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Infrastructure to 2030
Telecom, Land Transport, Water and Electricity

Chapter 1

A Cross-sectoral Perspective on the Development of Global Infrastructures to 2030

by

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Infrastructures are at the very heart of economic and social development. They provide the foundations for virtually all modern-day economic activity, constitute a major economic sector in their own right, and contribute importantly to raising living standards and the quality of life. However, infrastructures also have less desirable consequences. To name but a few – more roads may mean more traffic and more noise, power plants may add considerably to greenhouse gas emissions, and dams may entail the destruction of large areas of countryside and the displacement of population. The next decades are likely to see an accentuation of two facets of infrastructures. On the one hand, they will prove a vital tool in resolving some of the major challenges faced by societies – supporting economic growth, meeting basic needs, lifting millions of people out of poverty, facilitating mobility and social interaction. On the other, environmental pressures in the form of changing climatic conditions, congestion and so on are likely to increase, turning the spotlight firmly on the inherent tensions between the imperative for further infrastructure development and the quest for sustainability.

This is just one good reason for taking a long-term perspective on infrastructures – there are others. Infrastructures usually last a very long time, often generations, and also take a long time to build, so that bringing about change in their systems requires long-range thinking and vision. Moreover, globalisation is intensifying economic and other interlinkages among countries, making it increasingly necessary to plan, develop and finance infrastructures across national borders. The key players too change over time, as the roles and responsibilities of the public and private sectors shift and evolve. Such changes underscore the importance of taking a longer-term view of both the objectives of public policy – economic, social and environmental – and the regulatory and institutional framework within which they are pursued.

Hence, the next 25 years offer a useful time frame for exploring many of the issues that will need to be tackled if these various challenges are to be addressed successfully. How much investment in infrastructures is likely to be required, and what are the forces – economic, demographic, technological and environmental – shaping those requirements? How will they be financed? What difficulties is the management of infrastructure likely to confront?

These are some of the key questions this publication sets out to explore. In so doing, it will highlight the importance of considering infrastructure not just as distinct sectors but also as a series of interdependent systems.

The infrastructures covered in this publication – land transport, electricity, telecommunications and water – have for many years now shown signs of increasing convergence. The various systems interact ever more closely with one another and engender all kinds of synergies, substitution effects and complementarities, but also in some cases heightened vulnerability to disruption, technical failures and malicious attack. Policy makers need to take a holistic approach to infrastructure development and consider what infrastructure mix may be desirable in light of the tradeoffs that will have to be made between the various policy objectives. (For example, environmental concerns may lead to attempts to shift traffic from roads to rail or to increase the share of renewable energy sources, but without unduly constraining economic development.)

This introduction is organised as follows. In order to put infrastructure development into a proper overall policy perspective, it begins with a brief overview of the economic, social and other benefits that infrastructures have generated in the past and might be expected to provide in the future, before turning to the question of the most important factors likely to shape the development of infrastructures in the coming years. After summarising the findings of projections on future investment requirements from each of the sectoral chapters, it addresses some of the specific interdependencies among the different infrastructure sectors. Finally, it draws out a number of relevant cross-sectoral issues and policy challenges, and then reflects briefly on the way ahead.

1. Benefits from infrastructure – past and future

The economic benefits of infrastructure have been the subject of much debate since at least the 1980s, with the discussion focusing on both the direction and magnitude of the effects. While it is possible to establish a link between infrastructure development and economic development, it is difficult to ascertain the direction of the causation: does infrastructure contribute to economic development or *vice versa*? Moreover, there was considerable scepticism about the initial estimates of the productivity gains stemming from investment in public infrastructure. Over the past few years however – with improved data, new methodological approaches and refinements to models – there has been much less controversy. A review of the more recent literature suggests that public infrastructure has a positive productive effect on the economy, but that the size of the effect is not as large as that estimated by earlier studies [such as those by Aschauer (1989)]. Based on samples of several OECD countries and broken down according to economic sectors, the findings indicate that the efficiency impacts of infrastructure tend to be positive – but relatively modest – in almost all sectors.

What is important to note is that the returns on infrastructure investment take time to materialise. The more recent studies indicate that the long-term impact of infrastructure on the economy is positive, and that while an increase in investment in public capital acts as a substitute for private capital initially, in the long run the dominant effect is one of complementarity. However, it would appear that investment in infrastructure does not, on the whole, create (directly) long-term employment. The studies also suggest that patterns of underinvestment in infrastructure in some countries may have something to do with the difficulties governments experience in estimating the overall long-term effects of infrastructure on the economy. Making the "right" decision regarding infrastructure development is often difficult because of the public good nature of the benefits (how much is enough, who should benefit). Moreover, the broader impact of infrastructure is clearly conditional on how efficiently it is used. Poorly managed or poorly conceived infrastructure does not necessarily generate the same return.

The productive impact of an infrastructure depends not only on the magnitude of the investment, the project's design and efficient management, but also on the nature of the investment and its integration into an existing set of infrastructures, *i.e.* how it improves the network. Thus, first infrastructures only have limited impact on private sector productivity since their effect is primarily local. The addition of new infrastructures to create a network, however, allows considerable productivity gains by extending the use of existing infrastructures to everyone. Subsequently, when the network is largely completed, the addition of new infrastructures again has only limited impact, if any, on private sector productivity.

But such additions can still have an effect on the economy, namely by making the regions in which infrastructures are abundant more attractive and thereby enhancing their competitiveness. This in turn may give rise to relocation of factors of production among regions. Attractiveness is therefore a factor, irrespective of whether the infrastructures lead to productivity gains. The political dimension of this process is clear, since it will benefit some regions at the expense of others as they compete among themselves to attract labour, capital and know-how. From an overall economic perspective, this highlights the importance of conducting cost/benefit analyses for large projects that also take into account the loss of attractiveness of those regions not concerned by the new infrastructure. Attention should also be paid to consumers' intrinsic evaluation of the infrastructure since this can generate knock-on effects, for instance in the form of higher property prices.

What of the eventual economic benefits of infrastructure? As more and more networks are completed, for example, will the economic benefits stagnate? Generally, this seems less likely. As Stamford points out in his chapter on land transport, notwithstanding political factors that may have resulted in some

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uneconomic projects going ahead, it can be assumed that in OECD countries most of the transport infrastructure investments over the past 20 years have been cost-beneficial; and that it is very likely that some amount of cost-beneficial new construction has been constrained by limited availability of public finance. Moreover, in most of the so-called Big 5 economies (Brazil, China, India, Indonesia and Russia) and developing countries, there has been chronic underfunding of transport and other infrastructure, also reflecting limited public finance availability. On these assumptions, it seems safe to say that also in future, the benefits of road infrastructure spending will exceed the costs.

In comparison with the economic benefits generated by infrastructure, the value of infrastructure as a contributor to higher living standards and quality of life has received much less attention. Yet it is likely to be very high, given that households and private individuals are heavy users of infrastructure systems. Part of the problem is that the value of unpriced goods is difficult to measure. However, broad indicators of infrastructure availability can give a flavour of the difference to living conditions that infrastructures may make.

By way of illustration, it is clear that the coverage of 98% of the population in developed countries with sanitation services produces health and welfare outcomes greatly superior to developing regions with an average of only 49% coverage. More concretely, since in some cases health and welfare outcomes can in fact be approximated, it is estimated for the developing regions of the world that the benefits of halving the proportion of people without access to improved water sources by 2015 would be 9 times the costs incurred. Universal access to improved water and sanitation services by 2015 would generate an even higher benefit/cost ratio, in the range of 10. (See the contribution by Ashford and Cashman.)

By the same token, raising worldwide electrification rates from 74% in 2002 to 83% in 2030 (as projected by the IEA in the *World Energy Outlook*, 2004) would provide millions of people with electricity for the first time, contributing hugely to social development through education and public health, satisfying more effectively basic human needs of food and shelter, and reducing use of traditional biomass for energy purposes, with attendant benefits in terms of slower deforestation. Similarly, the rise in the number of mobile telephone service users across the globe from 800 000 in 2004 to over 5 billion in 2020 (see the chapter by Bohlin, Forge and Blackman) holds out the promise of greatly enhanced access to communications and vastly improved mobility for millions of people. This could also have major overall economic benefits, by raising productivity and accelerating the diffusion of knowledge.

2. Driving forces, trends and uncertainties affecting the longer-term outlook for infrastructure investment

A whole host of factors driving the development of infrastructures need to be taken into account in any forward-looking analysis of long-term investment requirements. The core assumptions underlying almost all projections of this kind concern economic growth (GDP) and population. But other driving forces may also affect the projections, thereby constituting an important source of uncertainty. While in shorter-term projections some of these drivers may be assumed away as playing only a minor role, they cannot be ignored realistically when a longer-term time frame is considered, as is the case here. Even if only a qualitative and highly tentative exploration of their impact can be made, it is important to do so for policy purposes. This helps policy makers better understand the risks involved in the projections and the consequences this may have for policy.

The authors of the sectoral chapters in this volume have explored a range of drivers and uncertainties from a variety of perspectives.

Geopolitics

All the authors acknowledge explicitly or implicitly the role played by geopolitical factors and their interaction with infrastructure development (though none of the papers takes into account the possibility of a major conflict that could seriously disrupt the economic and political environment in the coming decades). Bohlin *et al.* stress in particular the important role played by telecoms as a political asset for popular movements and its ability to change the balance of government and to contribute to the decline of the nation state. Morgan is not as explicit in the IEA paper, but he acknowledges that concerns related to the need to ensure the reliability and security of supply – which involves geopolitical considerations – is likely to influence investment decisions, for instance with regard to the fuel chosen for generating electricity (*e.g.* nuclear power in France and coal in the United States). Security of supply considerations may also influence the direction of research efforts to find alternative sources of energy or make existing ones (*e.g.* coal) more acceptable from an environmental point of view.

The geopolitical dimension may be less important for land transport than it has been in the past, but the critical role of road and rail for international connectivity is acknowledged. In the case of water, geopolitical considerations relate particularly to the potential conflicts that may arise among countries sharing water resources (see Ashley and Cashman). Some 40% of the world's population live in the 250 major river basins shared by more than one country. In Africa one-third of all water flows through the Congo, while only a tenth of the population lives within its basin. Economic development in Sudan and

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Ethiopia will draw on the Nile's waters, making the potential for conflict with adjacent states a real concern. Notwithstanding a number of established international mechanisms for mediating the problems of shared water resources, there is ongoing potential for water-related problems to contribute to regional tensions, such as in the Middle East (surface water resources) and Palestine (groundwater). Like Bohlin *et al.*, Ashley and Cashman see a decline of the nation-state as it is hollowed out upwards to the benefit of supranational organisations and downwards through devolution.

Security

Infrastructures need to be as resilient as possible so that when disruptions occur, their consequences are as limited as possible in time and scope. In recent years, concerns about infrastructure security have grown. Societies' dependence on infrastructure services has increased, and the consequences of major disruptions can be very serious indeed. Moreover, the scope for disruption has increased, as critical infrastructures become more closely interlinked and the activities of organised crime and terrorist groups take on a wider international dimension.

All the authors recognise the importance of security considerations. Bohlin *et al.* note that security concerns will be a significant driver of telecom infrastructure development. Moreover, they point out that the Internet will become a prime target of economic threat, forcing the development of a security architecture that assures not only that operations are secure, but also that the privacy of the individual is respected.

In the IEA chapter, Morgan stresses as well the importance of security considerations and the need for investment in upgrading and improving system operating tools that would enhance operators' capacity to effectively monitor, understand and more flexibly control transmission systems in real time. The chapter also notes that there is enormous potential for developing and deploying appropriate technologies for this purpose as well as for improving the quality of service.

According to Stambrook, safety and security considerations are also important for land transport. They are not considered a particularly new problem as far as road transport is concerned, since such considerations are already built into the estimates. The author, however, notes that security concerns may affect modal choice. Recent experience with terrorism targets and accidents suggests that travellers may in the future prefer the security of road transport relative to rail, in addition to the time and flexibility advantages. It is unclear whether (relative to air) there is a clear security/safety benefit for high-speed rail. Hence, additional security/safety costs are likely to be required to be built into rail systems to counteract these travellers' concerns.

Water facilities are also vulnerable to security threats. Certainly in North America the risk of malicious attack is becoming an increasingly important factor in infrastructure investment decision making. Attack could take the form of direct action to contaminate water supplies. But widespread disruption would likely be effected more easily via cyber attack, disrupting power, communication and control systems. The effects can be demonstrated by the power failure in the northeastern United States in August 2003, in which a number of wastewater treatment plants failed, leading to environmental pollution and households being advised to boil water (Ashley and Cashman). This illustrates the interdependencies across infrastructures and the need to take a holistic approach to security.

Economic growth and structure

In all four chapters, economic growth, notably growth in per capita income, is acknowledged as the major determinant of the growth in the demand for infrastructure. Indeed it is the only variable explicitly used in the projection exercise with the exception of the chapter on water, where an attempt is made to quantify the impact of four drivers of change (socioeconomic, technology, environment and political) on projected expenditures for water infrastructure as a percentage of GDP after 2015. Bohlin *et al.* note that increased income will drive all forms of telecom takeups, most specifically mobile. At the same time, telecom will drive economic development and will contribute to reducing income inequality across countries, as the main expansion of the telecoms network will take place outside the developed countries.

Morgan notes in the IEA chapter that the demand for electricity is closely related to changes in gross domestic product. Over the past 30 years the global economy grew by 3.3% a year while electricity demand grew by 3.6% with a very close tracking between the two variables. However, this remarkable stability in the relationship between GDP and the demand for electricity at the aggregate level hides striking differences between OECD countries, where the amount of electricity per unit of output produced has declined over time, and developing countries, where it has risen. Hence, changes in the structure of economic activities play an important complementary role to GDP growth. In this regard, a key question for the future is how fast the industrial mix in developing countries is likely to evolve, notably how fast the share of services will expand. For instance, over the next ten years it is expected that employment in the service sector will increase much faster than total employment in countries such as India and China, suggesting perhaps a substantial decline in the energy intensity of output at the margin in these countries. One should remain cautious in this regard since employment mix is not closely linked to output mix and hence to input mix. It is true that manufacturing employment in developing countries is not expected to increase much in the future. However, the manufacturing sector is the major

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source of labour productivity growth. In this context, increasing the output/labour ratio means that even if employment growth is modest, output growth and resource use growth may be substantial indeed.

GDP per capita is acknowledged as the main determinant of the demand for land transport, but various measures of road usage are also related to income: estimates of the elasticity of vehicle stock with regard to income vary between 0.75 and 1.25, with the elasticity of vehicle distance driven with respect to income in the 0.2-1.60 range. However, the link between per capita income and the demand for rail transport is not as clear-cut, since the expansion of rail, notably passenger rail infrastructure, is driven more by policy considerations (notably sustainability considerations) than by revealed consumer preferences.

GDP growth is also a main driver of the demand for water infrastructure and affects as well the ability of countries – notably developing countries – to carry out the necessary investment. In this regard, Ashley and Cashman note that if developing countries overall grow faster than developed countries over the next three decades, as suggested by World Bank projections, there should on the whole be a proportionately greater ability to pay for water services in the future (a notable exception being sub-Saharan Africa). Also important here is the development of international trade. As Rosengrant *et al.* (2002) point out, if trade in agricultural products increases in the future, this will be a way for water-poor countries to acquire water-intensive products and specialise in the production of goods requiring limited amounts of water.

Finance

Given the large amount of resources needed for infrastructure development, financial considerations – including the role to be assigned to public and private investors – play a key role in infrastructure investment.

In the case of telecommunications, the substantial funding needed for infrastructure upgrade and expansion will be largely carried out by private actors. Hence, the health of the lending market is essential (Bohlin *et al.*).

IEA also stresses the importance of access to capital for electricity investment. While such access is relatively easy in OECD countries where capital markets are well developed, the higher risks brought by market liberalisation and the uncertainties regarding future environmental policies will increase investment risks for operators in the coming decades – hence debt servicing charges are likely to rise.

In non-OECD countries, the situation is much more critical. First, capital markets are not well developed. More importantly, the private sector is being called upon to finance a larger share of electricity investment than in the past, in an economic, political and regulatory environment where the profitability of such investment appears highly problematic. Whether the capital needed can be mobilised quickly enough in this challenging context is a major uncertainty for the future. It may prove less so for countries with traditionally high saving rates.

Stambrook notes that in land transport, where the public sector plays a dominant role, the biggest challenge will be the public willingness-to-pay for increased land transport mobility – either through general taxation (as mediated by public finance authorities), specific taxation (where this exists) or user charges (including in support of private participation *i.e.* PPP). It is further noted that given individual users' preference for road transport over rail, there is no "sustainability" fiscal dividend involved in any attempt to favour rail over road. Whatever they do, public finance and transport authorities will have to spend more on road infrastructure in the future or face dire economic and political consequences. At best, spending more on rail will only moderate the future increase in road infrastructure spending, not eliminate it.

Finance plays a key role in the water sector as well. An important trend has been the growing use of private capital as a way to shift the burden of funding from the public to the private sector. On the face of it, the water sector should be an attractive prospect: it is an essential service; it is technologically relatively low in risk and if reasonably well managed, offers steady though not spectacular returns. However, Ashley and Cashman note that private investment in the water sector is not without problems, as experiences in South America, South Africa and the Philippines suggest. Despite these difficulties, the involvement of the private sector in the public provision of services such as water is likely to grow in importance – especially given the huge engineering and financial challenges to be faced either in the provision of new infrastructure or the maintenance of existing assets. The nature of the relationship between the public and private sectors in this regard will have to evolve from the present models in order to gain greater political and social acceptance, especially in developing countries. Notwithstanding the possible growth in the role for the private sector, there is also potential for some forms of public financing, *e.g.* user fees, and the wider use of bonds.

Demography

Together with economic development, population growth is considered the most important driver of the demand for infrastructure. However, it is not the only demographic factor at play. For instance, Bohlin *et al.* acknowledge the importance of population ageing, of urbanisation in the developing world and of international migrations as important determinants of the expansion of telecom networks. Increase in the number of households could also be a factor here, as it is in the case of electricity.

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The IEA chapter also notes that changes in the level and age composition of the population affect the level and composition of electricity demand, directly and through its impact on economic growth and development. Ageing increases the number of households and therefore per capita electricity consumption. Migration also affects the need for new capacity investment in production transmission and distribution.

In the case of land transport, Stambrook points out that, together with GDP growth, population growth is the most important determinant of growth in the demand for infrastructure. He also points to the significance of population density, notably for the development of high-speed rail (HSR). However, he sees population ageing as having only an indirect effect, *i.e.* as putting pressure on health care systems and leading to many competing policy pressures for limited public funds – especially with the apparent "cap" on taxpayer willingness-to-pay. This position contrasts interestingly with the view expressed in other studies where population ageing is perceived to have an important impact on peak infrastructure use, a major determinant of infrastructure requirements.

Demography will also be a major determinant of the demand for water infrastructure. In developing countries, the rapid growth of population in urban areas, coupled with the pressures of economic growth, will give rise to considerable demands for water services both to provide industry with a base resource and also for the survival of the population. Given the low level of income of the majority of the population, the challenge will be to provide and extend a basic level of service to the burgeoning population centres at an affordable cost to both government and citizens alike. In the developed world, shifting patterns of human settlement may put sustained pressure on freshwater resources in some regions, possibly leading to tensions between urban and agricultural communities over priority setting for water use. However, the challenges are more likely to arise as a result of the consequences of population ageing (and the attendant increase in the number of households) rather than the need for new water services, given that the overall population will be stable. Indeed the rising expectations and relative wealth of their populations may well result in calls for higher levels and different forms of service from the existing infrastructure (Ashley and Cashman).

Technology

Technology plays a role in the development of all infrastructures, but its importance varies across sectors. Past experience also suggests that technical change is highly unpredictable and can have far-reaching impacts on infrastructure (*e.g.* the impact of mobile telephony on fixed line infrastructure, and of the Internet on the telecommunications sector and the economy at large).

Technology is considered particularly important for telecoms, as it is likely to be a driver behind the very rapid expansion of telecom networks expected in the coming decades by bringing about drastic reductions in communications costs (Bohlin, *et al.*). Particularly significant in this regard will be the widespread adoption of VoIP, further progress in fibre optic, greater data processing capabilities, the development of new mobile technologies, the introduction of location-based services, the further miniaturisation of equipment, progress in storage capacity, improved batteries and the development of local energy technologies for powering telecom equipment. Moreover, RFID could change logistics and medical care infrastructure services and will require new infrastructure for their effective implementation. In addition to the prospects identified by the authors, there may prove to be greater than expected potential both for space telecommunications (*e.g.* development of intelligent satellites and routers in the sky with onboard processing and multiple spot beams) and for the convergence of content and carriage (*e.g.* development of virtual reality applications). However, given the rapid evolution of technology in this sector, it is important to keep in mind that any attempt accurately to anticipate change over a 30-year period is obviously an impossible task. In particular, it is impossible to anticipate what technology will find widespread acceptance.

Technological change is expected to proceed at a more sedate pace in the electricity sector, although technical progress in telecoms could have important spillover effects for the management of electricity networks. According to the IEA chapter, technical advances will be reflected in part in the improved energy efficiency of electrical equipment, notably in developing countries. This could moderate increases in the demand for electricity in these countries, but it is not clear by how much. New technology could also contribute to cut distribution losses, thereby reducing the need for generating and transmission capacity. The choice of generating technology [*e.g.* natural gas-fired combined-cycle gas turbine (CCGT)] affects the size and location of power plants and therefore the need for transmission capacity. For instance, the volatile production patterns that result from a high proportion of renewable energy supply most likely mean increased investments in the grid, since it has to be particularly robust in order to secure reliable supply from both conventional and renewable energy production plants. However, technological factors need to be balanced against other factors, notably security of supply considerations. For instance, growing concerns about the reliability of supply of gas from Russia may dampen somewhat the enthusiasm for gas-fired electricity generation in Europe. On the other hand, technological progress may have important geopolitical consequences. For instance, over the long term, effective carbon sequestration could considerably strengthen the position of coal over oil and gas, and favourably influence the geopolitics of energy for consuming countries. And the successful development of long-life batteries could significantly accelerate the widespread adoption of electric cars.

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Technology seems to be least important for land transport. Stamford does not anticipate breakthrough technologies over the 2000-30 period that could fundamentally affect land transport demand. High-speed rail (and Maglev) technology is already around and tried. Improved vehicle technology (*e.g.* fuel efficiency, fuel technology) and vehicle design can offer substantial environmental benefits but should not affect the demand for road infrastructure. And ICT-inspired improvements in road capacity utilisation will probably only operate at the margin of incremental demand, although other studies do suggest a greater influence over the longer term.

By contrast, technology could play a key role in the development of water infrastructure in the future. First, advances in information technology and communications coupled with space technologies such as Earth observation could lead to a much greater ability to monitor all aspects associated with water-related service provision – the circumstances and the events surrounding it – in greater detail and to a greater extent than is currently technically possible. Second, biotechnology could significantly improve pollution prevention, monitoring and remediation. It has the potential to completely revolutionise water treatment processes and may well enable service providers to dispense with conventional treatment plants as they are known today. Much of the treatment would not require a large capital investment for the provision of large fixed infrastructure, as this would be replaced by in-system and on-site processes, tailored to specific circumstances and requirements. It could even lead to the elimination of the distinction between water distribution and sewage systems as it becomes possible to combine them without impacting on public health. And thirdly, in the field of nanotechnology, advances are likely to have the greatest impact on maintaining and enhancing the performance of infrastructure. This could come about through the use of sensors, smart materials and materials with the ability to self-heal and regenerate.

3. The outlook for infrastructure investment requirements

This section provides an overview of the projections presented in each sectoral chapter and gives a brief outline of the basis on which they were made. To begin with, however, a few cautionary remarks are in order. It is important to note that the purpose of long-term projections is not to forecast the future. Rather, it is to explore how the future might evolve given a set of economic, social, technical and political assumptions, among these usually the absence of any new policy actions. Despite the uncertainties naturally attached to such long-range projections, experience has shown that they offer a useful framework for identifying critical factors and for reflecting on the policy levers that could be used to steer the economy and society at large towards a more desirable future. Moreover, consideration of the major shaping factors can also help governments identify some of the policy levers that could be applied in pursuing objectives. With this in mind, the findings of the sectoral chapters should be treated solely as indicative of the order of magnitude of the investments that are expected to be required.

Telecommunications

Annual total infrastructure spending worldwide is expected to rise from USD 650 billion in 2005 to USD 745 billion in 2010, falling thereafter to USD 646 billion in 2015, USD 572 billion in 2020 and USD 171 billion by 2025. After a period of rapid expansion of capacity (notably in developing countries) in the initial phase, the sharp reduction towards the end of the period is due, according to the authors of the sectoral chapter, to a steep drop in technology and equipment costs and in new-build investment, as saturation in user populations is reached and the vast bulk of spending concentrates on renewals and support maintenance. Indeed, maintenance and renewal spend is assumed to represent by far the largest share (about 80% in 2010 and over 90% in 2020) of annual infrastructure expenditures. The major part of future infrastructure will be in the form of fibre optics and, even more importantly, radio access networks. The largest proportion of infrastructure investment will be devoted to multiple forms of mobile packet radio. Fixed line will act as complementary long distance and feeder access network.

Future infrastructure demand is likely to be determined by the increasing economic power of the developing world and by its populations' needs for accessibility – 3.5 billion potential users beyond the 2 billion or so current users of telecommunications in all forms. Although over the 25-year period OECD countries are likely to account cumulatively for more than half of all global telecom infrastructure investment, spending on infrastructure investment in non-OECD countries is likely to overtake that in OECD countries sometime towards 2020. In consequence, the developing countries and their requirements will begin increasingly to shape future telecommunications infrastructures, and future infrastructure technology could well leapfrog current OECD progress. The architecture of telecommunications infrastructure will move to simpler, less smart networks, with intelligence based at the edges in servers and new devices.

Electricity generation and networks

Large amounts of investment will be needed in the coming decades to meet the increase in demand for both the quantity and quality of electricity services, as well as to maintain and replace existing infrastructures that will be retired. In a reference scenario, in which no new government policies are assumed, total annual worldwide electricity investment needs through to 2030 average around USD 350 billion. More than half of this investment (about 53%) will go to transmission and distribution, with the latter claiming

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the lion's share of overall network investment. Although the bulk of the spending will be in developing countries (notably in China), new investment in Europe and North America will be substantial, so that OECD countries will nonetheless account for over 40% of worldwide investment in the electricity sector (and around 35% of transmission and distribution). Refurbishment of transmission and distribution infrastructure, including replacement of cables, substations and control centres, will account for well over half of total network investment worldwide.

In an alternative policy scenario, which considers the impact of new government policies to curb demand growth and promote switching to cleaner fuels (including more use of renewables and distributed energy), world electricity demand and investment needs grow less rapidly in almost every region, on average 15% less over the 25-year period. The main uncertainties surrounding the adequacy of electricity investment worldwide relate to the impact of market reforms, environmental constraints and access to capital. In general, the effects of market reforms and environmental constraints are most uncertain in OECD countries. Policy makers are seeking to address concerns about the adequacy and timeliness of investments to ensure system reliability and an adequate quality of service by establishing a market framework that sends efficient market signals to investors.

Land transport

Two modes of surface transport are addressed, road and rail.

Road transport: The report estimates new infrastructure construction (*i.e.* net additions and maintenance/replacement) over the period 2000 to 2030 at between USD 220 billion and USD 290 billion per year. The largest component of the road infrastructure requirement arises from the need to maintain, upgrade and replace existing road assets, which deteriorate over time. A smaller component actually goes to augment the road capital asset value. These estimates are broadly in line with previous albeit shorter-term projections (*e.g.* World Bank). Roughly two-thirds of all new infrastructure construction is expected to take place in OECD countries, and about one-fifth in the Big 5 economies.

Rail transport: Infrastructure requirements (new construction) of between USD 50 billion and USD 60 billion per year are projected over the period 2005-30. These are substantially higher than previous studies suggested, in part because they reflect some significant rail upgrading plans envisioned and commenced under the EU TEN-T programme and major rail-building plans (including high-speed rail) in China and other Big 5 economies. Again, some two-thirds of the rail infrastructure construction over the forecast period is expected to occur in OECD countries, followed by the Big 5 countries; the latter will account for around one-quarter of total investments.

There is some scope for deliberate government policy to influence modal use – and shift more road use to rail – through the diversion of up to 10% of new road construction (*i.e.* USD 20 billion to USD 30 billion per year) to rail (in addition to the levels of investment already forecast). These could have some attendant (though probably bearable) consequences in terms of deteriorating overall road infrastructure quality and rising road congestion. Also, road and rail connectivity to airports and ports is critical to growing international movements, and there is a risk in many cities for local planning and amenity issues to override national and international interests in improving these connections.

Water supplies and treatment

The projections for annual investment in water systems through to 2025 point to significantly higher levels of investment requirements than previous studies suggest. In the OECD and Big 5 economies annual expenditures in the range of USD 770 billion are projected up to 2015 and over USD 1 trillion by 2025. Much of this spending in Europe and North America will be on maintenance, repair and replacement rather than on additions to existing networks, since water systems in many of these countries are now very old and in poor condition. It is primarily in the developing world that new construction and expansion of networks will be required: in Africa only some 40% of the population are served with adequate water supplies, and only 80% in Latin America, the Caribbean, Asia and the Pacific. Not least in OECD countries, environmental pressures will continue to grow, as will the expectations of the general public with respect to environmental protection and natural resource management. These factors are expected to add significantly to the costs incurred in the supply of water services and wastewater treatment.

The projections indicate that as we progress through the next three decades, water-related infrastructure investment requirements are likely to grow significantly and could well dwarf the requirements in the other three sectors under investigation by 2020-30. This suggests that governments will need to pay particular attention to water in the future – not only because, like air or food, it is essential for life, but also because investment outlays will be huge throughout the world.

Total investment across all infrastructures

On the basis of the estimates provided in each of the sectoral chapters, it is possible to provide an overview of the findings on likely global infrastructure investment requirements through to 2030. These are presented in tabular form below. However, it is important to bear in mind not only the caveats spelled out at the beginning of this section, but also the fact that the projections for each sector have been developed on the basis of different approaches, different methodologies and different data sets. Hence, the table

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can only provide an indication of the orders of magnitude of the infrastructure investment requirements worldwide over the next few decades. Moreover, the figures reflect needs, which for many different reasons may not necessarily translate into effective demand.

Table 1.1. **Estimated average annual world infrastructure expenditure (additions and renewal) for selected sectors, 2000-30, in USD Bn and as a percentage of world GDP**

Type of infrastructure	2000-10	Approximate % of world GDP	2010-20	Approximate % of world GDP	2020-30	Approximate % of world GDP
Road	220	0.38	245	0.32	292	0.29
Rail	49	0.09	54	0.07	58	0.06
Telecoms[1]	654	1.14	646	0.85	171	0.17
Electricity[2]	127	0.22	180	0.24	241	0.24
Water[1, 3]	576	1.01	772	1.01	1 037	1.03

1. Estimates apply to the years 2005, 2015 and 2025.
2. Transmission and distribution only.
3. Only OECD countries, Russia, China, India and Brazil are considered here.

In addition to highlighting the importance of telecoms and water infrastructure investment requirements, the table gives some idea of the relative weight of infrastructure spending within the economy. Annual investment in the five sectors taken together is likely to account on average for about 2.5% of world GDP. If electricity generation and other energy-related infrastructure investments (oil, gas, coal) are included, the share rises to around 3.5%. An equally rough calculation suggests that for the period through to 2030, total cumulative infrastructure requirements in the above sectors amount to about USD 53 trillion. Adding in electricity generation would lift the figure to around USD 65 trillion, and other energy-related infrastructure investments to about USD 71 trillion. Clearly, the figure would rise further if one were to include other infrastructures not covered by this project, *e.g.* ports, airports, storage facilities.

Over the time scale considered here, it can be seen that investment in land transport and telecommunications is likely to decline, whereas that in electricity and water looks set to remain steady or increase slightly. The expected fall in telecoms infrastructure spending results not only from the assumed progress in technology but also from the main focus of the analysis on telephony.

Contrasting challenges in OECD countries and non-OECD countries

OECD countries already have much of their infrastructure stock in place. Nonetheless, over the next two or three decades they will require very significant amounts of investment in all the sectors covered here. These requirements stem to an important degree from the need to replace and maintain existing networks.

But these also have to be upgraded and modernised as demands on the quality of infrastructure and related services rise. In a rapidly globalising economy, it will prove essential for OECD countries and regions to strengthen their competitiveness by using modern, efficient infrastructure to attract technology, mobile capital, skills and knowledge. With mounting costs – *inter alia* from environmental regulations, rising urban land prices and the increasing complexity of projects, as well as from growing pressures on public finances – there will need to be changes in the ways that many infrastructures are organised and financed.

At the same time, a rising share of world infrastructure investment will be conducted in the developing world, notably in the Big 5 economies. However – except perhaps in the case of telecoms, and in countries with traditionally high rates of saving – it is not clear whether developing countries in general will be in a position to mobilise effectively the enormous resources that will be needed to carry out the necessary investments, unless far-reaching reforms are undertaken to improve the governance of infrastructure development and management, as well as the efficiency of these countries' financial markets. If they fail to do so, such countries could experience major disruptions of service with significant adverse effects on their economies, leading to economic slowdown or even stagnation.

4. Interdependencies and synergies among infrastructures

As becomes increasingly clear from the analysis conducted above, developments in one infrastructure sector can have important implications for developments in another. These may be complementary effects, as in the case with the application of satellite and other remote sensing technologies to increasingly sophisticated road pricing or metering of electricity and water consumption. Another example is the role that transport infrastructures have historically played in providing right of way for communication networks. The effect may on the other hand be substitutive, as with the use of telework and teleshopping, although to date the overall impact appears to be relatively limited. The incidence on other infrastructures however may in fact be of a different nature, creating for example situations of close dependency which in times of technical breakdown, natural disaster or malicious attack may lead to cascading disruption of critical infrastructures. Finally, the complexity of dealing with several different infrastructures at once may be an important cost factor. Road construction works for example increasingly have to cross or handle other surface transport modes as well as pipelines for district heating, natural gas supplies, electricity cables and drainage systems. Indeed, the cost of managing such interaction with other types of infrastructure may well prove increasingly burdensome in the future, unless appropriate solutions can be found (*e.g.* the application of GIS technologies).

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In addition to the direct interdependencies described above, there are indirect interdependencies which result from the impact of infrastructure on patterns of human settlements. For instance, the automobile has historically favoured a more dispersed habitat, which has a bearing on the requirement for, say, water or electricity distribution. These indirect effects are particularly important for the longer-term perspective.

Table 1.2 presents examples of such interdependencies and synergies among different infrastructures in a simple, illustrative matrix.

5. Cross-cutting issues and policy challenges

The previous sections have considered the benefits that infrastructures can generate, explored how requirements for infrastructure services may evolve over the next thirty years or so, examined some of the main factors and uncertainties that may affect these projections, and identified some of the key interdependencies among the various infrastructures. It seems appropriate at this juncture to take stock of several of the broader cross-cutting issues and policy challenges that emerge from the discussion.

The challenges arise first of all from the fact that demand patterns for infrastructure services will change between and across countries as well as within countries. At the same time, the nature of infrastructure is likely to change as technology and user requirements evolve. Finally, financing the maintenance of existing infrastructure and deploying new ones, as well as managing change in an holistic manner across separate albeit interrelated facilities, will raise challenges of their own.

Challenges relating to the changing geography of infrastructure

The growing internationalisation of the economy and its impact on infrastructures

Globalisation impacts on infrastructures in different ways. As the economy's engagement in international trade and services increases, so does the need to ensure that transport, energy, water and telecommunications have the capacity to absorb intensifying levels of economic activity. Congestion problems may become particularly acute at a country's entry and exit points (ports, airports, frontier road crossings) and on the transport corridors leading to them. This is currently the case in parts of North America, Europe and Asia, as many economies struggle to cope with the surge in business generated by China's rapid growth. Similarly, the demands of an expanding world economy on supplies of electricity are straining many OECD countries' networks, making it vital to ensure that power transmission across frontiers is able to smooth out fluctuations in demand and make up for lost supply capacity in the event of disruption. And as markets grow, the search for economies of scale and scope accelerates and supply chains become increasingly global and sophisticated, notably as the volume of

Table 1.2. **Illustrative matrix of interdependencies among infrastructures**

Infrastructure	Telecommunications	Electricity	Land transport	Water
Telecommunications		Intelligent electricity networks, including remote metering (better demand management). Greater efficiency in spot and futures markets for electricity. More dispersed electricity consumption patterns.	Telework, teleshopping, videoconferencing, telemedicine – leads in some cases to reduced commuting and other travel. More effective vehicle fleet management. Intelligent highway systems – greater security, less congestion, more sophisticated road network pricing. Faster emergency response to accidents. JIT management and longer supply chains – generating more traffic.	With ICT and sensors – better monitoring and control of pollutants, degraded drainage systems etc., and potential for remote metering (better demand management). Possibly greater vulnerability of installations, requiring back-up and fail-safe mechanisms.
Electricity	Dependence on electricity, vulnerable to outages and voltage fluctuation. Electricity network can be used for transmission of information.		Source of power for trains. Progress in battery technology – greater use of electric and hybrid cars – may mean more charging stations. Wider coverage of household electricity – more dispersed habitat – more travel. Cost factor where road construction crosses underground electricity cables.	Dependence of water and wastewater systems on electricity, vulnerable to power failures. Hydropower plants. More widespread pumping and high-energy treatment of wastewater. Cross-subsidisation between electricity and water – depletion of aquifers and other natural water resources.
Land transport	Increases demand for mobile communications, location-based services, navigation systems, emergency services. May stimulate demand for video conferences. Provides telecoms with right of way to lay communications cable.	Use of trains to transport fuel for energy generation (coal, oil). Modal split in favour of rail results in net increase in use of electricity (consequences for sustainability objectives).		Impact on water infrastructure since this is often built alongside or under major highways. Where transport improves accessibility, new settlements will increase demand for water services. In emergencies, drinking water can be transported to disaster-affected locations.
Water	Extension of water infrastructure to new locations and new housing engenders increased demand for telecommunications.	Extension of water infrastructure to new locations and new housing engenders increased demand for electricity services. Use of waste for energy generation. Required to cool nuclear power plants.	Waterways as alternative to road and rail. Poor water infrastructure poses risks to road and rail infrastructures though flooding, pipe breakages, etc. Cost factor where road construction crosses drainage/ water pipes.	

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intra-industry and intra-firm trade expands. Large conglomerates – international as well as national – are emerging in the domains of highway and rail construction, power generation and distribution, and water supplies.

The upshot is that in the next decades the role of infrastructures in underpinning the international economy is set to grow further. This will inevitably turn the spotlight onto the importance of transnational networks and of communications and power links that secure the gateways to global markets. Equally, it will raise all kinds of issues around the need to balance international objectives (*e.g.* the expansion of ports, airports and cross-border transmission lines) with national and local interests, the protection of citizens' rights and so on, as well as underlining the need for well-functioning frameworks for international competition.

Urbanisation and new urban forms

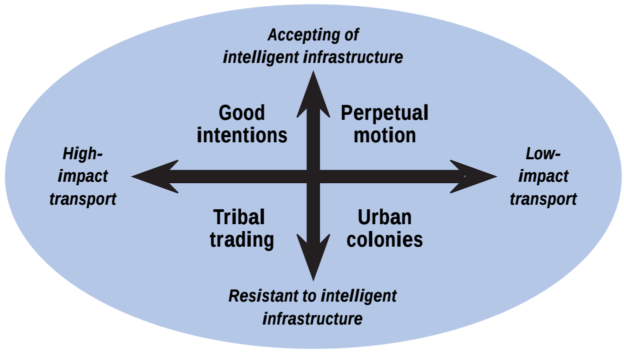
The ongoing overall trend in OECD countries' populations is still a slow but steady incremental increase in urbanisation. However, several emerging patterns might affect this process in the medium term, both quantitatively and qualitatively, and ultimately have an impact on infrastructure needs.

One such trend is the notion of "super-urban sprawl" described as the Telecomia by Bohlin *et al.* After the surge towards suburbia, there is now a movement of populations in OECD countries towards new profiles of residential properties such as low-cost villages and small towns with good amenities or remote large properties in open countryside. This pattern is creating needs for infrastructure (both *in situ* and networked) and for local services, but it is not likely to have a major impact in the short or medium term because of the dis-utilities and opportunity costs associated with it.

Telecomia should not be confused with other population shifts such as the movement towards coastal areas – be they in sunbelt, resort or high-tech cluster locations. This trend is driven by high-tech workers' preferences but also by retirees and telecommuters, who create real needs for additional capacity in infrastructure. Although these needs often occur in high-density areas they are sometimes very costly to satisfy (for instance water in California or European countries because of distant sources, or acceptance of waste disposal plants in the neighbourhood and right of way in the case of power transmission).

In the context of cities, four original scenarios towards 2055 were presented by the UK Foresight Directorate as part of the Intelligent Infrastructure Futures project. Although intended to cover the UK situation, the analysis is based on 60 trends and key drivers that are "universal" at least in the case of OECD countries, and therefore they are not only driven by ICT prospects. The discussion of potential impacts and issues here is limited to the 2025 timeline and the principal scenario.

Figure 1.1. **The axes of uncertainty and the four scenarios defined by combinations of those axes**



Source: DTI Foresight Intelligent Infrastructure Futures, The Scenarios – Towards 2055, Scenarios overview, p. 8 (2006).

The two axes behind the four scenarios are based on two major uncertainties: whether or not environmental issues will impact the design of urban infrastructure (high or low impact axis) and whether or not people will accept intelligent infrastructure. As a result the four scenarios are coined "good intentions" or "perpetual motion" when intelligent infrastructure are accepted and "tribal trading" and "urban colonies" when there is strong resistance to them.

The "perpetual motion" scenario which is the "hyper" one in this context (but not necessarily desirable or plausible) describes a society where people are "always on", meaning that the norm is constant information, consumption and competition. Continued globalisation, economic growth and demand for travel are on the rise. New cleaner fuel technologies, including nuclear capacity and renewable sources, have reduced dependency on oil. Automated highway systems and on-board driver assistance are largely in use by 2025 as well as all the instant communication devices and services. Workloads are high and stress is a growing problem.

As recognised by the authors, this scenario represents the dominant discourse in western culture and assumes that constraints can be overcome by technology and innovation. It is the favourite scenario for the designers, suppliers and operators of intelligent infrastructure goods and services. As can be expected, this kind of scenario is "resource intensive" in financial and human capital, pace of innovation, raw and new material and social acceptance of risks and breach in privacy, potential losses of societal cohesion.

In a way, "perpetual motion" is also best illustrated or at least compatible with a linear infrastructure concept of urban development, shown below, in which cities are built as input-output models, taking all kind of resources from the environment at large and expelling all sort of wastes as a result of the process.

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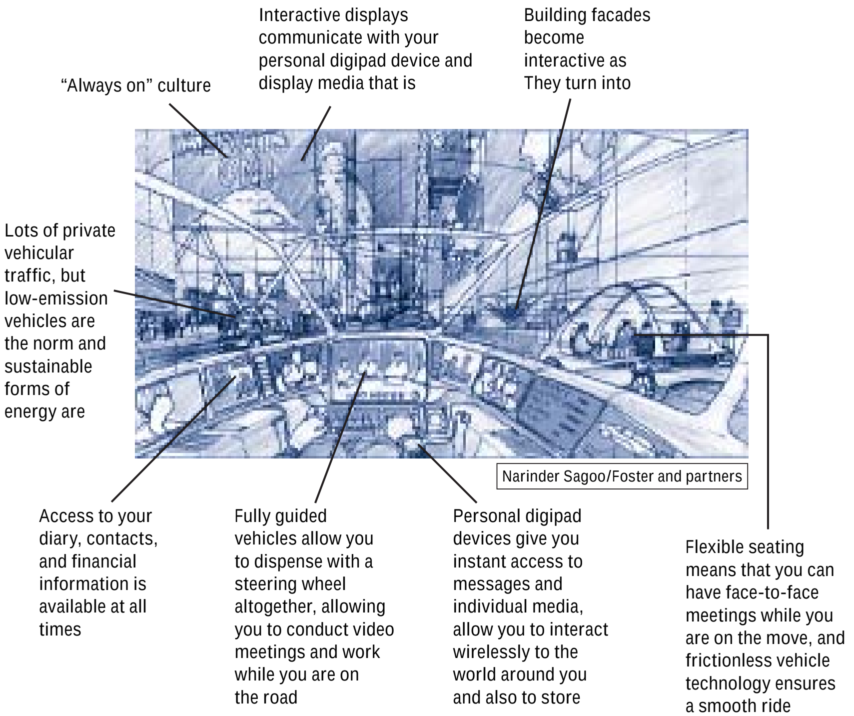
Figure 1.2. **The "perpetual motion" scenario**



Source: DTI Foresight Intelligent Infrastructure Futures, The Scenarios – Towards 2055, Scenarios overview, p. 10 (2006).

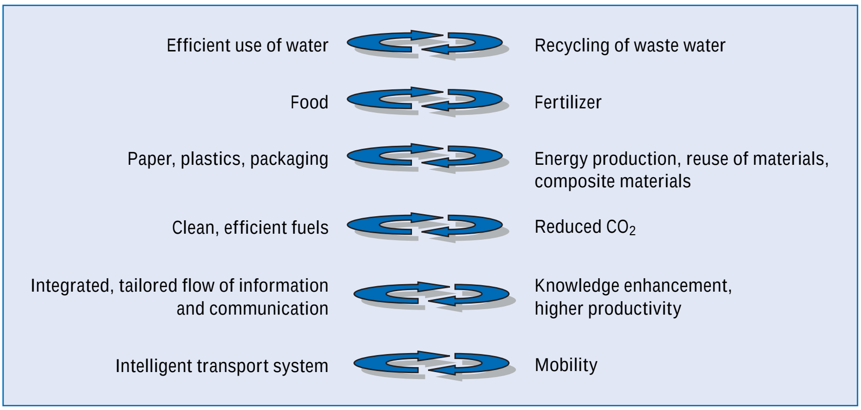
Figure 1.3. **Linear infrastructure**

Food and water →	Sewage
Paper, plastics, packaging →	Waste dumps
Fuels and energy →	Emissions CO_2, NOx
Building materials →	Waste disposal
Information →	Information overload, missed signals
Transport →	Congestion

Source: Adapted from Girardet, H. (1992), *The Gaia Atlas of Cities, New Directions for Sustainable Urban Living*, London: Gaia Books Limited.

As discussed in the previous sections on small-scale and distributed systems, a more organic concept of urban infrastructure can be imagined which would rely much more on closed loop processes. In this case of more sustainable infrastructure, the advantages of high-density patterns and economies of scale could be combined with more eco-efficient modes of production, consumption and transport.

Figure 1.4. **Sustainable urban infrastructure**



Source: Adapted from Girardet, H. (1992), *The Gaia Atlas of Cities, New Directions for Sustainable Urban Living*, London: Gaia Books Limited.

The two models would require significant investments in R&D, strong political will and social acceptance. The second would require more commitment and continuity since it would imply more institutional and organisational changes from the standpoint of many stakeholders and incumbents. As stated elsewhere in this publication and in the literature, big emerging markets would in principle have more leeway to choose the second route because of less legacy constraints, but it would require strong direction nonetheless.

In all cases, policies will matter. Among the many policy issues that would need to be addressed, three stand out as particularly challenging: the willingness to curb individual mobility rights; the level of internalisation of costs expected from operators and end users; and the level of polarisation acceptable to society.

Challenges related to the changing nature of infrastructure

Convergence, security and reliability of supply

A key question relates to the convergence that seems to characterise the future evolution of the four infrastructure sectors under consideration and its possible consequences. Such convergence is reflected first of all in the *growing*

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interdependence across infrastructure, in the sense that the service provided by one infrastructure is becoming an increasingly important input in the operation of other infrastructures. This is illustrated, for instance, by the greater reliance on telecoms expected in the future for the management of electricity transmission and distribution, as well as for land transport. But, as discussed earlier, the dependence also runs the other way, for instance the effective operation of the telecom infrastructure depends on the quality of the power provided by the electricity network. Similarly, failure of the electricity network can have dire consequences for the management of water facilities, and so on.

Convergence is also reflected in the existence of *economies of scope* in the provision of infrastructure services, *i.e.* the fact that as technology evolves, it may become more efficient to produce jointly several infrastructure services. Within the telecoms sector, this evolution is illustrated by the growing popularity of "triple play" offers, where the operator provides at the same time telephony, Internet and access to broadcast services. In the future, the importance of economies of scope in the provision of infrastructure services may increase, leading for instance to the possible merger between the telecommunications network and the electricity network for long distance transmission as well as the distribution of electricity and telecommunications services in the local loop. Another example is water utilities, which may assume a growing role in the production of electricity.

Convergence may have important consequences for the state of competition in the provision of infrastructure services, as well for the pricing of individual services. For instance, in the case of telecoms, providers of triple play may offer telephony for "free" since the marginal cost for them of providing the service (VoIP) is close to zero. As well, one may conceive of water treatment operators, eager to get hold of waste for producing electricity, offering sewage services at a discount to their customers, or electricity utilities offering free telecom services. The consequences for industry structure could be profound.

While such interaction across infrastructures may generate synergies, it is also a source of additional vulnerability: failure in one infrastructure may have serious domino effects on the others. It is unsurprising therefore that this growing interdependence of critical infrastructures is gaining attention in discussions of safety, security, and reliability of supply.

Large scale versus *small scale*

Another trend that seems to emerge from the analysis is a movement away from the large monolithic infrastructures of the past in favour of greater reliance on local autonomy, self-reliance and mobility. Clearly, in many cases economies of scale will ensure the persistence of large-scale installations. But equally, a trend toward smaller, more distributed systems can be observed. This trend is driven in part by technology, in part by deregulation and liberalisation, in part by security concerns, in part by environmental considerations, and in part by the difficulties governments have in raising capital for large infrastructure development projects.

Examples abound. In telecommunications, ATW (alternative wireless technology) local loops are emerging for health services and care of the elderly. These systems can be financed, built and operated by the local municipality (or private local operators) without the intervention of large operators. On the downside, the spread of such local systems might eventually put considerable strain on the frequency spectrum. In the case of water, a number of drivers such as environmental pressures (drought, floods, pollution), security concerns and mounting operating costs will create opportunities for recycling water and creating local loops. This model is likely to apply primarily to the urban and rural residential users as well as to industry. In the near term, developed countries could be the main users because the upfront investment will be borne by the end user and they need to have access to sophisticated technologies such as biotechnologies. As was seen in the case of recent privatisations, such moves may well create liability issues and the need to adapt regulatory oversight mechanisms.

In the case of energy, the diversification of sources is already high on some countries' national policy agenda. Distributed generation technologies may offer a number of advantages. For example, they tend to reduce the need for investment in long distance high-tension transmission lines. In the case of land transportation, by contrast, there is no obvious link to smaller-scale operations, although it has been noted that ageing populations in developed countries might create slower growth in vehicle ownership rates, little or no growth in km per vehicle and declining rates of road capital stock. But they could also create more needs for specific services such as minibus taxis and small buses. The increasing shift from taxes to "user fees" could also lead to reduced appetite for mobility, but the jury is still out on this issue.

An indirect impact of the emergence of smaller-scale systems may be to modify the industrial structure of the supply side. Instead of large systems built by the large engineering companies of this world (such as ABB, Alstom, Areva, GE, Siemens, Westinghouse in the case of energy) a share of the market might be supplied by a different breed of suppliers having more to do with high tech appliances, mass market and retailing capacities than with engineering-type operations. This in turn is likely to require norms, certification processes, and regulatory oversight in order both to protect the consumers and to make sure the potential risks are understood and efficiently allocated.

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A further indirect consequence of more widespread decentralised systems could be to shift funding needs from large operators to the end users or local suppliers. One result could be that investment volumes become atomised and handled on a day-to-day basis by a myriad of financial operators. Hence, business might move away from the structured financing departments of banks towards credit retailing departments (in the case of residential users) or leasing departments. The end result could be to reduce the overall burden of financing infrastructure by dividing the risks and spreading the transaction costs.

From the standpoint of efficiency gains, productivity and overall life cycle costs, it is too early to assume that cost/benefit analysis would militate in favour of decentralised systems as is often advocated by interest groups and non-governmental organisations (Gulli, 2006). Indeed, there is strong evidence that concentration is increasing within several sectors (telecom, road transport, electricity). Moreover, if economies of scope are significant as suggested in previous section, concentration across sectors is likely to increase as well. However, underlying trends and pressures are undoubtedly creating room for smaller-scale systems. It is impossible at this stage to predict which share of the market will see demand peak, or when. In this field policy matters, and incentives are already in place in some OECD countries – *e.g.* for windmills and use of local biofuels – that could accelerate uptake.

The rise of intelligent infrastructures

Whether centralised or distributed, in all four sectors, emerging technological capabilities are creating room for intelligent infrastructure. As in the case of other markets, the potential for intelligent infrastructure is not mainly technology driven (existing technologies in the 60s could have already augmented significantly the efficiency of some infrastructure). Other socioeconomic pressures, such as costs, environmental or safety/security concerns and public acceptance of risks, are much more likely to provide the impetus. A system perspective is therefore more appropriate as an analytical tool. Material in this section is based on the contributions from authors but also from members of the Steering Group of the project and particularly from the DTI Foresight Project: Intelligent Infrastructure Futures (2006).

In the electricity sector, decision support models and automation can create opportunities for optimisation of generation capacity, transmission lines and the grid. Distribution losses could be reduced, peak consumption better handled, reliability enhanced and environment better protected. The electricity sector is already one of the biggest users of ICT but this will imply an even greater deployment of ICT and software, and of sensors, remote sensing capabilities and interoperable components.

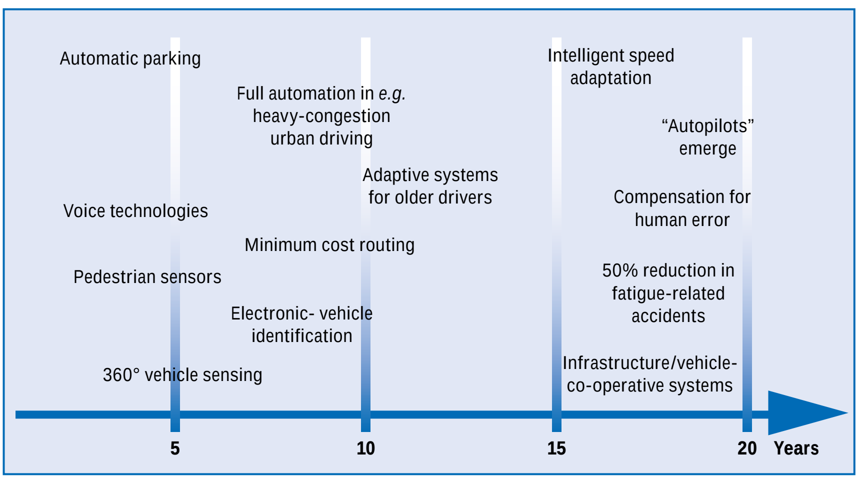
In the water sector, intelligent system modelling technologies can provide a greater ability to monitor and control in real time the water cycle. At local level or end user level, the virtual closing of the water cycle can also be monitored with sensors, embedded software and artificial intelligence.

In telecommunication systems, the integration of multiple AWT into a single multi-service platform can lead to a highly simplified infrastructure including self-healing and perhaps also self-organising networks.

Such integration will for instance in turn facilitate the creation of integrated health care systems, or "smart house" concepts for the elderly.

In the land transportation area, intelligent highways systems and advanced vehicle technologies could bring substantial benefits to network management, accident response, driver information and road/rail capacity (see Figure 1.5).

Figure 1.5. **Foresight vehicle technology roadmap: main capabilities identified**



Source: DTI Foresight Intelligent Infrastructure Futures, Technology Forward Look, Part 2, p. 11 (2006).

Intelligent infrastructure deployment has the potential to augment the capacity at a more or less constant level of fixed capital stock: for example, Stambrook mentions that safety and security enhancements on roads/rail can imply an additional upfront cost of 5%, but savings on maintenance cost could be 5% per year, so a high return on incremental investment can be expected. Intelligent infrastructure can also create substitution effects, but it is not clear to what extent.

Other potential benefits are difficult to quantify but could be very significant: enhanced safety of systems could be key in the sustainability of infrastructure although they create a new frontier: increased dependency on

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automated systems poses new serious risks such as system design failures, software unreliability or vulnerability to malevolent behavior.

The demand for telecommunication backbone, location-based services, navigation systems, emergency services and software engineering would increase. In addition, the points of application would change in the following way:

- Centralised systems (decision support models, command and control systems, nodes and networks) will be needed, but will quite often be in the hands of private operators or public agencies.
- *In situ*, on-board systems: railways and cars but also airplanes or ships will have more and more on-board systems and terminals; end users and local operators in the case of energy, water and telecommunications will have more and more *in situ* "autonomous" systems.

A significant transfer of upfront investments and risks could occur as an unintended consequence of this architecture. For instance, the most "visible" part of signalling and control systems (traffic lights, speed limit signals) would migrate from the roads and railway tracks to be installed on board, while sensors on the ground and in the air would create the missing links with the "overarching" system. Users of cars, trucks, *in situ* generation systems and operators of trains, trucks, airplanes, etc. would then bear more of the costs of capital, maintenance and risks which were in the past borne by the "owner" of fixed capital assets.

Inevitably, such changes will be accompanied by a swath of issues that will need to be addressed by policy – the setting of standards, questions pertaining to intellectual property, implications for privacy, and the role that government could play in R&D efforts, notably in areas that have strong public-good features.

Challenges raised by the future development of infrastructure

Meeting future financial needs

Beyond these general remarks regarding the evolution of infrastructure, three more specific observations are worth making with respect to investment needs and whether they are likely to be fulfilled. First, it is clear that the investments that will be needed in the coming decades are very large indeed across sectors, in part because a significant share of this infrastructure has suffered from benign neglect in the past (for instance water infrastructure), in part because of the large transformation expected in developing countries in the future (growth in population, growth in per capita income, rapid urbanisation), and in part because of the new demands that will be put on such infrastructure for security reasons and in response to growing concerns about the environment.

The second observation is that, especially in OECD countries, public funds are very likely to come under considerable pressure in the next few decades as the demands of ageing populations on health, pensions and social services begin to take their toll and governments face shrinking tax revenues. This suggests that public authorities will need to be more innovative in moving away from taxes to other forms of revenue raising for infrastructures (*e.g.* user charges), but also in helping to shape the respective roles that the public and private sectors can play in financing, building and managing infrastructure.

The third observation is that – perhaps with the exception of the telecommunications sector – none of the other sectors has put in place an institutional framework that is up to the challenges of the future, including a regulatory framework that allows for the full and effective participation of private actors.

The pricing of infrastructure services

In a market economy, pricing plays a key role in maintaining a balance between infrastructure supply and demand, in providing guidance for investment decisions and in fostering efficiency. The role of prices has increased over the years in sectors that have moved from a command and control mode of regulation to a "regulated competition" regime. This is the case for network pricing in the telecoms sector and to a lesser degree for the electricity sector. On the other hand, the role of prices remains limited in the water sector and only marginal in the land transport sector.

In the telecom sector, competition is expected to foster the deployment of new technology and to drive cost and prices down to "near-zero" levels, creating thereby the conditions for the rapid expansion of telecoms in the developing world (Bohlin *et al.*). However, this will depend on how fast prices will converge towards costs, and notably on the evolution of the price of basic carriage, which in turn will depend on how such infrastructure will be regulated. Given the enormous capacity of optic fibres and the high cost of deploying them, economies of scale in basic carriage are likely to be very large indeed, resulting in a high degree of concentration. In this context it will be important for regulators to ensure that access to the infrastructure remains open and that access charges reflect costs.

The price of electricity plays a key role also in adjusting supply and demand in the short term (*e.g.* role of peak-load pricing). Electricity prices moreover have an impact on fuel choice. For instance, the widespread introduction of time-of-day electricity pricing at wholesale level that fully reflects the higher cost of generating power at peak would improve the competitiveness of gas against coal. Electricity pricing is also a key factor for investment decisions. For instance, low transmission rates have contributed to insufficient levels of transmission investment in the United States as well as in

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a number of European countries according to the US National Energy Policy Development Group (United States, 2001, p. 115). Despite the liberalisation of the sector, owners of transmission facilities (who continue to operate on a monopoly basis) often have little incentive to invest in new facilities. This is because current regulatory frameworks do not provide a mechanism for transmission owners to share the benefits that accrue to power plant owners and electricity customers from competition, even though transmission lines are what make the competition possible (APERC, 2003, p. 23).

If investments in transmission and distribution are to have a reasonable prospect of being profitable, they must be able to earn a return in excess of the weighted market cost of capital. Thus, in setting transmission and distribution rates, energy regulators should allow a regulated rate of return that at least equals the weighted cost of debt and equity in the marketplace (APERC, 2003, p. 23). Setting such rates at the proper level is particularly important in a liberalised environment to the extent that liberalised electricity markets are likely to require increased levels of investment in transmission to accommodate greater volumes of electricity trade. Moreover, investment in efficient transmission and distribution reduces losses and can be an effective way to lower costs to consumers as well as to reduce emissions of power generation-related pollutants.

In the water sector, pricing has been notoriously inadequate to ensure the necessary investment in infrastructure. The significant underinvestment that has prevailed for decades in some countries is a growing source of concern not only for the water utilities but also for the health authorities. Replacing or refurbishing transmission and distribution mains is critical to providing safe drinking water. Failures in transmission and distribution lines can interrupt the delivery of water and possibly allow back-siphonage of contaminated water. Distribution mains in poor repair can pose acute health risks by providing an environment in which bacteria will grow. Moreover, use of pesticides and fertilisers is also likely to lead to further deterioration of water quality and thus to rising costs.

This is clearly an unsustainable situation that calls for a substantial reform of the regulatory regime that governs the sector. In developed countries, a major effort to upgrade infrastructure over the next few decades is inevitable. In developing countries, the major new infrastructure needs resulting from population growth and urbanisation can only be accommodated if an appropriate pricing scheme is put in place. This will be a challenging task given the need of ensuring, at the same time, that the poor have adequate access to the water they need. This may call for the introduction of pricing schemes where the price per unit of water consumed increases with usage, so as to allow vital uses (*e.g.* drinking water) to be met at minimum cost to the user, while discouraging at the same time wastage and heavy use.

In contrast to the previous sectors, pricing plays only a limited role in land transport. In this regard, Stamford notes that unfortunately (for land transport authorities), the concept that there should be a "price" for public capital access and that such revenue should remain within the land transport sector appears to be rejected (or overridden) by other public finance "principles" and spending priorities. However, in this sector also, the gradual introduction of pricing appears both desirable and inevitable, although the main intent may not be the financing of capacity extension but rather attempts to moderate demand growth.

Meeting the environmental challenge

Environment policy is expected by all authors to be an important factor influencing the development of infrastructure in the coming decades, but its impact is hard to ascertain since it will very much depend on how strong political will to make the necessary reforms is likely to be, what measures will be implemented in practice, and what their impact and effectiveness will be.

As noted earlier, governments are likely to encourage the development of telecommunications as a way to reduce the need for land transport (although the evidence on this score is rather inconclusive to date) and make traffic flow more efficiently, thereby reducing the need to build new infrastructure. Telecommunications will also be used to improve the operation of other infrastructure. This includes for instance more intelligent electric networks capable of responding more flexibly to changing demand patterns, and more effective monitoring of water networks so as to reduce leakages and hence the need for water withdrawal.

Governments may also impose additional charges on some infrastructure so as to curb demand or introduce resource-saving measures. For instance, future demand for electricity could be moderated by taxes that increase the cost of electricity for final users, as well as by measures to promote energy efficiency (standards, labelling, building codes).

Higher electricity prices will be needed to cover the additional costs imposed by environmental policies for the generation, transmission and distribution of electricity. Regarding generation, environmental costs may account for 10% to 40% of total plant costs in fossil-fuel plants and more in nuclear plants according to the IEA. Transmission costs are also likely to rise because of the need to reduce emissions of SF6 (used in transformers and other equipment), which contribute to global warming, and the impact of electromagnetic fields around cables.

Environmental policy is also likely to pay particular attention to water utilities. Indeed, water is integrally linked to the health of the environment. Water is vital to the survival of ecosystems and the plants and animals that live in them; in turn, ecosystems help to regulate the quantity and quality of

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water. Hence, environmentalists will put growing pressures on the water sector to close the water cycle, *i.e.* to ensure that used water is fully recycled. This could add considerably to the cost borne by water utilities, a cost that should logically be reflected in higher water prices.

In any case, higher water prices are likely to be increasingly considered as desirable *per se* by environmentalists, if only because of the substantial environmental benefit they can bring about, simply by curbing the demand for water. Indeed, simulation results suggest that higher water prices induce a dramatic reduction in the ratio of withdrawals to total water availability and a significant improvement in water quality as the re-use of water declines, and the reduction in water withdrawals provides a major increase in environmental flows (Rosengrant *et al.*, 2002, p. 153).

Environmental policy will also affect the demand for land transport. This includes for instance sustainability-inspired measures to shift traffic from road to rail for urban and inter-city use, although Stambrook does emphasise here the limited margin of manoeuvre available.

The creation of markets for carbon emission permit trading will also have a bearing on future infrastructure development, notably in the energy sector. A case in point is the European Union Emissions Trading Scheme (ETS) established in January 2005, which affects the activities of 13 000 factories and power stations in five different industries in Europe. Up to now, there is no sign that the permit regime has brought about a switch to cleaner fuels; indeed the reverse has been happening. Part of the reason is that gas has become so much more expensive than coal that power stations have chosen to pay higher permit prices and switched to coal; moreover, it seems that too many permits have been issued. Another factor is the uncertainty that exists regarding the future evolution of the market. However, these teething problems are likely to be ironed out in the future and the use of carbon trading extended to other sectors of the economy. This could have major implications for energy use in the future (*The Economist*, May 6, 2006).

The challenge of managing future change

Balancing infrastructure policy objectives

Public policy plays a key role in shaping infrastructure investment decision for all four types of infrastructures. However, it is highly unpredictable. One can only speculate on the direction it might take in the coming decades and its possible impact on infrastructure requirements.

Regarding telecom, Bohlin *et al.* note that liberalisation and democratisation have had an enormous impact in the past on the ownership, structuring and operation of telecom networks, on the quality and reliability of service, on the nature and range of the offerings, and on accessibility. In many countries, the move has been away from a command and control model or monopoly incumbent to a more competitive environment, including separation of service from infrastructure and the opening of infrastructure to competition. In the future, harmonisation of infrastructure standards globally will be essential, including an opening up of the radio spectrum towards more unlicensed bands and the weakening of national regulators in favour of regional regulators, with global co-ordination becoming more important. Given the convergence of content and carriage, such international co-ordination/regulation should logically extend eventually to content. However, this is likely to raise serious sovereignty issues. At the local level, the use of AWT is likely to increase, driven by municipalities. However, incumbents are expected to continue to fight a rearguard action to protect their sunk costs in existing infrastructure against the price onslaught of VoIP. It will be up to the regulators to ensure that the entry of new players is not unduly constrained by such delaying tactics, that a healthy state of competition prevails in the industry, and that new technology is used to its full potential for the benefit of consumers. However, main players should not be discouraged from investing in new technologies. This means that regulators will need to strike a fine balance between maintaining an open environment and stimulating innovation by incumbents and challengers alike. Whether they will be able to do so effectively remains an open question.

Liberalisation and unbundling (*i.e.* separation of power generation, transmission, distribution and supply) has also had a major impact on the energy sector. However, the outcome is more mixed than in the case of telecoms: while such reform may have led to efficiency gains it is also creating a more uncertain environment for infrastructure investment decisions, and raises questions regarding the appropriate level of capacity reserve. Hence there is a danger that not enough investment will be carried out in the future unless more effective risk management techniques are put in place. Alternatively, governments may have to step in or allow a partial reconsolidation of the industry, which may raise important competition issues as noted by Morgan in the IEA chapter.

Public policy plays also a dominant role for land infrastructure. Indeed, because of the overwhelming presence of the state in the sector, land transport investment may well fall victim of the "short-termism" that characterises the public decision-making process, according to Stambrook. Land transport infrastructure (road and rail) has a very long economic life (30+ years) – and capital planning and budgeting requires a lengthy (10-20 year) cycle that clearly conflicts with 7-year business cycles, 3-5 year political cycles and 2-3 year budgetary cycles. Any time there is a short-term crisis, long-term plans for land transport infrastructure funding will be sacrificed for short-term expediency to meet other, more pressing political pressures and policy agenda goals.

Stambrook points out also that, even if new construction is economically desirable, public finance policy and constraints may not allow the "wealth/ output-maximising" level of road new construction to occur. Several of the political/finance factors that might be limiting include: degree of political stability, degree of public corruption, lack of public revenue raising capacity, tax avoidance, high inflation, etc. One (albeit contentious) solution to the problem could perhaps be to move responsibility for land transport infrastructure away from the political arena to an arm's-length regulatory agency (as is already the case for telecom and energy) and to allocate at least a share of the tax revenues generated by the use of land vehicles to land infrastructure investment.

Public policy plays also a central role in the management of water resources. It is a particularly complex task as it involves a broad range of public and private stakeholders at the international, national and local levels with disparate and sometimes conflicting interests. In this complex institutional context, the state of the water infrastructure is largely determined by the way lines of responsibility and financing are established, by how conflicts between the different stakeholders are resolved, by what overall government policy objectives are established and by how such objectives are pursued. In developed and developing countries alike, a major challenge for the future will be to make the institutional changes required to modernise and strengthen the legal, policy and administrative arrangements that govern the sector, so as to balance effectively the interests of users, give due consideration to health and environmental concerns and ensure at the same time that the sector is put on a secure financial footing. This is no easy task.

As Ashley and Cashman note, there is a growing need for effective regulatory oversight, no matter how services are provided, and a need for central government to continue to play a strategic role, especially with respect to social, environmental and fiscal policy direction. The potential challenges for regulation are likely to increase as new technology is adopted and organisational forms respond to its deployment. It could well be that responsibilities in the area of service delivery become blurred, requiring a greater level of governance to protect the public. The interrelationship of different spheres of regulation, safety, economic, quality, environment, consumer protection and perhaps others will become more challenging and complex. Moreover, the private sector's participation in water services will inevitably grow – not necessarily as a result of privatisation, as there is only weak evidence that privatisation does actually result in greater investment in water services. Decentralisation and more effective private sector involvement are seen to be the way forward through various forms of outsourcing as service providers seek to improve efficiencies and adopt technological innovations.

Adapting to the changing institutional context

These reforms will have to take place in a changing institutional context where in many parts of the world the responsibilities of the nation state are being "hollowed out" upward, *i.e.* where greater oversight responsibility is assumed at the supranational level. This is because states have increasingly sought to establish international mechanisms to facilitate and mediate their relationships as such inter-state relationships have become more complex. In this context, supranational bodies, such as the EU and WTO, will become increasingly important with respect to policy issues and the terms of engagement. For example, the EU plays a particularly important role in the European water sector, as it is instrumental in setting standards and requirements that have a significant impact on water services and infrastructure.

The "hollowing out" of the nation state is also taking place downward, as responsibility for a range of infrastructure service functions are devolved away from central government either to local or regional bodies, or delegated to state or non-state agencies. Making the right decisions in this increasingly complex institutional environment will become ever more challenging.

Improving the policy toolbox

Finally, an important aspect to emerge from the sectoral chapters is the need to improve the tools at policy makers' disposal. Among the items addressed in these chapters are the quantitative and qualitative inadequacy of the infrastructure-related statistics and data sets currently available; the utilisation of more sophisticated cost/benefit analysis, notably methods that include consideration of indirect effects of infrastructure development and not just the direct effects; more widespread use of accrual accounting for infrastructure cost, depreciation expense and financing costs; and the potential of network-wide asset planning and project identification as well as comprehensive asset management and performance measures.

6. The road ahead

The economic, demographic, political and technological changes that the next two to three decades are set to bring will have significant implications for infrastructures. It seems very likely that the changes will necessitate a thorough review of the strategic objectives, financing mechanisms, risk- and burden-sharing (both among stakeholders and across society), management methods, planning procedures and operating modes currently in place – in short, a re-examination of the prevailing infrastructure business models and their long-term viability. Needless to say, that viability is inextricably intertwined with the policy environment and the governance context in which infrastructures are developed. The next stage of this Project will therefore

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focus on the likely evolution of the business models prevailing today, the pressures for adaptation, the potential for innovation, and the kind of policy frameworks that will need to be implemented if infrastructures are to play in full the role required of them in supporting and enhancing economic and social development worldwide.

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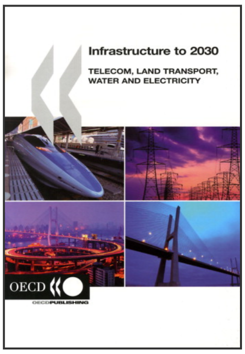

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