparency and strengthen the global pipeline of private and public infrastructure investment opportunities. It showcases investment-ready projects to multilateral banks and private investors. As of February 2017, the project pipeline consisted of 44 projects from eight countries, with a total value of more than USD 29 million (although several early-stage projects have not yet disclosed their values) (GI Hub, n.d.). Out of the eight countries that have contributed to the GI Hub Project Pipeline, only four are G20 countries. The participation of more G20 countries in the Hub would provide a more complete and transparent picture to investors of the direction of infrastructure plans as a whole.

Other global initiatives also help to improve the transparency of infrastructure project pipelines. These can be divided into influencers, mobilisers and tool providers (Mercer and IDB, 2016). *Influencers* – such as the OECD Centre on Green Finance and Investment, the New Climate Economy and the Global Infrastructure Investor Association – provide research and leadership to align infrastructure investment plans with sustainability targets. *Mobilisers*, such as the GI Hub, assist *i)* governments in developing bankable projects and *ii)* investors in funnelling funds into those projects. *Tool providers* – such as the IRENA Navigator and the World Bank's REFINe – aim at facilitating the integration of environmental and social components of infrastructure projects into investment decisions (Mercer and IDB, 2016).

Other platforms provide information on public-private partnerships (PPPs) for infrastructure projects, with the aim of matching investors to projects. For example, the World Bank's Private Participation in Infrastructure (PPI) Project Database contains data on 6 400 infrastructure projects in 139 low- and middle-income countries (World Bank, n.d.b). The World Bank also provides a range of other resources on PPPs for infrastructure, including regional and sectorial updates on overall infrastructure investments through PPPs, as well as sample agreements, checklists, risk matrices, standard bidding documents and other material facilitating the establishment of PPPs, notably in developing countries (World Bank, n.d.c; n.d.d). Strengthening those existing tools to improve the data quality on existing infrastructure investments and future plans and needs is a key priority for G20 countries, and critical to gain the confidence of private sector investors in low-carbon, climate-resilient infrastructure (Chapter 5).

Notes

1. All estimates were converted to 2015 USD for comparability.
2. Bhattacharya et al. (2016b) explain that such an increase is the result of a different methodological approach, and argue that previous estimate failed to reflect the increase in infrastructure spending over the past decade, mainly in middle-income countries. Batthacharya et al.'s (2016b) methodological approach consists of calculating an updated baseline of infrastructure spending in 2015 for major countries, and projecting investment requirements on assumptions of growth and investment rates (which are in turn based on assessments of investment plans and identified gaps across major economies and regions).
3. Details of the assumptions on costs are available in IEA (2017).
4. Pre-construction includes power plants announced, in pre-permit development and permitted. "On hold" includes plants announced as being on hold. In the absence of an announcement that the sponsor is putting its plans on hold, a project is considered "shelved" if there are no reports of activity over a period of two years. At the global level, coal power plants in pre-construction development and "on hold" amount to 570 GW and 607 GW respectively.
5. See Iyer et al. (2015); Rozenberg, Vogt-Schilb and Hallegatte (2014); Johnson et al. (2015); Fay et al. (2015).
6. Although there is value in assessing the cost of shifting the building stock to meet the energy requirements of a low-carbon transition, retrofitting and renovation would add value to buildings, which is not the case of stranded assets in the energy sector. IRENA estimates stranded assets in the buildings sector to amount to USD 12.5 trillion in its Delayed Policy Action case and USD 5 trillion in the REmap reference case; computed as "the difference between cost of deep retrofit and the additional cost to build a new fossil-free building" (IRENA, 2017a).
7. It also assumes oil demand would be at 45% (IRENA) and 41% (IEA) of today's level by 2050. Other methodological differences include that IRENA estimates the impact on the oil and gas sector through the capital value of registered companies, then extrapolates to global oil and gas production. For power and industry, it calculates stranded assets based on the nominal value of a plant shutting down before the end of its economic lifetime.

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