CHAPTER

2

THE INFRASTRUCTURE – INEQUALITY – RESILIENCE NEXUS

The 2030 Agenda attributes crucial importance to the interlinkages and integrated nature of the SDGs. Goals and targets are interlinked and their formulation highlights the connections between them. Drawing from the work of the scientific community, this chapter examines the nexus between three specific areas that are explicitly interlinked in the Agenda: infrastructure, inequality and resilience (see Box 2 1). Better understanding of that nexus is important because it addresses critical commitments of the 2030 Agenda. First, the pledge that no one will be left behind, which as discussed in the previous chapter; second, the promise to take bold and transformative steps needed to shift the world onto a sustainable and resilient path; and third, the commitment to adopt policies to increase the quality and resilience of infrastructure.

This chapter aims to highlight the main channels of interconnection among these three areas and to synthesize the results of scientific analyses of the synergies and trade-offs among them. The chapter continues the nexus approach adopted in the previous two editions to the Report, highlighting the need for integrated approaches to sustainable development by showing how actions in one area of the SDGs can affect other areas. The chapter aims to promote the science-policy interface by bringing to the attention of policymakers how key interlinkages are analysed by scientific community, while providing the scientific community with some key policy questions and highlighting areas that may need further research.

Infrastructure is one of the areas that are generally considered as a public good, and as such, its provision or regulation is usually the responsibility of governments.[1] The consideration of the nexus provides policy-relevant information that can assist policymakers to further develop infrastructure while reducing inequality and increasing resilience. It can also strengthen the capacity of policymakers and practitioners to approach development in an integrated way, by providing concrete examples.

The following observations further underline the importance of the nexus:

- There are large disparities in access to infrastructure: Worldwide, over 1.1 billion people still have no access to electricity.[2] 663 million people lack access to clean water, and 2.4 billion do not have adequate sanitation.[3] About one third of the world's population is not served by all-weather roads.[4]
- Closing those disparities would require large investments: The global infrastructure gap is estimated to amount to $1-1.5 trillion annually in developing countries.[5]
- Investment in infrastructure should be mindful of its long lasting effects: Estimated useful life of infrastructure ranges from 20 years for roads to over 100 years for concrete bridges, sewer and water structures.[6]
- The need to make infrastructure resilient to disasters: Since 2010, disasters caused by natural hazards have accounted for over US$ 900 billion in economic damage, mostly in terms of damage to infrastructure.[7]

Extensive bodies of literature have focused on each of the three areas of the nexus. For example, infrastructure has received significant attention in development circles, due to its perceived critical role in spurring economic growth and development. Yet, scientists focusing on each of those distinct fields, typically hail from different communities, making links between the three areas less commonly studied than any of the three areas taken in isolation.

This chapter was prepared based on a broad call for inputs, reaching out to scientists and experts who have published in peer-reviewed journals on topics related to the nexus, as well as other experts within and outside of the United Nations System. Scientists were invited to contribute to the chapter by identifying and describing interlinkages between infrastructure, inequality and resilience, identifying synergies, trade-offs and constraints, and providing evidence of the empirical strength of the interconnections. This was complemented by the analysis of scientific articles related to the nexus. Clearly, the analysis is not exhaustive but serves to highlight the broad range of research and scientific perspectives that exist in relation to the nexus. The methodology used is described in Annex 2.

Given that the nexus is comprised of three broad areas that may be defined differently by various scientific disciplines, this chapter adopts the working definitions listed in Table 2-1. As discussed in Chapter 1, inequality is characterized by discrimination and the disparity in opportunities or outcomes between people or groups of peoples. Similar to poverty, inequality is multidimensional, including dimensions such as education, culture, health, nutrition, security, power, social inclusion, income, consumption and assets.[8]

Infrastructure, in the broader sense, is a means to fulfill a human need.[9] It is composed of basic assets and objects that, in the aggregate, are deemed essential for the functioning of society and the economy. The scope of infrastructure considered in this chapter comprises basic services such as water, sanitation and energy, and connectivity infrastructure, including roads, transport systems, and information and communication technologies.[10]

Resilience is an attribute of such complex systems as ecosystems, people's livelihoods, cities and infrastructure, and is usually defined as the ability of a system to adapt to a shock and maintain its core functions.[11] In this chapter, the focus is on the resilience of people as characterized by their ability to adapt to economic, social and environmental shocks so they could continue to lead the life that they have reason to value.

The interlinkages within the nexus indicate how a change in one area affects, and is affected by, other areas. Interlinkages can result in synergies when an improvement in one area results in an improvement in another area. For example, improvements in the quality of rural roads may increase access of poorer households to markets and job opportunities, which may reduce income inequality and increase resilience.

On the other hand, interlinkages can result in trade-offs when an improvement in one area results in a decline in another area. For example, improvement in the quality of rural roads could create incentives for the specialization of agricultural households in a particular crop, which would reduce the diversity of their livelihoods and, in turn, their resilience to shocks. It may also be possible that households that are already better-off would benefit the most from the improvement in the roads given their initial advantage in terms of stock of capital, which could contribute to increase inequality.

As illustrated by these examples, interlinkages in the nexus are complex and conditional to existing levels of infrastructure, inequality and resilience. This chapter highlights some of the key interlinkages based on evidence from science.

Table 2-1: Working definitions

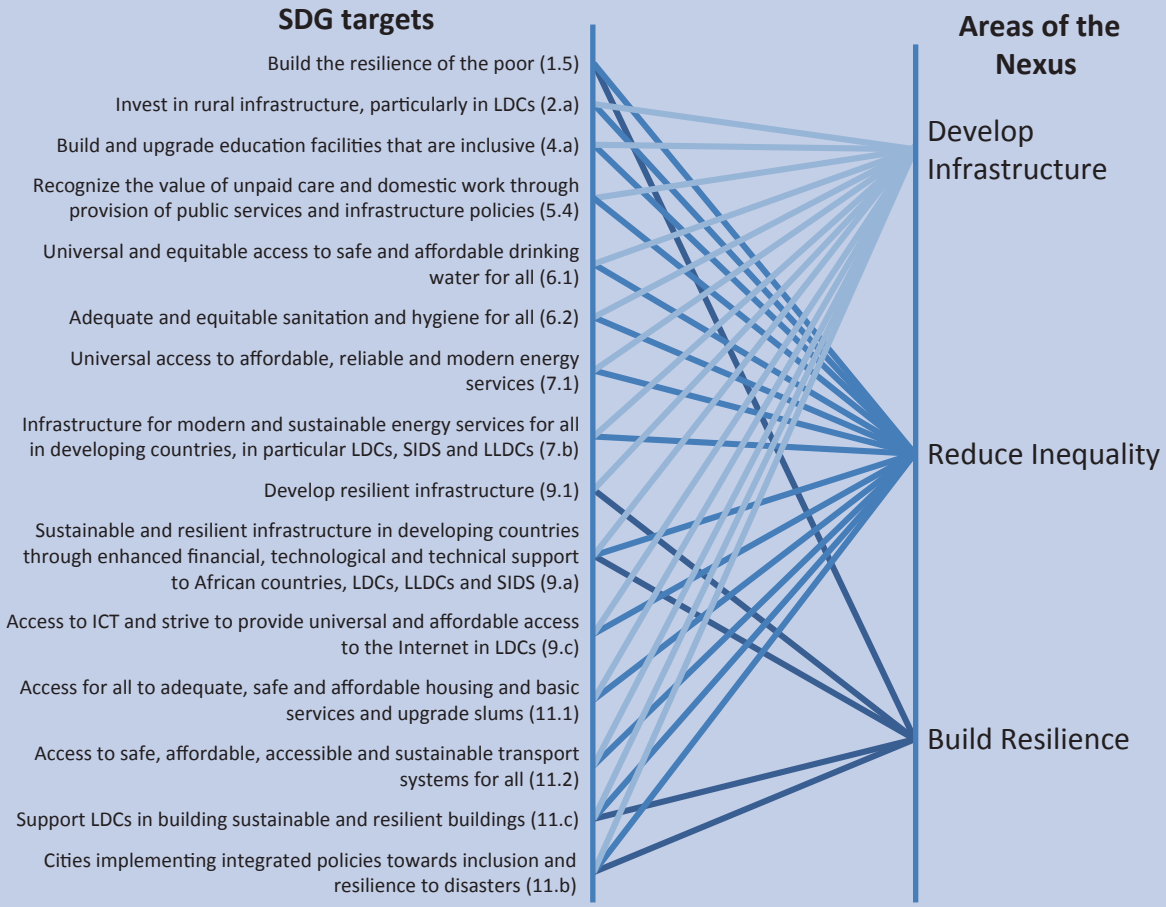
Inequality	Infrastructure	Resilience
The disparity in opportunities or outcomes between people or groups of peoples	Basic assets and objects that are considered essential for the functioning of the society and economy	Ability of people to withstand and adapt to economic, social or environmental shocks so they can continue to lead the life they have reason to value

Source: Authors.

Box 2-1: Infrastructure, inequality and resilience nexus in the 2030 Agenda

The areas of infrastructure, inequality and resilience are individually addressed in many goals and targets of the SDGs. The interlinkages between these areas are explicitly highlighted in 15 SDG targets. The majority of those targets are related to providing universal access to infrastructure to reduce inequality (e.g. drinking water, sanitation, modern energy services, ICT and Internet, housing, and transport). Another two targets link resilience to infrastructure (developing resilient infrastructure – target 9.1) and to inequality (building resilience of the poor – target 1.5). Finally, the interlinkage of the three areas of the nexus is highlighted in three targets: facilitate sustainable and resilient infrastructure in developing countries through enhanced financial, technological and technical support to African countries, LDCs, LLDCs and SIDS (9.a); support LDCs in building sustainable and resilient buildings (11.c); and increasing the number of cities that implement integrated policies towards inclusion and resilience to disasters (11.b).

Figure A. SDG targets directly related to the nexus



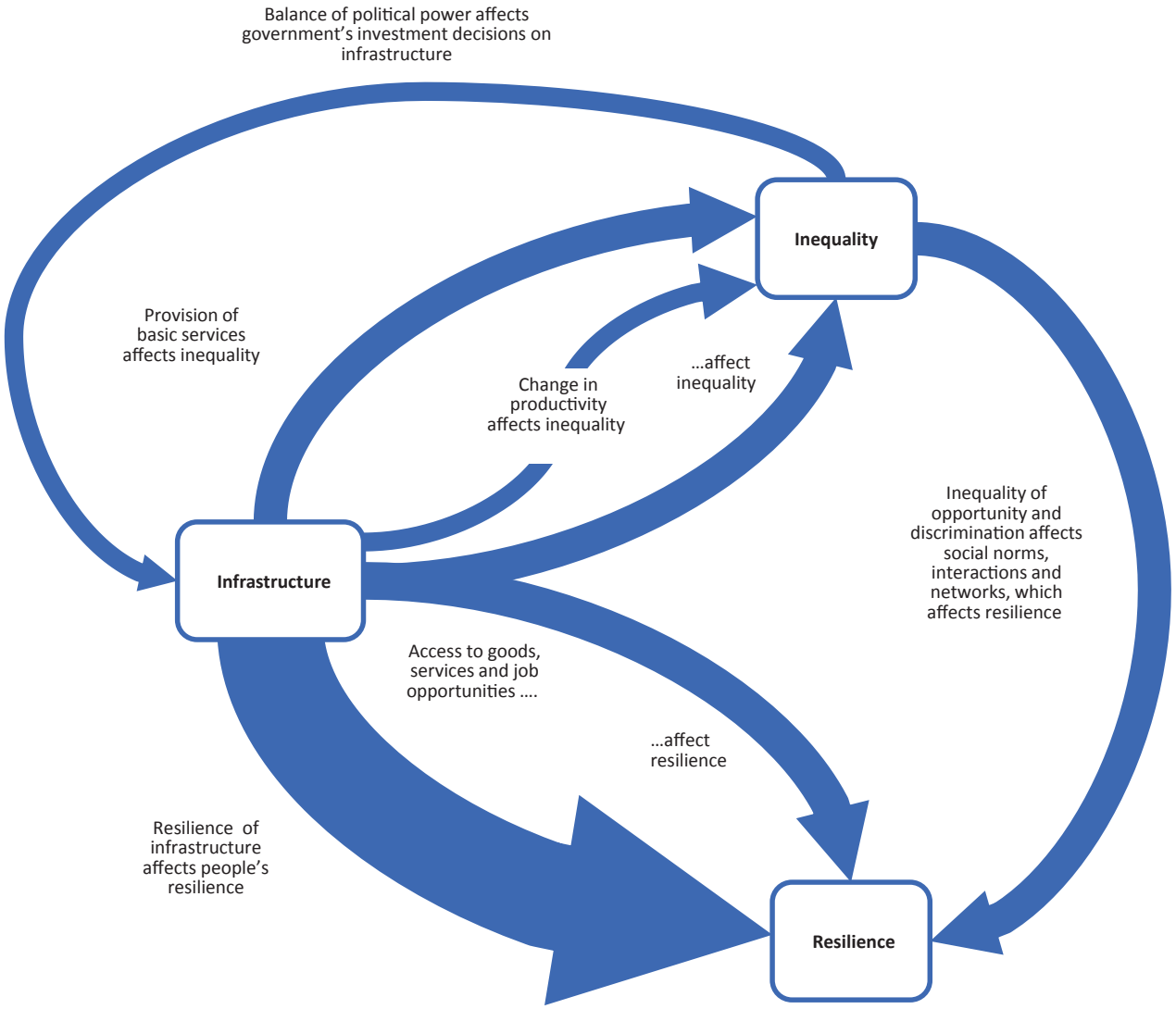
Source: Authors.

2.1 Key interlinkages

Consultation with experts and the review of scientific literature have identified several links between the elements of the infrastructure, inequality and resilience nexus, which for simplification were grouped in the key interlinkages presented in Figure 2-1. The Figure was designed with a view to breaking down the various causal links that exist between the three areas under consideration (represented by the boxes). The arrows between boxes indicate the interlinkages; the nature of the links is indicated in the text near the arrow. For example, one arrow links infrastructure to inequality and indicates that provision of basic services affects inequality. The sizes of the arrows indicate the relative amount of illustrative research focusing on a particular linkage, based on the inputs by contributing experts and meta-review conducted in preparation for the chapter. The links presented were selected by clustering the information provided by experts into logical relationships. Given the complexity of the nexus, the map is only illustrative and is not intended to include all the relevant links.

The interlinkages identified by experts and described in Figure 2-1 can be summarized as follows:

Figure 2-1: Evidence map of the infrastructure – inequality – resilience nexus



Source: Authors elaborations based on inputs by experts and literature review.

Infrastructure affects inequality of outcomes and opportunities through three main channels. First, infrastructure that provides basic services such as water, sanitation and electricity may affect inequality depending on the quality, design, coverage, accessibility and distribution of that infrastructure. Infrastructure such as irrigation, electricity, ICT, and roads increase productivity and reduce trade costs, which affects the structural dynamics of the economy, including levels of income and distribution of jobs, and may have an effect on inequality. The third channel is through connectivity infrastructure such as roads and ICT, which affects the access of people to goods, services and job opportunities, and therefore may have an effect on inequality.

On the other direction of the interlinkage, inequality of outcomes affects infrastructure through its effect on the balance of political power and, consequently, government decisions and the involvement of private companies on the provision of basic services, including infrastructure.

Infrastructure affects resilience through its effect on access of people to goods, services and job opportunities, which have an effect on the ability of people to adapt to shocks. The quality, design, distribution, interrelation and operation of infrastructure also affect the resilience of the infrastructure itself, which has an effect of people's resilience to economic, social and environmental shocks.

Inequality of opportunity and discrimination affect resilience through their impacts on social norms, interactions and networks, which have an effect on the ability of people to adapt to shocks.

Two potential links in the nexus seem not to have received much attention from the contributing experts and literature reviewed. They are the links from resilience to inequality and to infrastructure.[12] Further research is required to uncover the reasons for that gap, but a possible cause may include the fact that there is still an ongoing debate on the ways to measure resilience, which has been noted by many experts and is reflected in the sizeable number of publications dedicated to that the topic.[13]

2.1.1 Infrastructure and inequality

Contributing experts noted numerous studies related to understanding the interlinkages from infrastructure to inequality. Table 2-2 further details these interlinkages, with contributions from experts of examples, illustrative research and suggested areas for further research.[14]

Infrastructure has historically been considered key to economic growth and development,[15] but research on the link between infrastructure and inequality has shown a more nuanced story.[16] Econometric studies at the aggregate level have found that infrastructure development has positive effects reducing poverty[17] and income inequality.[18] However, the impacts of infrastructure on income inequality may differ based on the type of infrastructure and the income category into consideration.[19] The mechanisms through which these effects operate remain relatively unexplored through econometric techniques.[20]

Microeconomic studies that evaluate the impact of particular infrastructure interventions have found that physical infrastructure in roads and communications facilitates spatial access and information flows, raising labour mobility, advancing rural non-farm economies, and reducing the incidence of poverty in some geographic areas.[21] Other empirical studies have found that improved access to infrastructure services can raise the income of the poor through its impact on human capital, specifically education and health outcomes, and that public infrastructure provides a boost for local community and market development.[22]

Table 2-3 summarizes the potential impact of infrastructure in various development areas as found in the literature, looking at the relation between infrastructure and areas related to the SDGs. The magnitude of the effectiveness is given as large (+++/---), moderate (++/--), small (+/-) or neutral (0).[23] Infrastructure is found to reduce income poverty and to affect non-income aspects of poverty, contributing to improvements in health (SDG 3), nutrition (SDG 2), education (SDG 4), and women empowerment (SDG 5).[24] The magnitude and direction of the effect of infrastructure on income inequality depends, as mentioned above, on such factors as the type of infrastructure.

Clearly, such analysis includes a large dose of arbitrary judgment but it serves to illustrate the complex nature of the impact of infrastructure on the distribution of outcomes and opportunities. In summary, the table shows that in general there is a positive effect of the quantity and quality of infrastructure on the level of attainment in different areas of development, but the effects on inequality, illustrated by the effects on income inequality, are not always positive. They depend on several factors such as the initial level of inequality of opportunities and outcome that affect the extent to which people benefit from the improvements in infrastructure

Many studies have also assessed the impact of infrastructure on inequality through the effects of the former in increasing productivity and reducing trade costs, which affects the structure of the economy and the levels of income and distribution of jobs. A considerable share of that research focuses on the rural context. In general, development of infrastructure improves agricultural productivity and reduces rural poverty. For example, research in China, India, Philippines, Thailand, and Viet Nam shows that

Table 2-2: Important interlinkages from infrastructure to inequality

Infrastructure → inequality Interlinkages	Illustrative research	Areas for further research suggested by experts
The quality, design, coverage, accessibility and distribution of infrastructure that provides basic services affects inequality *Examples:* • Historical inequities can be perpetuated as an unintended result of the method of delivery of essential services such as water and sanitation • In urbanizing regions, emphasis on basic service and environmental service infrastructure building on the core area and its neglect in the peri-urban has structured placed-based inequalities.	• Analysis of the role of income, maternal education and social capital on how sanitary infrastructures affect child health.[25] • Development of policy and practice guideline for local, provincial and national government to promote the expansion and improve the operations at wastewater treatment works.[26] • Analysis of the connection between access to water, equity and development.[27] • Analysis of the multiple practices and arrangements by which the peri-urban poor access water and sanitation to help in the identification of service delivery options that work for them.[28] • Analysis of the consequences of water tariffs that use sliding-scale prices to assess the aggregated consumption of households in terms of equity.[29]	• Analysis of the key factors that improve the use of infrastructure and reduce inequities.
Infrastructure increases productivity and reduce trade costs, which affects the structural dynamics of the economy, including changes in levels of income and distribution of jobs, and may have an effect on inequality *Examples:* • Construction of rural roads had led to increased agricultural production. • Coverage and reliance of electrification increase productivity of economic activities. • Better roads are associated with lower transport costs.	• Analysis of the impact of infrastructural investments in roads, electricity and irrigation on agricultural productivity.[30] • Analysis of the effect of inadequate provision of public Infrastructure and services on private investment.[31] • Analysis of the benefits of rehabilitating rural roads for enhancing income opportunities for the rural poor.[32] • Analysis of the impact of agricultural extension and roads on poverty and consumption growth in the rural context.[33] • Impact evaluation of interventions in support to rural transport infrastructure.[34] • Case studies on smallholder agriculture trends, constraints and opportunities.[35] • Analysis of the impact of rural roads on poverty.[36]	• Direct impacts of investment in electricity and telecommunications infrastructure on agricultural productivity. • Analysis of impact of rural infrastructure on long-term changes related to crops portfolios, technological changes at both agricultural activities level and non-agricultural activities level, and the change in consumption patterns.
The quality, design, coverage, accessibility and distribution of connectivity infrastructure affect people's access to goods and services, and job opportunities, which have an effect on inequality *Examples:* • Transportation infrastructure may deepen inequalities based on its absence, its design and its consequences to better policies enhancing development. • Rural and poor villages without efficient connections (infrastructure) may perpetuate their isolation hampering income convergence across the country and even enlarging inequalities. • Infrastructure may drain activity of less dynamic nodes and concentrate activity to the largest more dynamic nodes. • Access to Internet and mobile telephony increase the access to goods, services and job opportunities.	• Analysis of causes and effects of the broad pattern of gender disparity in transport access and use.[37] • Analysis of the impact of roads on poverty reduction.[38] • Analysis of the infrastructure and poverty linkages.[39] • Analysis of the impact of transport sector on maternal and child mortality development goals.[40] • Empirical Investigation on the effect of volume and quality of infrastructure in income distribution.[41] • Assessment of the historical influence of housing policies on social inequality, disadvantaged neighbourhoods and transport deprivation.[42] • Analysis of renewable energy-based electrification projects in reducing social inequalities and improving people's well-being.[43]	• Besides better transportation, analysis of other factors may help increase adequate and affordable housing opportunities in major cities. • Analysis of the interrelation between road access and migration. • Compare financial and time costs for poor and non-poor households to access all forms of health intervention for improved maternal and child health outcomes. • Consideration of long-term population changes into the design of urban infrastructure to reduce vulnerability and exclusion of aging population.

Source: Authors, based on inputs by experts and literature review.

Table 2-3: Infrastructure's potential impact on key development areas

	Income poverty	Education	Gender parity in education	Child and infant Mortality	Maternal Health	Communicable disease	Environmental protection	ICT and trade	Income Inequality
Infrastructure:									(-, +++)[abcdef]
Transport (local)	+++	++	++	+	+		+	+	(---, +++)[agh]
Transport (regional)	+++	+	+	++	+	+	–	+++	
Modern energy	+++	+	+	++	+	+	++	+	(--, +++)[afh]
Telecom	++	+	+	+	+	+	+	++	(0, +)[ahi]
Water (private use)	++	++	+	+++	+	+	+++	+	(+, +++)[ad]
Sanitation	+	+	++	+	+	+	++	+	+++[d]
Water management	+++		+	+			++		

Source: Willoughby, C., (2004). Infrastructure and the MDGs, sponsored by DFID, unless noted otherwise. a - Calderón & Chong (2004);[44] b - Calderón & Serven (2004);[45] c - Seneviratne & Sun (2013);[46] d - Calderón & Serven (2008);[47] e - Calderón & Serven (2010);[48] f - Majumder (2012);[49] g - Khandker & Koolwal (2007);[50] h - Bajar & Meenakshi (2015);[51] i - Lopez (2004).[52]

Notes: The magnitude of the effectiveness is given as large (+++/---), moderate (++/--), small (+/-) or neutral (0). Large is thought as more than 20% improvement with significant infrastructure development or more than 0.2 point increase with 1 point infrastructure increase. Moderate is considered as 10-20% improvement or 0.1-0.2 point increase, and small is 5-10% improvement or 0.01-0.1 point increase that is statistically significant. The values for inequality denote the range of infrastructure development's impact on income\consumption inequality. The first value refers to the most negative effect identified, and the second value refers to the most positive.

inequality is statistically lower in irrigated areas[53] with higher agricultural output per worker.[54]

Experts also noted that infrastructure provides different opportunities and challenges depending on where and to whom it is intended.[55] For example, in the rural context, certain types of infrastructure have a higher impact. Many rural and remote areas are cut off from economic opportunities, markets, and public services, which locks residents in low productivity and poverty. Experience from Bangladesh, Cameroon, China, Ethiopia, India, Viet Nam and other countries shows that investment in secondary rural roads tends to have positive effects on the private sector productivity,[56] poverty reduction,[57] school enrolment,[58] access to health services,[59] and economic growth,[60] and comparison studies have found a higher benefit to cost ratio than investment in higher-volume roads.[61] Better rural infrastructure also facilitates women's free movements and can lead to empowerment.[62]

Research related to the infrastructure-inequality link has also explored how traditional inequalities can be perpetuated as an unintended result of the method of delivery chosen for essential services such as water and sanitation. For example, inequalities can be reinforced if service charges or uses fees do not take into consideration disparities in income. Elements of equity in access to and use of water and the distribution of the impacts of interventions in water resource development include: social equity between different groups of people living in the same location; spatial equity between people living in different regions; equity access between men and women efforts to access and use water, and its benefits; and inter-generational equity in enjoyment of water resources.

Transportation infrastructure may also deepen inequalities depending on its design, by draining activity from less dynamic nodes and concentrating it in to the largest, more dynamic nodes. There is also considerable research on how some transport infrastructure may benefit high income users who make use of private cars while some others may have wider economic effects improving welfare of a larger amount of the population reliant on public services, particularly those with low income in developing countries.

Regarding the link from inequality to infrastructure, there is the overall sense that investments and the quality of services favour wealthier areas and that the design of infrastructure and the operation of public services tend to follow the wider balance of power (Table 2-4). Experts also noted a large literature on the politicised basis behind the production of the uneven landscape of urban areas, especially cities that experienced rapid expansion without inclusive policies, which shows the persistence and reinforcement of social and spatial inequalities.

2.1.2 Infrastructure and resilience

The interlinkages from infrastructure to resilience account for almost half of the research identified by contributing experts as related to the nexus. Examples of illustrative research are shown in Table 2-5.

In the experts' view, there seems to be a high level of knowledge on how the quality, design and distribution of infrastructure affect the resilience of infrastructure to shocks by natural hazards. By damaging the infrastructure and its functionality, disasters also impact the socio-economic fabric of communities. Quantitative models predicting impact of disasters have been developed by many research groups. However, although much is known in the case of more predictable and lower intensity events, technology and countermeasure strategies are still being developed for making infrastructure resilient to more severe disasters.

There is also a significant focus of research on the so called critical infrastructure, such as interurban transport, and

electricity and ICT infrastructure, whose disruption causes major negative effects on the economy and functioning of society. The complex nature and high interconnectedness of these infrastructures makes them particularly vulnerable to "chain reaction" effects during crisis.[63] Contributing experts noted that some nations have conducted mapping of infrastructure dependencies and redundancies, which has advanced the understanding of the interdependencies across different types of infrastructure.

Table 2-4: Important interlinkages from inequality to infrastructure

Inequality→infrastructure Interlinkages	Illustrative research	Areas for further research suggested by experts
Inequality affects the balance of political power and, consequently, government decisions on the provision of public services, including infrastructure *Examples:* • Investments and the quality of services favour the wealthier, regular areas. • The design of urban infrastructure and the operation of public services tend to follow the wider balance of power. • The needs of people living far from central areas (State capitals and main cities) receive less attention from public interest litigators who could help them vocalizing their claims.	• Development of framework that is able to capture the multidimensionality of the relations between nature and society increasingly mediated by the state.[64] • Analysis of empirical relationships between spatial factors and travel behaviour for men and women in a cross-section of low-income communities in large metropolitan areas.[65] • Analysis of human rights, inequality and public interest litigation on provision of sanitation.[66] • Analysis of centralization as a determinant of government investment in infrastructure.[67] • Study of the colonial roots of inequality in the access to water in urban context.[68]	• The political, ideological and operational influences behind investments and urban planning, comparing countries and cities in the Global North and in the Global South. • How to make sanitation policies a topic politically appealing for governments.

Source: Authors, based on inputs by experts and literature review.

Table 2-5: Important interlinkages from infrastructure to resilience

Infrastructure→resilience Interlinkages	Illustrative research	Areas for further research suggested by experts
The quality, design, distribution, interrelation and operation of infrastructure affect the resilience of the infrastructure itself, which has an effect of people's resilience to economic, social and environmental shocks. *Example:* • The design of urban infrastructure can influence social vulnerability. • Pre-event assessment of vulnerability and resilience can lead to better infrastructure design and retrofit choices. • The functionality of interurban traffic infrastructure is critical for the economic efficiency of a society. To fulfil this task, structures have to be resilient as well as sustainable. • The recovery strategy after natural disasters affects resilience. Climate variability/change as well as sea level rise impact urban infrastructure that was designed long time ago with design criteria assuming stationarity. • Planning and urban design strategies can increase the resilience of cities to climate change impacts. • Older infrastructure is less resilient and more susceptible to failure due to extreme weather.	• Review of coastal disaster risk management, engineering analysis of infrastructure resilience to natural disasters, analysis of threats and assessment of vulnerability.[69] • Development of strategic framework for assessing organizational and network resilience of critical infrastructure.[70] • Analysis of critical Infrastructure dependencies to determine how such infrastructure is affected when another critical infrastructure fails.[71] • Development of unified approach for addressing resilience and sustainability of civil infrastructure.[72] • Development of approaches for identifying the trade-offs between quickly restoring infrastructure services versus taking time to consider and consult on alternative options.[73] • Development of methods to quantify the resilience of water networks.[74] • Analysis of factors that affect the resilience of electrical power distribution infrastructures.[75] • Resilience assessment of interdependent infrastructure systems, and analysis and modelling of optimum strategies to their joint restoration after failure.[76] • Development of models to quantify the effects of changes in international production from a disruption in supply chain caused by natural disasters.[77] • Case studies on the potential effects of failure of heavily used, outdated locks and dams.[78] • Development of dynamic framework to assess multi-regional, multi-industry losses due to disruptions on commodity flow on the waterway networks, including ports and waterway links.[79]	• How to truly build a multi-layer protection system. • The issue of rapid recovery vs improving long-term resilience. • Quantitative measures to describe the relationship between structural design, resilience and sustainable development in model based approaches. • Evaluation of different approaches to public-private partnerships (PPP) and relationship to governance of critical infrastructure. • Methodologies that can quantify social and economic damage. • Different ways in which to provide incentive to increase resilience of infrastructure. • Interrelations between different kinds of infrastructures. • Unification of concepts of infrastructure resilience and sustainability. • Quantitative assessments have mostly been done for the various sectors in isolation. Research on infrastructure interdependencies and resilience is required. • Development of specific water distribution network infrastructure adapted to earthquakes (automatic sluice valves, buried tanks for firefighting, special joints for absorption of displacements, etc.). • A more systematic understanding of the required adaptation measures for ports and other critical transport infrastructure, in the light of the projected impacts of climate variability and change.[80]

Table 2-5: ***(continued)***

Infrastructure→resilience Interlinkages	Illustrative research	Areas for further research suggested by experts
The quality, design, distribution and operation of infrastructure affect people's access to goods and services, including natural services, and job opportunities, which have an effect of people's resilience to economic, social and environmental shocks. *Examples:* • Location and concentration of basic service infrastructures such as pipe water system and drainage system, and paved roads is related to the vulnerability and resilience of certain areas to natural disasters such as flooding.	• Proposal of resilience-based approach for assessing sustainability of regions to changes that threatens to cross biophysical, economic, and social thresholds operating at different scales, with possible knock-on effects between them.[81] • Development of methods for evaluation of performance of water supply utilities under varying climatic condition using reliability, resilience and vulnerability metrics.[82] • Analysis of the relationship between socio-economic development and water resources management strategy to attain sustainability in water management.[83]	• Sustainable urbanism design. • The co-production of 'natural' disasters and vulnerability. • Analyses linking infrastructure like irrigation works, or other connectivity between communities and broader trade networks, and resilience at community and national scales. • How the design of infrastructure should encourage change of habits that are helpful to local populations such as walkability (encourage individuals in general to walk, which should directly help them exercise).

Source: Authors, based on inputs by experts and literature review.

Underlining much of that research is the view that the shape and structure of infrastructure networks affect how resilient they are against shocks. For example, many infrastructure networks tend to be formed by continuously adding new segments to existing parts of the network that are already well connected.[84] That fact is important because these types of networks are robust to random failure but vulnerable to failure on nodes with many links. Public transport networks, for example, seem to be robust under random failure but vulnerable to more targeted shocks that disrupt nodes that are more connected or more central in terms of having largest influence on the available paths in the network.[85] Other infrastructure may also be affected in this way depending on their structure.[86]

Experts also noted that recovery strategies implemented after natural disasters affect resilience and can lead to increased social vulnerability;[87] therefore substantial research is going in the direction of optimizing the various phases of disaster management. For example, considering that pre-event assessments of vulnerability and resilience can also lead to better infrastructure design and retrofit choices, research has focused on techniques to identify the most important interventions and most beneficial choices. A basic and descriptive framework dealing with resilience of civil engineering structures exists.

Contributing experts also suggested many areas for further research. For example, noting that research has addressed the fields of resilience and sustainability through different perspectives, and contributing experts have suggested that the two concepts have to be united since infrastructures have to fulfil requirements of both fields at the same time. Other areas for further research suggested by contributing experts include: the apparent trade-off between rapid recovery strategies after a disaster and the need for improving long-term resilience; the development of quantitative measures to describe the relationship between structural design, resilience and sustainable development in model-based approaches; the development of multi-layer protection systems; and further research on the interrelations between different kinds of infrastructures. Similarly, more systematic approaches need to be developed to support vulnerable countries in assessing and adapting to the impacts of climate change on their critical transport infrastructure such as ports and airports. [88, 89]

The governance of infrastructure also influences the resilience and vulnerability of society to disasters; participatory governance and pro-actively informing citizens supports their ability to cope with disasters.[90] The relationship between the private and public sectors in providing resilient infrastructure is also an area that requires additional research. Specific topics identified include the relationship of different approaches to public-private partnerships (PPP) and the governance of critical infrastructure, and the different ways in which the public sector could provide incentives to increase resilience of private sector-provided infrastructure.

Relatively less developed is the research on how the quality, design, distribution and operation of infrastructure affect people's resilience through their effect on people's access to goods, services and job opportunities. A pattern in this area of study is the focus on specific areas and case studies to try to identify and quantify the effects of infrastructure on the capacity of people to withstand and adapt to shocks.

Contributing experts noted that the location and concentration of basic service infrastructures such as water distribution systems, drainage systems, and paved roads is related to the vulnerability and resilience of certain areas to natural disasters. It is also acknowledged that there are large disparities in adequacy and quality of

basic infrastructure between the core area and peri-urban edge of mega urban regions, causing the latter to be more vulnerable than the former during extreme events.

Some research has focused on the impact on jobs of building and maintaining infrastructure, and experts gave examples of how maintenance of inland waterways infrastructure (i.e., locks, dams, channel dredging) supports local and regional economies, and how the construction of drought-related infrastructure creates jobs.

Suggested areas for additional research include sustainable urban design, and analyses of infrastructure connecting communities to broader trade networks and its effect on resilience at community and national scales.

2.1.3 Inequality and resilience

The research on the link from inequality to resilience focuses on social capital and the effect of inequality on social norms, interactions and networks, which are considered to influence the capacity of people to recover and adapt following a natural disaster or economic shock (Table 2-6). There is recognition that particular attention should be paid to vulnerable populations following natural disasters, in particular women, children and persons with disabilities, as they are the most severely affected. Also covered is inequality in access to resources and the potential impact of shortage and differences in costs and quality of basic services such as water in triggering conflicts between different groups. The research in this area also highlights the existence of poverty traps, in which inequalities have an impact on infrastructure policies and then on vulnerability and resilience.

Some of the areas that require further research suggested by contributing experts include the study of quantitative links between resilience and inequality, and how the quality of social and political organization affects vulnerability and resilience.

2.2 Harnessing synergies and addressing trade-offs

This section highlights policy areas suggested by contributing experts to harness the synergies and address the trade-offs between the three areas of the nexus (infrastructure, inequality and resilience). Policies aiming at reducing inequalities in all its dimensions are considered to have positive effect in infrastructure provision and increasing resilience by, for example, increasing the likelihood of infrastructure investments that benefit vulnerable groups.[91] Many policies and strategies to reduce inequality are illustrated in chapter 1 of this Report. This section focuses on the narrower set of policies related to infrastructure and their effects on inequality and resilience.

The discussion of interlinkages in the previous section highlighted that improvements in infrastructure, in terms of provision of basic services and facilitation of access to goods, services and job opportunities, in general increase the resilience of people to all kinds of shocks; however, its effect on inequality mainly depend on where infrastructure is placed and who it serves. Reflecting this, contributing experts recommended that infrastructure policy should focus both on efficiency and on equity goals. In that respect, there is the view that an important policy component is the principle of geographic equity – that is, 'no place left behind', to correct the perceived disparities in the provision of basic services infrastructure in rural and peri-urban areas while public resources are concentrated in upgrading core areas. There is the recognition that urbanization in developing countries is rising fast[92] and, therefore, policies should be

Table 2-6: Important interlinkages from inequality to resilience

Inequality→resilience		
Interlinkages	**Illustrative research**	**Areas for further research suggested by experts**
Inequality of opportunity and discrimination affects social norms, interactions and networks, which have an effect on people's resilience *Examples:* • Women and persons with disabilities are often disproportionally affected by natural disasters • Particular attention should be paid to vulnerable populations following natural disasters, as they are the most severely affected. • Analysis of child deaths in developing countries suggests that while boys and girls benefit equally from positive shocks in per capita GDP, negative shocks are much more harmful to girls than to boys.	• Analysis of the role of social capital in building resilience for post-disaster recovery.[93] • Studies using social capital lens to assess adaptive capacity.[94] • Analysis of determinants of urban resilience.[95] • Role of social networks and civil society in coping with the effects of large natural disasters.[96] • Analysis of social resilience to the threat of water scarcity.[97] • Analysis of social resilience as is the capacity of social groups and communities to recover from, or respond positively to, crises.[98]	• Personal and interpersonal connections with wider urban and national trends • Links between resilience and inequality quantitatively, especially at broad scales is open for research and would have a broad audience. • Connections of scale between local and urban processes and regional and national pressures; how the quality of social and political organization affects vulnerability and resilience; the complex interconnections between state reform and the growth of vulnerability and resilience.

Source: Authors, based on inputs by experts and literature review.

in place for the development of inclusive and sustainable infrastructure in urban areas.

In terms of synergies between infrastructure and resilience, contributing experts highlighted three key areas of policy intervention. First, there is a need to make infrastructure resilient to disasters by integrating disaster risk reduction into all phases of the infrastructure life cycle through regulation, norms and standards, urban planning, building codes, etc. Second, to reduce the risk of failure of critical infrastructure such as transport, energy, and telecommunications and its negative social and economic impact, experts highlighted the importance of policy directives on the security and resilience of these infrastructure.[99] Damages to infrastructure sometimes are unavoidable and appropriate recovery plans should prioritize infrastructure components that are most critical for affected communities. Third, infrastructure becomes more resilient when funding mechanisms and incentives to reduce risk are in place, for example, through the adoption of resilient-based requirements in the tendering and contracting process.

Contributing experts also noted the need to further disaggregate the analysis between rural and urban contexts to be able to provide more specific policy recommendations. For instance, for rural areas infrastructure investments are essential to connect individuals to livelihoods and opportunities for rising out of poverty. Conversely, urban areas provide easier connectivity due to concentration, but in many cases fragmented governance structures, congestion, and higher incidence of poverty in inadequately serviced and disadvantaged urban informal settlements and peri-urban areas require concerted efforts in order to achieve balanced development. The next sections take a look at the different challenges faced by urban and rural areas when addressing the interlinkages. It aims at summarizing a variety of actionable interventions highlighted by the contributors to this chapter to give a flavour of potential tools for policy makers dealing with these interlinked issues.

2.2.1 Infrastructure – inequality – resilience in rural areas

Lack of infrastructure investment in rural areas has received much attention more recently. Such investments may help people get out of the marginalization spiral, if properly designed and implemented. However, investment risks to disproportionally benefit the upper socio-economic strata if the needs of the marginalized groups are not duly taken into account.[100]

Also, conventional cost-benefit analyses based on rural road appraisal models often fail to justify investment costs, as the traffic levels are normally too low to show a net discounted benefit.[101] Wider economic and social benefits are generally ignored and insufficient attention is paid to the value of time for different groups. Some studies propose ways in which the social costs and benefits of rural roads can be better measured and built into road appraisal programs.[102] However, these studies have not yet led to mainstreaming pro-poor (and pro-marginalized groups) social measurements into conventional rural road assessments. This is mainly due to the challenges of identifying and measuring consistent and robust statistics, and the considerable differences in perceptions and weightings given by local communities and national authorities.[103]

Despite the challenges, many countries have found important to invest in rural transportation. The government of India has made a policy decision to connect all villages with more than 500 inhabitants (250 inhabitants in the remoter areas) to an all-weather road. China also aims to connect all 'administrative villages' to all-weather roads. New designs of trail bridges and footpath construction have been developed and tested by local communities.[104] Some countries, such as Lesotho and Nepal, even have specific units responsible for installing and maintaining rural footbridges. A rural transport project in Peru rehabilitated and maintained 7,000 km of trails, primarily used by women and children.[105]

An additional pro-poor transmission channel can be secured by associated labour-based programs in these types of infrastructure projects. Many guidelines are available to help planners and engineers adopt labour-based approaches,[106] and ILO, for example, has prepared guidelines for adapting tools so that people with disabilities can be included in these programs. [107]

Quite often transport planning and decision making tend to be conducted as a technocratic process with minimal information released to the public until construction begins. Infrastructure projects would benefit from participatory processes that involve local communities and their various segments such as women, youth, minorities and other constituencies. A participatory approach would increase the likelihood that the needs of those further behind are prioritized. Participatory planning tools such as the Sustainable Transport Appraisal Rating (STAR) and the Integrated Rural Accessibility Planning (IRAP) allow for consulting with local communities when preparing investment plans based on multi-dimensional measurement tool that includes economic, poverty and social, environmental and sustainability risk criteria.[108]

2.2.2 Infrastructure – inequality – resilience in urban areas

Compared to rural areas, cities have different challenges to address when dealing with interlinkages in the nexus. Cities tend to have governance structures that are fragmented both horizontally and vertically, making it difficult to

coordinate the design, implementation and management of infrastructure.[109] Cities, particularly in developing countries, also face particular challenges in relation to funding infrastructure as they show a tendency to collect limited own-source revenues and privilege the funding of recurrent costs, such as salaries, over capital expenditure. As a result, the capitals of many developing countries (many of which are LDCs) rank at the bottom of global indexes of liveability,[110] which report an increasing burden on people's perceptions in terms of socio-economic opportunities and equality of access. [111]

In 2014, there were estimated 900 million passenger cars and light duty vehicles in developing countries. This is expected to increase to nearly 1.6 billion vehicles by 2035. Mexico City's car population is increasing twice as fast as its population, while India's private vehicle population is increasing three times as fast.[112] Congestion has been an increasing problem. Financial costs of efficient public transport development are often too high for many cities in developing countries[113]. Due to this financial and capacity constraint, informal transport dominates service provision in most developing countries.

In urban areas, many poor can benefit from infrastructure investment and maintenance that focus on affordable public transport and in facilitating the use of less expensive means of transport such as bicycles and motorcycles. Since the poor live disproportionally in peri-urban slums and since these areas are the least served and connected, the poor tend to be disproportionally affected by the inadequate status of infrastructure. Indeed, they are disproportionally affected by the time spent on getting access to a given service – be it transport, or securing water, electricity, fire, etc. And since women have multiple daily journey patterns, including taking children to school, going to work, going to healthcare facilities, going shopping, etc., they are disproportionally affected by the lack of services and investment in these peri-urban areas. In addition, these are areas where pollution levels tend to be most concentrated and reach the highest levels.

Labour-intensive road construction programs have been carried out in few urban projects in which the objective was to provide employment for the poor. Examples include the South African Expanded Public Works Programme (EPWP) and the Bangladesh Local Government Engineering Department (LGED), as well as several small urban community-based employment programs in Africa, such as storm water drainage and footpaths in Kampala and Dar es Salaam, roads and drains in Lusaka, bicycle lanes in Kisumu (Kenya) and road rehabilitation in Nairobi. [114]

The urban planning process in many cases involves undertaking surveys and collecting data on travel patterns.[115] To this extent, data need to be collected from different groups in society, including poor people and slum dwellers. However, often lacking is a comprehensive dialogue with different groups on the key urban transport choices. To alleviate this, urban planning involve civil society organizations more systematically in their decision-making process. For example, in a well-known case in Mumbai, India, CSOs saw that organized groups of slum dwellers were able to reach an agreement with the Railroad Transport Authority and municipal authorities to relocate and resettle several thousand households living in slum settlements located alongside railway tracks.[116]

Several policy brief contributions to this Report have focused on emerging issues in urban areas related to inequality, vulnerability to the effects of climate change, and insufficient infrastructure systems. A summary of the key messages of these contributions is presented in Box 2-2.

2.3 Conclusions

This chapter aimed to illustrate the importance of adopting an integrated approach towards sustainable development, by highlighting some of the main interlinkages between infrastructure, inequality and resilience. Among the possible interlinkages in the nexus, the areas that are usually covered by scientific research are the links between infrastructure and inequality, and how people's resilience is affected separately by infrastructure resilience and by inequality. The links that are not covered are those from resilience to inequality and from resilience to infrastructure. These are relevant linkages and further research in this area is needed to uncover important synergies and trade-offs.

In terms of policy areas related to the nexus, focus on both efficiency and equity goals is needed to harness the synergies between infrastructure, inequality and resilience. An important policy component is geographic equity in the provision of basic infrastructure. Regulation and incentive mechanisms need also to be in place to integrate disaster risk reduction into all phases of the infrastructure life cycle, and to ensure the resilience of critical infrastructure to natural disasters. Contributing experts have also noted the need to further disaggregate the analysis between rural and urban contexts to be able to provide more specific policy recommendations.

Further cross-disciplinary collaboration and engagement between researchers, practitioners, decision makers and other stakeholders could be a way of achieving the mutual learning and transfer of information that would enable scientific knowledge to be transformed into practical strategies to harness the synergies and address the trade-offs between the three areas of the nexus.

Box 2-2: Emerging issues in the urban context related to the infrastructure, inequality and resilience nexus

Holistic, large-scale and integrated changes are needed to make cities more sustainable and resilient—to build capacity for absorbing future shocks and stresses to social, economic, and technological systems, and to develop infrastructure through processes of evolution and adaptation. Many cities are undergoing urban sustainability transformations, which aim to integrate resource efficiency, resilience and quality of life, and address the social and political challenges inherent in transformative change.[117] Green infrastructure approaches to urban planning maximize the functions of the natural environment in urban areas while simultaneously protecting it, and have multiple ecological and social benefits, including for sustainable water management, CO_2 storage and removal, reduced energy use in buildings, air quality improvement, and human health and wellbeing.[118]

In areas where the process of industrialization in still in the early stages, it is important to promote air pollution mitigation technologies such as catalysts, filters and renewable energy replacements to make cities safer, sustainable, and more resilient.[119] Successfully integrating climate change mitigation measures in cities will require disaggregated data to better inform policies and planning in areas characterized by high levels of urbanization and poverty and by low levels of infrastructure provision (e.g. river delta regions).[120]

Implementing clean and affordable modern technologies inside homes can reduce death and disease rates due to indoor air pollution, increase women's empowerment, and ensure a healthy learning environment for children. Bottom-up interventions such as "E-VOIDs", which upgrade the infrastructure of high-density slums to allow for better lighting and ventilation, are being designed and implemented by poor communities in densely packed urban areas.[121] Innovative financing such as Social Impact Bonds (SIBs) that reward investors with financial return aligned to positive social impacts (e.g. investing in safer road infrastructure to reduce road traffic deaths),[122] and green bonds that link investment to reductions in carbon emissions (e.g. through low emissions public vehicles or investments in walking and cycling infrastructure) are being promoted through efforts to achieve more sustainable and resilient cities.

Source: Science-policy briefs submitted for the GSDR 2016.

Endnotes

1 In many countries the private sector largely owns and operate infrastructure.

2 Estimates from the Global Tracking Framework 2015 led by the World Bank and International Energy Agency (IEA), in coordination with the Energy Sector Management Assistance Program (ESMAP) and 20 other partner agencies. Information available from: http://trackingenergy4all.worldbank.org/

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4 https://www.weforum.org/agenda/2015/10/why-infrastructure-investment-is-key-to-ending-poverty/

5 Infrastructure gap refers to the difference between the expected level of infrastructure development based on past trend and the level required to meet internationally agreed development goals. Source: Inter-agency Task Force on Financing for Development (2016), Addis Ababa Action Agenda – Monitoring commitments and actions – Inaugural Report 2016. Available from: http://www.un.org/esa/ffd/wp-content/uploads/2016/03/Report_IATF-2016-full.pdf

6 For examples of estimates of useful time of infrastructure in terms of capital asset depreciation, see http://www.osa.state.ms.us/downloads/gasb34infrastructure.pdf; http://www.bls.gov/ore/pdf/ec000040.pdf.

7 D. Guha-Sapir, R. Below, Ph. Hoyois – EM-DAT: The CRED/OFDA International Disaster Database – www.emdat.be – Universite Catolique de Louvain – Brussels – Belgium.

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11 The IPCC defines resilience as "the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions." (see Lavell, A., M. Oppenheimer, C. Diop, J. Hess, R. Lempert, J. Li, R. Muir-Wood, and S. Myeong, 2012: Climate change: new dimensions in disaster risk, exposure, vulnerability, and resilience. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 25-64.Lau, S.H.P. and Sin, C.Y. (1997), Public Infrastructure and Economic Growth: Time Series Properties and Evidence. Economic Record, 73, 125-135, Australia).

12 For example, low resilience to economic and environmental shocks due to lack of social protection programs could lead to an increase in inequality, since the poor would suffer more.

13 The World Economic and Social Survey 2016 examines and presents relevant lessons on these links from resilience to inequality and to infrastructure.

14 A list of additional illustrative reports is available at https://sustainabledevelopment.un.org/globalsdreport/2016/chapter2.

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World Bank, Washington D.C.). Gachassin M, Najman B and Raballand G, 2010 (The impact of roads on poverty reduction: a case study of Cameroon. Policy Research Working Paper 5209, World Bank, Washington DC, USA.) use the Cameroonian national household survey (2001) and report that it is not road availability per se that helps to reduce poverty, but the labor opportunities opened by roads. Rehabilitation of rural roads raises male agricultural wages and aggregate crop indices in poor villages of Bangladesh (Khandker S R, Bakht Z, Koolwal G B, 2009. The poverty impact of rural roads: evidence from Bangladesh. Economic Development and Cultural Change, 57 (4): 685-772). In Viet Nam, public investment on infrastructure has resulted in an increase in the availability of food, the completion rates of primary school and the wages of agricultural workers (Mu R and van de Walle D, 2011. Rural roads and local market development in Vietnam. Journal of Development Studies, 47 (5): 709-734). In addition, other studies find that access to new and improved roads in rural areas enhances opportunities in non-agricultural activities in Peru (Escobal J and Ponce C, 2002. The benefits of rural roads: enhancing income opportunities for the rural poor. GRADE Working Paper 40. Grupo de Análisis para el Desarrollo (GRADE), Lima, Peru. 56p. ISBN: 9972-615-25-I) and in non-farm activities among women in Georgia (Lokshin, M., and R. Yemtsov, 2005, Has Rural Infrastructure Rehabilitation in Georgia Helped the Poor? The World Bank Economic Review 19(2):311-333). Finally, Jalan and Ravallion, 2003 (Does Piped Water Reduce Diarrhea for Children in 31 Rural India? Journal of Econometrics 112(1):153-173) showed that the water supply system had a relatively stronger economic effect among poor households than it did among non-poor households.

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61 A study from Nepal has shown very high benefit to cost ratios for new rural roads (Shrestha I and Starkey P, 2013. Economic analyses of three DRSP roads. Annex 3 (pp 53-62) in: Starkey P, Tumbahangfe A and Sharma S, 2013, External review of the District Roads Support Programme, Final Report. Swiss Agency for Development and Cooperation, Kathmandu, Nepal). A study of public investments in rural Uganda suggested that the most basic 'feeder' roads had a benefit-cost ratio of 7.2, with 34 people taken out of poverty for each million shillings invested (Fan S, Zhang X and Rao N, 2004. Public Expenditure, Growth and Poverty Reduction in Rural Uganda, Development Strategy and Governance Division, Discussion paper 4, International Food Policy Research Institute, Washington DC, USA). In contrast, the benefit-cost ratios of gravel roads were not significant. Fan and Chan-Kang (2005, Road development, economic growth and poverty reduction in China, Research Report 138, International Food Policy Research Institute, Washington DC, USA) concluded that the greatest returns to investments in China came from the construction of low-volume rural roads as their benefit-cost ratios were four times greater for national GDP than investments in high-volume roads. Banjo, Gordon and Riverson (2012, Rural transport: improving its contribution to growth and poverty reduction in Sub-Saharan Africa. SSATP Working Paper 93, World Bank, Washington DC, USA) also emphasized the need to focus rural transport investments in rural community roads, paths and trails.

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