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Infrastructure Finance in the Developing World

Green Infrastructure: Definition and Needs

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About GGGI

Based in Seoul, GGGI is an intergovernmental organization founded to support and promote a new model of economic growth known as "green growth." The organization partners with countries to help them build economies that grow strongly and are more efficient and sustainable in the use of natural resources, less carbon intensive, and more resilient to climate change. GGGI's experts are already working with governments around the world, building their capacity and working collaboratively on green growth policies that can impact the lives of millions. To learn more, see http://www.gggi.org and visit us on Facebook and Twitter.

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About the project

The *Infrastructure Finance in the Developing World Working* Paper Series is a joint research effort by GGGI and the G-24 that explores the challenges and opportunities for scaling up infrastructure finance in emerging markets and developing countries. Each paper addresses a unique piece of the infrastructure finance puzzle and provides critical analysis that will give impetus to international discourse and play a catalytic role in the creation and success of new development finance institutions. The papers have been authored by top experts in their respective fields, and the process has been carefully guided by the leadership of both organizations. This work has important implications in the post-2015 environment, given the essential role infrastructure must play in achieving sustainable development. To this end, GGGI and the G-24 look forward to further development and operationalization of the contents of these papers.

Green Infrastructure: Definition and Needs

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1. Introduction

Making the right investment decisions regarding infrastructure is crucial now for three reasons. The first is the need to support growth. Emerging markets and developing countries (EMDCs) are growing faster than their more developed peers, with estimates of 2015 growth at 5.4% in EMDCs compared to 2.3% for the developed economies.[1] The former's economic success and long-term environmental impact on the world will hinge on the way in which their economies grow, which in turn will hinge on the types of infrastructure they build and operate. The second issue concerns laying a foundation for sustainable development. Climate change is placing increasing pressure on the sustainability of current economic growth models. Energy and transport infrastructures that add more carbon into the atmosphere will ultimately undermine growth, and poor decisions in water and land-use infrastructure will render it difficult to cope with adaptation needs, which are especially important in the developing world. The third issue is timing of investment decisions. Major infrastructure investment decisions (which areas will receive investment and how that will be financed) that are currently being made will determine whether developing countries are able to achieve their growth targets and development aspirations over the next couple of decades while avoiding the catastrophic consequences of climate change. The challenge ahead is to find solutions that enable investors to channel funds into better infrastructure for more sustainable growth, despite the perception that this will be more costly upfront. This paper is a step in this direction.

Efforts have been frequently made to quantify infrastructure needs over the next decades, particularly in the developing and emerging world. Some estimates of infrastructure needs that would reduce carbon emissions to levels deemed acceptable in terms of their implications for climate change also exist. Little work has been done, however, to develop a wider framework for infrastructure that lays the foundation for a sustainable model of economic growth, and then cost it in a way that is useful to inform the debate on infrastructure finance. This paper expands upon existing literature by proposing a wider definition of what constitutes green infrastructure. We then develop a holistic cost model by defining and quantifying the investment categories that should be considered part of green infrastructure. This e paper achieves three main objectives. First, we advance the concept of green infrastructure as a critical tool for sustainable economic growth. Second, we develop a new cost model and attempt an initial quantification of the additional needs for green infrastructure. Finally, we outline an agenda for further research required to provide more accurate estimates of such needs.

This paper is structured as follows. In the first section, we explain the role of infrastructure in economic growth and it's particular importance to growth in the developing world. We then propose a definition of green infrastructure. Next, we suggest a methodology, rationale, and estimates for each component of what we call green infrastructure. Finally, we outline an agenda for future research. The key result of the paper is an estimate of additional inputs needed to provide green infrastructure. After accounting for the additional costs to provide infrastructure that can tackle climate change, ensure environmental sustainability, and enable higher resource productivity, as well as considering savings on the foregone fossil fuel infrastructure and inevitable accounting overlap, the total annual cost for green infrastructure over the next 15 years is estimated to be $0.1–0.5 trillion beyond estimates of "grey" infrastructure needs in the developing world.

2. Evolution and Framework for Green Infrastructure

2.1. Infrastructure and Economic Growth

Infrastructure is central to development and economic growth. It not only has a direct effect as an input in the production process of different sectors but also has an indirect effect in terms of raising the productivity and efficiency of economic activities, thereby increasing total factor productivity.[2] In this paper, infrastructure is understood to mean "economic" infrastructure, which includes energy, water, transport, network utilities, digital communication, and so on.[3] Although the theoretical link between infrastructure and growth is strong and clear, empirical studies on the relationship between infrastructural investment and economic growth have not yielded unanimous results across sectors and countries over time. The majority of studies, though, indicate a positive correlation between infrastructure and growth. The channels and causalities of such relationship are not fully supported by empirical evidence, but results have indicated more clearly that a lack of infrastructure reduces growth. Recent estimates, which benefit from improved methodologies, show a modest and heterogeneous relationship in this sense. To the extent that suboptimal investment in infrastructure constrains other investments, it also constrains growth.[4]

Regardless of the empirical evidence, it is clear that policies that shape infrastructure investments are critical to the nature and scale of development as these investments have strong "lock-in" effects, leading to outcomes that have long-lived impacts on patterns of development. This lock-in nature of investment implies that its impacts are difficult and expensive to reverse. In addition, this challenge is much more significant in EMDCs with high unsatisfied needs, as their infrastructural decisions carry significant inertia in shaping development pathways. This is true in the developed world as well. In the United States, past investment in urban planning and transportation has locked in a carbon-intensive infrastructure and has led to carbon-intensive behaviors. Comparatively, many European countries have lower carbon intensity due to their urban mass transit systems and high urban population densities (Figure 1). From this perspective, the existing infrastructure gap in developing countries offers opportunities to build sustainable infrastructure and "leapfrog" to more productive, less carbon- and natural resources-intense modes of development.[5] Greening infrastructural investments (i.e., investments in "green infrastructure") will play a critical role in directing development toward a sustainable pathway.

2.2. Green Infrastructure Concepts

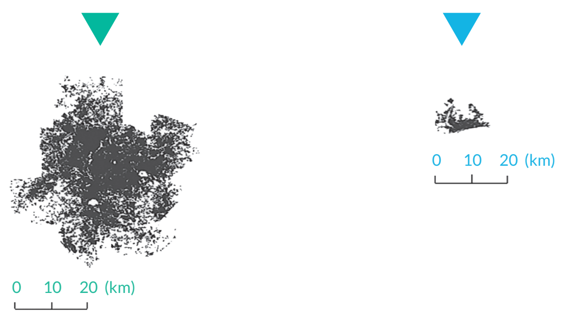
The term "green infrastructure" does not have a widely accepted definition, but is nevertheless increasingly being used by various disciplines. Most of the earliest references come from conservation-related disciplines to describe multifunctional green spaces that support sustainable development. In this definition, natural spaces are integrated or combined with man-made systems to create synergies, such as floodplains, green roofs, and rain-water harvest systems.[6] These early concepts of green infrastructure emphasize the importance of goods and services provided by nature's ecosystems and are often built to produce such, often intangible or unpriced, goods and services. However, in recent years, the term green infrastructure has evolved to include man-made infrastructure that preserves or increases the productivity of natural resources, including reducing emission intensity. This would comprise energy efficiency infrastructure, mass urban transport infrastructure, renewable energy infrastructure and so on. This definition expands the narrower concept emphasizing the "green features" of nature. The definition can be further expanded; the OECD, for example, indicates that even gray infrastructure can be made green if its environmental impact is mitigated.[7] Similarly, several development banks have referred to green infrastructure when considering environmental

Figure 1. Impact of Metro Density on Carbon Emissions

Atlanta and Barcelona have similar populations and wealth levels but very different carbon productivities

ATLANTA'S BUILT-UP AREA

BARCELONA'S BUILT-UP AREA



Atlanta

Population:	5.25 million
Urban Area:	4,280 km^2
Transport Carbon Emissions*:	7.5

Barcelona

Population:	5.33 million
Urban Area:	162 km^2
Transport Carbon Emissions*:	0.7

*tons CO_2 per person for public and private transport

Source: Bertraud and Richardson 2004 in New Climate Economy 2014.

safeguards, a guiding set of principles for investment that aims to mitigate (if not avoid) the impact on natural habitats and on emissions (Quintero 2012)[8]. The finance sector has also used the term to identify several broad categories eligible for green infrastructure ("green projects"), which generally include investments in renewable energy, energy efficiency, sustainable waste management, clean transportation and so on (Green Bond Principles 2014).

This paper utilizes the evolving concept of green growth to define green infrastructure. Green growth aims to avoid unsustainable pressure on natural assets by decoupling economic activity from resource use and its related environmental impacts as embodied in the following working definition:

> *Green growth is a pathway toward sustaining economic growth while at the same time ensuring climatic and environmental sustainability* (GGGI 2011).

The essence of green growth lies in finding opportunities to engage in and support activities that promote growth while reducing carbon emissions or the use of natural resources, and prioritizing activities that maximize synergies between economic and environmental objectives while minimizing the trade offs.

By incorporating the green growth concept, the scope of what constitutes green infrastructure expands to include all growth-enhancing new infrastructure that reduces emissions and/or the natural resource intensity of an existing or new system, including both stand-alone new infrastructure and additional infrastructure (such as improving the energy efficiency of an existing building). The chart below (Figure 2) gives a pictorial description of the implications of this expanded definition. Green infrastructure enables economies to expand the frontier of the perceived tradeoff between environmental/climate sustainability and economic growth.

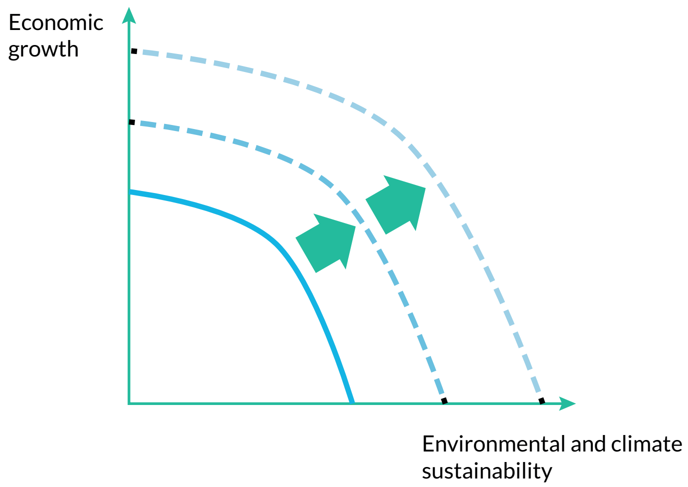
Referring to Figure 2, infrastructure investment that can move in the direction of the green arrow toward a higher frontier can be considered green infrastructure. For example, renewable energy systems such as solar power plants and wind farms are increasing economic growth by producing power that enables economic activities while reducing emissions from burning fossil fuels. Carbon capture and storage systems (CSS) are green infrastructure as they allow for the delivery of power through fossil fuels, thereby enabling economic growth while increasing environmental and climate sustainability.

Some considerations are important when using this definition of green infrastructure, as it relies on a concept of tradeoffs that would require similar metrics to measure economic growth as well as environmental and climate sustainability.

First, the environmental and climate sustainability improvements (movement to the right along the horizontal axis of the chart in Figure 2) can sometimes be clearly quantified and monetized, as for example with energy efficiency or emission reductions where a carbon market exists. However, some sustainability improvements, especially where a market does not exist or is illiquid, are difficult to quantify or monetize (improvements in quality of air, or access to green spaces, and so on).

Second, movements along the vertical axis are not always easy to measure. There is an ongoing debate regarding whether current methods of measuring economic growth (i.e., by looking at variations in GDP) fairly reflect improvements in quality of life. Considerations regarding quality of growth, environmental inequality, and happiness are all part of this debate.[9] These considerations sit at the heart of our definition of green growth, and by including an explicit component around environmental and climate sustainability in our definition of green infrastructure, we implicitly place this paper in that literature. However, we want to clearly distinguish between the economic growth component and the environmental and sustainability

Figure 2. Green Infrastructure Expands the Frontier of Environmental Sustainability and Economic Growth



component, and accordingly, we keep the two separate and perpendicular in our definition of green infrastructure.

Third, the impact of infrastructure on growth, even when defined narrowly in terms of GDP growth, is often difficult to measure. While the static, narrow impact of an infrastructure investment can be estimated through the traditional cost and benefits approach, this is generally inadequate given the long-term, transformational nature of most infrastructure investments. The implications of investment in infrastructure will have dynamic effects across the economy, both in the short and long term. All of these effects need to be considered to comprehensively assess the overall impacts. Such assessments are complex and often unreliable.[10]

The definition of green infrastructure adopted in this paper, therefore, may not always lead to identifying and quantifying clearly what is and is not green infrastructure. Nevertheless, it can serve as a general guide and enable us to perform an order of magnitude estimation of green infrastructure needs at an aggregate level. The above considerations may also serve as an agenda for future research that can help further clarify the concept of green infrastructure and capture a broader role for it to play in economic growth.

3. Infrastructure for Green Growth: A Cost Model

The first part of this paper has proposed a definition of green infrastructure based on the concept of green growth. The remainder of the paper performs an order of magnitude estimation of the additional needs for implementing green infrastructure over the coming decades. The assessment of additional investment presented in this paper utilizes the overall needs for infrastructure as estimated in Bhattacharya and Holt (2014).[11] It explores the likely additional requirements to meet both emission reductions in line with a 2C climate change goal and, more generally, to improve the economy's resource productivity. The estimation's outcome is that the overall incremental additional cost of green infrastructure is a capital expenditure of $0.5–1 trillion annually between now and 2030. However, when considering the potential savings on operational expenditure over the life of green infrastructure, much if not all of the additional cost can be recovered.

This paper does not explore the overall economic impact of the green infrastructure component, nor does it attempt a cost–benefit analysis of the potential investment in green infrastructure. There is a rich body of literature on this topic, particularly with reference to taking action on climate.[12] This paper examines the additional financing that would be required to prioritize green infrastructure to an extent consistent with the goals of global climate change policy, sustainable development, and green growth. It therefore makes an implicit assumption regarding the allocation choices in infrastructure project investments that need to be made over the next decades. This paper does not examine the macroeconomic cost of the transition, as it only explores the static additional investment requirements rather than the dynamic impact on the economy, which is bound to differ. The rationale and methodology for the assessment of green infrastructure investment needs are summarized below.

Rationale. In considering the fundamental elements of green infrastructure, we include the following:

- Infrastructure required to tackle climate change, both in terms of meeting greenhouse gas (GHG) emission targets and in terms of adapting to inevitable consequences of increasing temperatures;
- Additional activities and investments that are required to mitigate and manage adverse environmental consequences of infrastructure investment, often local in nature;
- Infrastructure that enables improvements in resource productivity across a range of natural resources.

Estimates. To estimate the additional costs of green infrastructure covered by the three categories above, we use a simple methodology based on the following five components:

- The baseline overall needs for infrastructure in EMDCs between now and 2030 based on a business-as-usual scenario;
- The cost of developing infrastructure that is consistent with GHG emission reduction goals and adaptation needs in EMDCs, based on a 2C trajectory (category A above);
- The cost of implementing and enforcing standard environmental safeguards, as a proxy for the costs related to managing adverse environmental consequences of infrastructure investment (category B above);
- The cost of adopting technologies and business models to allow improvements in resource intensity (category C above);
- Some estimate of the potential overlap between the above categories due to inconsistency in definitions/ double counting;
- The capex savings achieved over time due to investments in green infrastructure as opposed to fossil fuel infrastructure.

The following sections consider each component in sequence to estimate its magnitude.

3.1. Baseline Investment Needs for 2030

Estimate. This number is measured by compiling existing estimates of necessary infrastructure investments that either benchmark historical investment patterns or allow countries to maintain their forecasted growth in the future. This can be considered the level of baseline investments under an "investment as usual" scenario. The needs estimates proposed by Battacharya and Holt (2014) place the total baseline needs for growth close to $3.0 trillion per year for EMDCs. Other estimates for this category range from a low $864 billion annually for developing countries alone,[13] to a global annual total of $6.59 trillion to 2030.[14] Increasing demand for energy will generate the bulk of required infrastructure costs over the coming decades, reflecting the investments required in the energy sector. Considering that an estimated 61% of energy demand currently comes from non-OECD countries, a proportion that is expected to grow as development continues, initial estimates for the baseline needs of non-OECD member countries is $2.5 trillion per year to 2030.[15]

3.2. Emissions Reduction and Adaptation

Rationale. The literature on the additional cost of sustainable infrastructure has, thus far, mostly focused on the cost of low-carbon infrastructure versus investments in business as usual (BAU). For example, the International Energy Agency's (IEA's) 2012 Energy Technology Perspectives estimates that the additional needs to meet the 2C target are approximately $1 trillion on average a year between now and 2050. These estimates include both developed and developing countries' needs and cover the energy, buildings, and transport sectors. These are estimates of the up front costs and do not include reduced operating expense (OPEX) costs from the reduction in fossil fuel consumption (IEA 2012). Similarly, the OECD[16] has extended the analysis of the IEA looking at the additional infrastructure requirements for a low-carbon economic pathway across a number of sectors. Table 1, from Kennedy and Corfee-Morlot (2012), is a useful guide to the requirements across different sectors.

The Organisation for Economic Co-operation and Development (OECD) estimates are interesting as they show the extent of different sectors' interdependence. While the largest increase in infrastructure requirements appear to be in the buildings sector, the implications of a shift to a low-carbon economy for the transport sector are extremely difficult to estimate. Increased rail infrastructure due to a shift from road transport, for instance, may be offset by a reduced use of rail for moving coal. Nevertheless, the trade implications of a shift to a low-carbon economy would also impact freight transport. Such complexities and dynamic links between sectors make bottom-up estimates extremely difficult.

Research by the IEA and OECD forms the basis of the estimates in a recent report by the World Economic Forum (WEF). The WEF analysis includes additional sectors, such as water, agriculture, forestry, and telecommunications. They find that approximately $0.7 trillion a year is required globally between now and 2030 to meet the climate change challenge by limiting emissions in line with a 2C scenario (WEF 2012). Similar estimates have also been produced by a recent research effort in the context of the New Climate Economy (NCE) report.[17]

These estimates are again based on achieving a 2C scenario, based mostly on OECD/IEA assumptions as well as on new estimates by the NCE that examines sector wise the additional requirements needed to have an 80% chance at not exceeding a 2C temperature increase. The NCE estimates indicate that approximately an additional $14 trillion is required in the period 2015–2030 to move the economy to the low-carbon pathway, just under $1 trillion a year. Their analysis highlights the fact that much of these additional costs would be offset by a reduction in capital expenditure for fossil fuels and transmissions due to more compact cities. More importantly, substantial savings would result from reduced operational costs, mostly due to reduced consumption of fossil fuels.

Fewer estimates are available regarding the investment requirements for adaptation. These are an important component of future needs as the inevitable climate changes driven by emission levels will substantially impact coastal infrastructure, due to increasing surges and projected sea level rises, and, in particular, on water management infrastructure. Other areas, such as agriculture, hydropower generation, and transport, may also require substantial additional infrastructure investment to be climate-proofed. Recent estimates by Agrawala et al. (2010), based on an integrated assessment model focusing on adaptation cost curves, indicate that as much as $1 trillion a year would be required between now and 2060 on average, with the greatest majority needed for water infrastructure. These estimates, however, include the infrastructure required to meet needs currently unmet, quite independently from climate change effects, and are therefore not necessarily strictly additional on a BAU. Numbers for developing and emerging countries vary significantly, but taking South Asia and Sub-Saharan Africa as reference regions, by 2050, the costs of adaptation vary between 0.15–0.5 percent of GDP in these regions.

Estimate. In estimating the total needs on the 2030 horizon, we include projected need for infrastructure that contributes to (1) the 2C climate change target set by nations in the context of the United Nations Framework Convention on Climate Change (UNFCCC) negotiations, and (2) the climate resilience needs faced by developing countries due to a changing climate. We base our estimates on the range of existing assessments, considering as wide a sectoral coverage as possible. Table 2 compares the different estimates.

Estimates are difficult to compare as they are performed across different sectors, over different time horizons (which we averaged in the table above), and using different assumptions for the meaning of low-carbon as well

Table 1. OECD Estimate for the Incremental Cost of Low-Carbon, Climate Resilient (LCR) Infrastructure, 2015–2020 (USD bn/yr)

	Business-as-usual (6 deg C) Scenario	Low Carbon (2 deg C) Scenario	Incremental Cost of Low Carbon Scenario	Notes on Author's Estimates
Power Generation[1]	320	380	60	
Electricity T&D[1]	270	260	–10	
*Buildings[1]	320	620	300	
Industry[1]	280	310	30	
Water	772[2]	772[4]	0	
Telecoms	646[2]	646	0	
Road	245[2]	<245[4]	<0	Sequenced with transformation in vehicle technology
Transportation Vehicles[1]	3,300	3,370	70	
Rail	120[3]	120?[4]	0?	Decrease in demand for coal replaced by shifting of freight from road
Airports	120[3]	< 120[4]	<0	
Ports	40[3]	40? [4]	0?	Decrease in demand for oil and coal replaced by increased trade in green products
Oil, Gas & LNG Distribution	155[3]	< 155[4]	<0	Lower demand for oil and gas
Total	**6,590**	**~ 6500 to 7000**	**~ 0 to +400**	
Total (excl. buildings & vehicles)	**3,000**	**~ 2500 to 3000**	**~ –500 to 0**	

Source: Kennedy, C. and J. Corfee-Morlot (2012), "Mobilising Investment in Low Carbon, Climate Resilient Infrastructure", OECD Environment Working Papers, No. 46, OECD Publishing. http://dx.doi.org/10.1787/5k8zm3gxxmnq-en

as different baselines. We do not consider the OECD (2014) numbers, as they exclude the transportation-vehicles category, which is very significant in terms of new infrastructure needs. The estimates identify a range between $0.4 trillion (the top estimate of the Kennedy and Corfee-Morlot paper, which includes buildings cost) and $1.1 trillion globally. Using the assumption applied by the IEA World Energy Outlook (WEO) 2012, namely that the share of infrastructure needs for the energy sector in EMDCs is approximately 60% of the total GDP, we conclude that the range of needs for climate change mitigation in EMDCs ranges between $0.24 trillion and $0.66 trillion annually.

Adaptation infrastructure costs, the costs to adapt to the inevitable changes in climate that have already been locked in by existing emission trends, have been a topic of international discussion for nearly a decade. Using the results from Agarawal et al. (2010), and extrapolating numbers for EMDCs as a whole (assuming their total GDP will approach $14 trillion by 2030 according to the latest OECD projections[18]), we estimate that the cost of adaptation in EMDCs would be between approximately $20 billion and $70 billion a year by 2030.

Given all these estimates, the yearly additional infrastructure requirements for climate sensitivity in EMDCs, including both mitigation and adaptation, between now and 2030 would be approximately between $0.26 trillion and $0.73 trillion.

3.3. Environmental Sustainability

Rationale. Building infrastructure that manages and avoids the adverse effects on local environment is a key part of what we define as being green infrastructure. This reflects the fact that local environmental damages are widely recognized as incurring a substantial cost and imposing a negative impact on GDP growth (e.g., the impact of local pollution on a city's economic growth prospects) or imposing costs that are not fully captured by markets (e.g., the impact of reducing access to green spaces in a densely populated urban environment). Managing such costs efficiently, or avoiding them altogether by adopting different infrastructure solutions, can therefore lead to higher GDP growth, or, in case the benefits are not monetized, higher wellbeing. Such objectives are articulated by international standards on safeguards such as the Equator Principles.[19] These standards establish requirements that ensure a project's environmental soundness and strive to consider the lives of displaced poor and vulnerable groups throughout a project's construction and operation phases. The details of the appropriate safeguards measures are outlined in social and environmental impact assessments completed at an individual project level. After an assessment is performed, actions are identified to mitigate, minimize, and/or avoid any adverse impacts during the infrastructure production. Continuous monitoring over the life of the infrastructure is also recommended to ensure that necessary protection efforts are conducted through the project's lifecycle. Despite these steps being an essential part of the infrastructure development process, no clear and fully

Table 2. Estimates of Baseline Versus Climate-Sensitive Infrastructure Needs, Global

Source	Sectors Measured	Baseline Needs (USD trillion)	Climate Sensitivity (mitigation only) (USD trillion)	Needs Horizon
NCE (2014)	Power, transport, water, energy efficiency, telecom	6	0.4	2015–2030
IEA (2014)	Power, Buildings, Industry, Transport	3	1.1	2011–2050
World Economic Forum (2013)	Energy, Building, Industry, Transport, Water, Agriculture, Telecom, Forestry	5	0.7	2010–2030
OECD (2014)	Energy, Transport (excl. vehicles), Water	3.2	–0.448 to 0.352	2015–2030
Kennedy & Corfee-Morlot (2012)	Energy, Building, Industry, Transport, Water, Telecom	6.59	0–0.4	2015–2020

enforced global standards exists to manage project safeguards and monitor their impact on infrastructure development and functions.

Estimate. The cost of fully implementing safeguards (from assessment to identification of actions to long-term monitoring) for infrastructure varies widely according to project size and stringency of the financing institution's policies. Their implementation across the board is neither required by international law nor formally monitored or evaluated. While the costs of performing an environmental or social impact assessment and implementing recommended actions are often outweighed by the benefits of taking such action,[20] a lack of norms, standards, or laws for reporting safeguards implementation over the long run, even among the largest lending institutions, means the complete cost picture is difficult to paint. As our goal here is to suggest the cost in the best-case scenario, we set the additional cost of a fully functional and responsible project-level safeguard regime at a conservative 10% of an individual project's cost.[21] This is based on limited data from independent project reviews and staff surveys regarding safeguards implementation by the European Union, World Bank, and Asian Development Bank, which consider the cost to perform environmental and social impact assessments and to take any short-term actions to mitigate, minimize, and/or avoid adverse impacts to the surrounding environment.[22]

3.4. Economic Productivity

Rationale. The estimates available for infrastructure look at additional needs for climate purposes or, at best, for low-carbon growth. None consider a wider concept of green infrastructure as defined here, including infrastructure aimed at increasing natural resource productivity while supporting economic growth. While there are many elements of green infrastructure included in the infrastructure needs for low-carbon growth, it is likely that additional infrastructure—focused on reducing local emissions or increasing resource productivity for land, water, minerals, and so on—would be needed for this wider definition driven by the concept of green growth.

As described earlier in this paper, the transition to a green economy will involve fundamental structural changes to reduce the overall natural resources intensity of economic activities. In order to deliver such a fundamental transformation, we need to account for additional infrastructure costs. A potential classification of the required actions could look as follows (Heck and Rogers 2014):

- Substitution: Substituting higher-performing and less expensive, less risky, or less scarce materials in place of more resource-intensive ones, such as electric motors for internal-combustion engines;
- Optimization: The smarter use of equipment; for instance, by integrating new software into traditional industrial equipment or increasing the ability to share capital-intensive equipment between consumers or industries;
- Virtualization: Moving activities out of the physical world completely, or simply not involving processes that can be automated;
- Circularity: Designing and using products so that they retain value after their initial use; and
- Waste elimination: Greater efficiency, achieved by means including the redesign of products and services.

New business models that change the way in which we consume product and services will also play an important role in the transition to a more resource-productive economy, and will have substantial implications for infrastructure needs. The "sharing" business models that are currently emerging in several sectors of the economy, from cars to apartments to heavy equipment for construction, could have—for example—profound implications in terms of infrastructure needs over the next couple of decades. These new business models offer the opportunity to leapfrog traditional business models in countries and cities that are, for the first time, laying out the infrastructure to provide their citizens with products and services.[23]

Estimate. Estimating the potential cost of additional infrastructure arising from a shift toward a green economy along the categories outlined above is difficult. While we are already now observing trends and innovations along the lines suggested by these categories, it is difficult to predict at this stage what innovations will be able to gather momentum and shape our markets more than others. It is therefore very difficult to predict what the infrastructure implications of such innovations could be.

Let us take, for example, the "Circularity" category. Research carried out by the Ellen Mac Arthur Foundation (EMF) indicates that the potential for a circular economy is very large. In the EU alone, cost saving opportunities in the medium-lived complex industry sectors range from $340–380 billion a year to $520–630 billion a year. In fast-moving consumer goods, the opportunities would be even larger, with more than $700 billion in potential savings a year. These numbers are calculated net of the costs associated to the reverse-cycle processes required to reuse materials. While the report does not explore the implications in terms of existing and new infrastructure, these are likely to be very large given the scale of the opportunity. On average, across multiple products, the EMF's analysis indicates that the costs of recycling/refurbishing products is approximately 20–30% of the product's recoverable value, suggesting that the potential upfront capital and operational expenditures required for implementing a circular economy could be quite substantial, in the range of $300–560 billion per year. This would not be all additional cost—some would be offset by the reduced needs for infrastructure in activities that are made obsolete by new, circular models. This is just an order of magnitude calculation of the needs associated with such a fundamental economic transformation. More research is required to understand the exact needs in terms of infrastructure.

3.5. Overlapping Costs

Given the uncertainty surrounding the definition of each category of additional costs, and indeed of the original BAU needs assumptions, it is inevitable that some costs will be double counted. In particular, we can expect that some activities related to climate change mitigation and adaptation will generally be included in the safeguards cost. A percentage of these types of reductions can be made from the overall costs of ensuring that infrastructure is climate sensitive, as some safeguard-led investment will either implicitly or explicitly reduce emissions.
The resource-productivity category, which we do not quantify explicitly at this stage, could also pose some issues of double counting both within the category, as the classification proposed is not necessarily mutually exclusive, and between the resource productivity category and both the climate mitigation/adaptation category and the environmental safeguards category, as both of the latter include investments that could conceivably be part of a wider transition to a more resource efficient economy. At this stage, we do not estimate how big such an overlap may be, as further work is required to define precisely the potential components of the individual category estimates that may overlap.

3.6. Savings on Gray Infrastructure

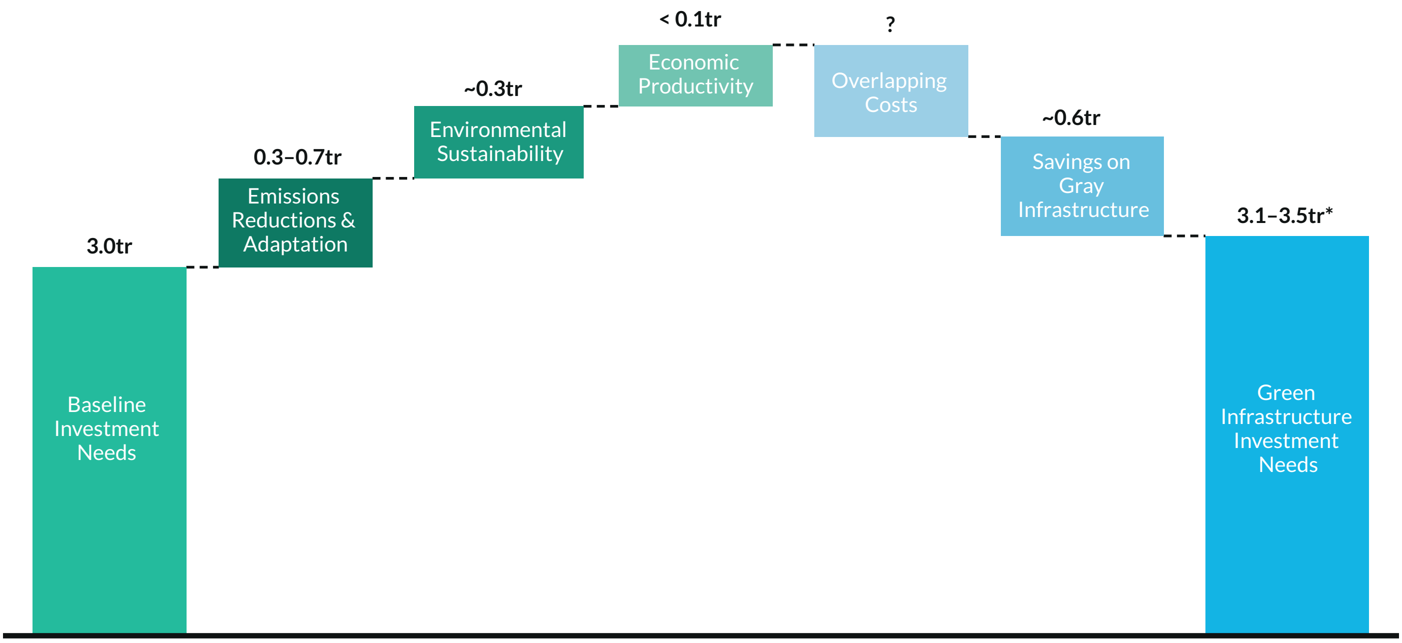
Several infrastructure needs identified across the categories above would not necessarily be additional, as they would instead replace "traditional" infrastructure that would no longer be required. While for some categories, such as resource productivity it is difficult to precisely predict what type of infrastructure would become obsolete, for other categories, such as climate-related infrastructure, estimations can be attempted. Recent research, for example, indicates that by 2030, the demand for electricity, oil, natural gas, and coal will be 26%, 12%, 9%, and 14% lower, respectively. The implications for investment are estimated to be substantial: over $6 trillion would be saved in infrastructure relating to fossil fuel power plants and supply chain and electricity transmission and distribution costs over the 15 years to 2030.[24] This would mean, on average, a reduction in annual investment needs of $400 billion. Analysis performed by the NCE Commission goes further, estimating the reduction in cities' infrastructure needs based on a more compact and connected model. This analysis reveals that 10% of planned urban investment could be avoided, totaling $3.4 trillion between 2015 and 2030, or $225 billion a year.[25]

Figure 3 organizes the different estimates and ranges from the components we have identified. This remains an order of magnitude estimation as many uncertainties remain regarding the nature of the different categories—and therefore whether they can be simply added to each other—as well as possible overlaps and double counting. Nevertheless, the analysis is useful in terms of giving a sense of the scale of additional needs. Overall, annual infrastructure needs between now and 2030 would equal approximately $0.6 trillion. This is approximately an additional $.06 trillion compared to BAU. Once savings are considered, this difference goes down to $0.6 trillion. This number may be still smaller due to some double counting, as noted above. Furthermore, this difference only considers the upfront capital costs required for investment, but does not include differences in infrastructures' operational costs. These could be significant, particularly in the energy sector, where the scenarios used assume a strong move to renewable energy, which would imply substantial savings in fossil fuel consumption.

4. Challenges, Assumptions, and Future Research

The approach we have taken is based on a meta-analysis of a wide range of information and research related to infrastructure needs, environmental sustainability, climate change mitigation and adaptation, and resource productivity. Each of these sources uses different methodological approaches, and their baselines and outcomes are developed according to different objectives, not necessarily focused on estimating total infrastructure needs. To the extent possible, we have tried to make numbers comparable by categorizing based on relevant green growth elements, while at the same time recognizing

Figure 3. Total Incremental Costs of Green Infrastructure



the uncertainty inherent in gathering total estimates. Accordingly, we offer approximate ranges to describe future infrastructure needs. Accordingly, some particular assumption must be considered in the overall estimate. These include the following:

- *2DS Assumptions.* We assume that the world takes action on climate and will over the next decade invest according to an over arching commitment to reduce the risk of exceeding 2°C. We assume that these actions are driven by rationality, thereby reducing emissions at the lowest cost. Using a range of different sources to obtain figures for Category 2, we reflect a number of different opinions and views regarding the necessary actions needed to reduce emissions. The results will also necessarily reflect certain assumptions regarding how actions targeting emissions are taken across both developed and developing countries. Again, reflecting a number of different studies and research results means that we incorporate a range of assumptions on the split between developed and developing countries on taking action on climate.
- *Operational costs and savings, differences in more dynamic modeling.* All the estimates we use are based on the total infrastructure cost requirements. This approach considers only new additional capital investment in infrastructure required to meet the green infrastructure criteria described in the different categories above. Hence, it does not consider any changes in the operational costs related to operating the infrastructure. We can expect that the increased infrastructure investment will reduce operating expenses in some cases (often associated with replacing fossil fuels) due to efficiency improvements; it must be indicated that this can sometimes imply higher operations cost. These would have implications on the net present value (NPV) of these investments, but not on the upfront investment requirements. Hence, these changes are not considered here.
- *Environmental and Social Safeguards.* Much work is left to be done in implementing an effective regime of environmental and social safeguards. Part of the challenge in acquiring data on safeguard costs is that no single accepted standard exists for financial institutions in the creation and enforcement of their safeguard policies. In addition, data on the associated costs are not currently available. Another challenge is the lack of transparency and enforcement in following up with the safeguards that exist. As an international effort toward corporate social responsibility, the Equator Principles are an important first step in setting global standards. However, more work can be done to harmonize and institutionalize a set of best practice environmental and social standards that would best protect the areas and peoples potentially impacted by the development of large-scale physical infrastructure.
- *Measuring the cost of resource productivity.* It is extremely difficult to properly account for the last component of our total estimate, i.e., the "green economy" component of the additional infrastructure needs. The approach we have taken, based on examining one of the elements of a more resource-efficient growth model, the circular economy, is a partial way to look at these issues. Further research is needed on this specific topic as few scholars have investigated and given an order of magnitude estimate of the nature and scale of the needs. As increasing numbers of countries are taking action on climate on the back of a domestic commitment on retreat growth, we will be able to access more and relevant data and experience on this issue.

Endnotes

[1] IMF (2014) "World Economic Outlook Update" January, 2014. http://www.imf.org/external/pubs/ft/weo/2014/update/01/pdf/0114.pdf

[2] See Aghion et al. (2013).

[3] This definition excludes "social" infrastructure (such as school and hospitals). See Wangewoort et al. 2010 for a more comprehensive overview of the definition of infrastructure.

[4] Identifying the exact channels that constitute the link between infrastructure investment and economic growth is complicated by both methodological issues (such as non-stationary aggregate outputs and infrastructure capital, simultaneity between infrastructure and income, bias due to cross-country estimation, etc) and by conceptual issues (non-linearity of infrastructure investment, relationship with policy, business environment variables, etc). See Aghion (2013) and Newbery (2012). For a review of recent literature of the relationship between infrastructure and growth see Romp and Haan (2007).

[5] See World Bank 2012.

[6] US EPA (2013).

[7] Kennedy and Corfee-Morlot (2012).

[8] Quintero (2012).

[9] Stiglitz, Sen, and Fitoussi (2009).

[10] See Aghion et al (2013) and Dietz and Stern (2014)

[11] See Bhattacharya and Holt (2014)…working paper 1

[12] See, most recently, New Climate Economy, Stern/Dietz, and Stern Review

[13] See Dailami et al. (2013).

[14] See Kennedy and Corfee-Morlot (2012).

[15] See IEA (2012) World Energy Outlook Fact Sheets and IEA (2014).

[16] See Kennedy and Corfee-Morlot (2012)

[17] See NCE (2014) – Technical Note

[18] OECD Statistics, Economic Outlook 95, May 2014. Extracted on November 29th 2014.

[19] See www.equator-principles.com

[20] See Oosterhuis (2007) for a thorough literature review and cost-benefit analysis of EU Environmental Impact Assessment implementation, and Gil (2009).

[21] Since this cost is allocated at the project level, actual costs of safeguards regimes vary in range from 1–10%. This is a conservative estimate.

[22] See Oosterhuis (2007) and Independent Evaluation Group (IEG) (2010). See also ADB (2006), an interesting staff survey on perceptions of costs for involuntary resettlement safeguards, which suggests the incremental cost could go above the 10% mark.

[23] New Climate Economy 2014. Chapter 2.

[24] Climate Policy Institute and New Climate Economy analysis based on data from the IEA and OECD. According to their research, net electricity transmission and distribution costs are lower due to higher energy efficiency, which lowers overall energy demand compared with the base case. This efficiency effect outweighs the increased investment for renewables' integration. See *Infrastructure investment needs of a low-carbon scenario*. New Climate Economy, Technical Note, November 2014. http://static.newclimateeconomy.report/wp-content/uploads/2014/11/Infrastructure-investment-needs-of-a-low-carbon-scenario.pdf

[25] Floater et al. *Cities and the new climate economy: the transformative role of global urban growth*. London School of Economics – Cities and NCE Working Paper, November 2014. http://static.newclimateeconomy.report/wp-content/uploads/2014/11/Transformative-role-of-global-urban-growth.pdf

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