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TOPIC GUIDE

Power Sector Topic Guide

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Executive summary

Access to affordable, reliable, sustainable and modern energy, for households and businesses, is an essential ingredient for poverty reduction and inclusive economic growth. In many developing countries, the lack of adequate energy services is a key constraint to growth and 'ensuring access to affordable, reliable, sustainable and modern energy for all' has become a priority in the development agenda, clearly articulated in the 7th Sustainable Development Goal (SDG).

This Topic Guide aims to provide a comprehensive overview of the importance of electricity to the achievement of the SDGs, and the major challenges and opportunities in providing access to affordable, reliable and sustainable electricity. It aims to highlight the entry-points for improving the performance of the power sector in developing countries, and the potential role of development agencies, as well a wider set of stakeholders including policy-makers and practitioners, engaged in strengthening the performance of the power sector.

In the power sector, major performance problems in developing countries undermine national effort toward economic growth and poverty reduction. Globally, 1.1 billion people do not have access to electricity, with 87% of them in rural areas. The impact this has is particularly profound for women and girls. Efforts toward electrification have been uneven, often with the poorest countries barely keeping up with their population growth. Surging demand for electricity puts even more strain on already underperforming systems. Unreliable supply threatens the viability of firms and businesses and undermines their potential for job creation.

Despite a growing momentum for renewable energy, the energy mix for power generation remains insufficiently diversified. Specifically, the overreliance on fossil fuels – close to 74% in non-OECD countries – causes environmental and health issues and exposes countries to the volatility of the commodity market. However, technological progress is triggering a growing interest in the use of new technologies to deliver electricity more efficiently and cleanly. This has enabled innovation in developing countries in how energy services are being delivered, in particular for increasing rural electrification.

Grid-connected systems are currently the only viable option to deliver reliable electricity at scale, and remain the most important component of the power sector. The sector is structured around different segments of the value chain: generation, transmission, trade, distribution and retail. The organisation and regulation of the sector differ widely around the globe, ranging from a traditional model consisting of a vertically integrated sector, often operated by a state-owned utility handling all functions, to an unbundled and liberalised model, where all the services in the value chain are performed by different actors. The structure of a country's electricity market can significantly affect the potential for private investments and the overall performance of the system.

Power systems must be endowed with an adequate amount of spare generation capacity and a complementary mix of energy resources and technologies in order to ensure grid stability and the reliability of the supply. A significant amount of flexibility in the system is needed to overcome the intrinsic and unique challenges linked with electricity: generation must match demand at every single point in time (although demand side response is growing steadily and offering new options); electricity cannot yet be stored in bulk at reasonable costs; and it cannot be transported without incurring technical losses.

Some renewable technologies, such as wind and solar, do not offer the possibility to adjust the level of their production and forecast with accuracy. Traditionally, this has been a deterrent for investments in renewables. However, technological progress, improved forecasting and the increasing inclusion of smart technologies in the grid are enabling a shift away from the traditional centralised model, relying on large scale and often conventional plants, to the inclusion of distributed generation capacity. This not only fosters the adoption of renewables but also provides new opportunities to increase access in remote areas, through collective (e.g. mini-grids) and individual (e.g. photovoltaic (PV) rooftop) solutions.

Developing countries face a persistent and significant shortage in public and private investment in new infrastructure, which is a major constraint on the overall performance of the power sector. This is a result of many institutional, financial and technical barriers to attracting investment, and its effective use, which are manifold, complex and intertwined, and affect both on-grid and off-grid systems..

Key initiatives can be introduced to foster investment in all segments and ensure it is used effectively to substantially improve the performance of the sector. There are a range of institutional, policy, financial and technological options that address a single or multiple challenges facing the power sector. Many have associated trade-offs that need to be managed, and they need to be selected and designed in light of the broader political and development agenda of the country.

- Power sector reform is complex and the optimal reform path will depend on country-specific parameters as there is no 'one-size-fits-all' model. Power sector reform has often consisted in promoting the full liberalisation and privatisation of the sector, and has been contested in many developing countries due to a mismatch between the reform objectives, political incentives and major capacity gaps at the institutional, organisational and individual levels. However, softer reforms, such as introducing some level of competition in generation, have proven effective, especially when combined with competitive tendering. This has resulted in greater transparency for investors and has decreased the unit cost of electricity sold to the grid operator. Other 'hybrid' models, i.e. not fully unbundled and liberalised, have also proven successful in some developing countries.
- Strengthening institutional capacity, particularly in terms of an independent regulator and a credible and long-term policy and regulatory framework, is essential for effective planning and management of the power sector. Strong capacity in forecasting and planning, public financial management (preparing budgets and expenditure frameworks), and performance review are also crucial for efficient management of the sector. Institutions can ensure women and girls receive equal and fair access to electricity services by carrying out gender impact assessments on power projects and plans, prioritising their needs in electricity services, and promoting their representation in decision-making.
- A well-designed tariff/subsidy regime can provide multiple benefits, including incentivising grid expansion to rural areas and improving the quality and reliability of supply and the affordability of electricity services. However, getting the right balance between consumer payments and government subsidies involves managing a range of political considerations.
- Increasing the efficiency of the sector, and reducing transmission and distribution losses, is important for increasing the reliability of supply and the financial viability of the sector. There are policy options, including demand-side management, and technological options, such as smart metering, that can help reduce electricity theft.
- Promoting cross-border trade and regional network integration creates a more efficient, robust and secure system and can increase the reliability of power supply. Regional integration in Africa will be critical to enable the transmission of power from large dams to load centres. However, strong regional institutions are a necessary pre-condition for regional integration, to allow a common vision and legal and regulatory framework for power trading and pricing.
- A range of financial instruments and initiatives can be implemented to overcome some of the barriers to investment, such as an efficient and transparent procurement

process for projects tendered to Independent Power Producers (IPPs), and improving the overall creditworthiness of utilities through cost-reflective tariffs, and/or some form of subsidy. Channelling investment into renewables can be incentivised through both price-based (e.g. feed-in tariff (FiT)) and quantity-based (e.g. quotas) approaches, as well as reform to fossil fuel subsidies. International climate finance can also be leveraged to attract private investment in renewable electricity.

- Off-grid systems of supplying electricity can play an important role in ensuring access prior to grid expansion, substituting unreliable grid-supplied electricity or reaching dispersed households and communities that cannot be economically reached by the grid. However, overcoming the perceived investor risk requires giving certainty to the role of off-grid systems within an overall electrification plan, establishing regulatory and technical rules and standards, and supporting financial viability when reaching the poorest.

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List of abbreviations

AC	Alternative Current
AFREA	Africa Renewable Energy and Access
BPDB	Bangladesh Power Development Board
CO_2	Carbon Dioxide
CSP	Concentrated Solar Power
DC	Direct Current
DFID	Department for International Development
ESCO	Energy Service Company
ESMAP	Energy Sector Management Assistance Program
FiT	Feed-in Tariff
GDP	Gross Domestic Product
GET FiT	Global Energy Transfer Feed-in Tariff
GHG	Greenhous Gas
GW	Gigawatt
HDI	Human Development Index
IEA	International Energy Agency
IPP	Independent Power Producer
KfW	Kreditanstalt für Wiederaufbau (‘Reconstruction Credit Institute’)
kWh	Kilowatt-hour
LCoE	Levelised cost of electricity
MoU	Memorandum of Understanding
MW	Megawatt
NGO	Non-governmental Organisation
OECD	Organisation for Economic Cooperation and Development
OPM	Oxford Policy Management
PPA	Power Purchase Agreement
PV	Photovoltaic
SADC	Southern African Development Community
SDG	Sustainable Development Goal
TANESCO	Tanzania Electric Supply Company Limited
UN	United Nations

1 Introduction

Access to affordable, reliable, sustainable and modern energy, for households and businesses, is essential for achieving the SDGs. The current level of energy poverty in developing countries is holding back economic and inclusive growth and poverty reduction efforts. All countries have recognised the importance of improving access to modern energy services, particularly access to electricity in developing countries. In 2012, governments renewed their commitment at the UN Conference on Sustainable Development (Rio+20) to a set of goals related to ensuring access to affordable, reliable, sustainable and modern energy for all by 2030 (SDG 7).

Globally, the recent progress in meeting this very ambitious target is not encouraging. Across all dimensions of sustainable energy for all – energy access, efficiency and renewables – the short-term rate of progress (assessed for the period 2010–2012) falls substantially short of what is needed to meet the targets by 2030. However, the situation varies across countries, and some governments are making particularly impressive gains. For example, in India 55 million people gained access to electricity over 2010–2012, while electrification in Sub-Saharan Africa only just managed to stay abreast of population growth (SE4ALL, 2015).

Achieving the SDG targets requires overcoming a series of significant technical, financial, institutional and political constraints faced by the power sector in developing countries. The problems are country specific, and the solutions need to be designed based on the local context. However, development agencies have an important role in supporting partner countries to improve the performance of the power sector, particularly through technical assistance, institutional reform, human capacity building and learning from relevant international experience.

1.1 Purpose of this Topic Guide

The Topic Guide sets out the importance of electricity to achieving the SDGs, and the major challenges and opportunities in providing access to affordable, reliable and sustainable electricity for all households and businesses. It is primarily targeted at development agencies interested in supporting developing country governments to achieve SDG7 related to energy access. It serves as a reference guide for staff and advisers to identify the entry-points for improving the performance of the power sector in partner countries, and the potential role of development agencies. However, it is also relevant to a much wider set of stakeholders, including policy-makers and practitioners engaged in strengthening the performance of the power sector in developing countries. The Topic Guide intends to present a neutral and unbiased picture of the power sector, although focusing on issues of relevance to the UK's aid policy. It provides a framework for analysing the problems facing a particular power sector, without being prescriptive of the solutions required.

The remainder of this guide is organised by the key 'steps' to examining the power sector of a partner country. It starts by making the case for why the power sector is essential to economic growth and poverty reduction, and by outlining the major performance problems facing the sector in developing countries (Chapter 2). It then provides an overview of the power sector, identifying the different segments and stakeholders in the power value chain (Chapter 3). This gives the reader the necessary technical understanding of how electricity is generated, transmitted and distributed, as well as some of the technical challenges facing the sector. The Topic Guide then presents some of the underlying financial, institutional and political barriers that need to be addressed to improve performance in the power sector as well as opportunities for addressing and overcoming these barriers (Chapter 4).

A comprehensive glossary of relevant terms is provided in Annex A.

1.2 Scope of this Topic Guide

The guide is focused on the power sector, and the supply of electricity to businesses and households. The term 'power sector' is used to refer to the generation, transmission and distribution of electricity. It does not cover other components of the wider 'energy sector' such as cooking and transport fuels, nor the extraction of the raw materials used in the generation of power.

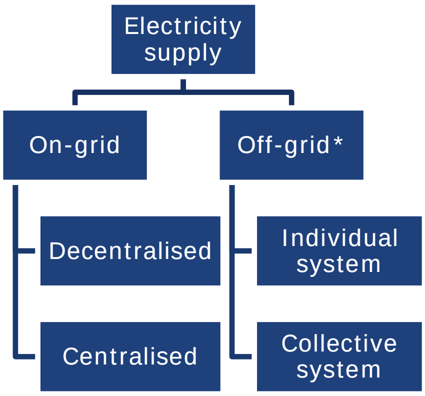
Most attention is given to on-grid systems of electricity supply. This is partly because on-grid systems are currently the most viable option to cost-effectively deliver the volumes of electricity required for large-scale economic transformation, but also because it is the most complicated and important component of the energy sector.

There is a continuous spectrum of grid-connected systems, varying from a centralised organisation, when the system solely relies on the provision of bulk power by large power plants, to a decentralised structure, when production and consumption are distributed or balanced to some degree at a local level. Therefore, the term 'decentralised power system', refers to a system that includes some degree of distributed power production and storage. Off-grid systems of electricity supply are introduced and discussed in terms of the potential role they can play in substituting or complementing on-grid systems. Off-grid systems are also commonly included in the set of 'distributed' options. Figure 1.1 illustrates the major difference between off-grid and on-grid projects from a technical and financial perspective.

In practice, a range of technologies and systems can be combined to supply electricity and the distinction between these categories is not necessarily clear-cut. For example, most power systems currently rely primarily on a centralised grid, even when they use some degree of distributed production. Similarly, some grid-connected mini-grids can help stabilise the grid and function in isolation of the grid during a power shortage and therefore sometimes act as off-grid systems.

The following is a simple diagram to illustrate how the Topic Guide has organised its description of the power sector.

Figure 1.1: Structure of the power sector



2 Power for economic growth and poverty reduction

This chapter sets the scene in terms of the importance of the power sector for wider sustainable development. It identifies global trends in the performance of the power sector in developing countries and common performance problems against certain economic, social and environmental criteria. A framework is proposed for assessing the performance of an individual power sector.

2.1 Social and economic impact of poor performance in the power sector

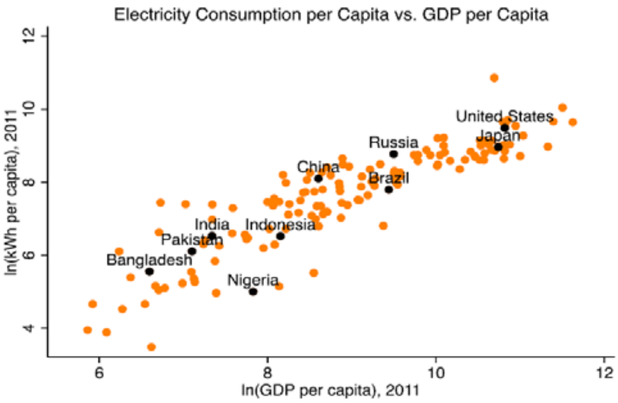
Poor power sector performance in terms of access, affordability, reliability, sustainability and security of electricity supply has a major impact on wider development efforts, including economic growth, poverty reduction and social inclusion.

Economic growth and job creation

Access to reliable and affordable electricity increases the productivity levels of both households and businesses, leading to higher incomes and new jobs, and thus contributing to the broader poverty reduction agenda. Figure 2.A in Annex B illustrates several different pathways from access to electricity to increased productivity and incomes.

- The economic literature has long correlated access to reliable electricity supply, with economic growth – see figure 2.1 – although the exact causal relationship has not been well examined. Box A introduces a DFID research programme addressing this evidence gap.
- The aggregated cost of power outages to companies, including equipment damage, loss of productivity and cost of private generators, amounts to a significant part of their operational costs and threatens their viability of operations. For example, the average sub-Saharan African firm experiences 8.5 electrical outages a month, losing 8.8% of annual sales (Enterprise Surveys, 2010–2016).

Figure 2.1: Correlation between electricity consumption per capita and GDP per capita



Source: Wolfram (2015)

- Electricity enables farmers to use pumps for irrigation, improve post-harvest processing and use cold storage for agriculture products, all advantages that reduce workload and increase profits, which can then be reinvested into new enterprises. However, other factors such as access to finance and markets are also decisive in ensuring these benefits are realised.
- The power sector accounts for two-thirds of global greenhouse gas (GHG) emissions, of which 73% result from the combustion of coal. Estimating the economic impact of climate change, particularly at a global level, is difficult and controversial, although

the Stern Report assessed that unabated climate change could cost the world from 5% to 20% of GDP each year.

Box A: DFID's Energy and Economic Growth Research Programme

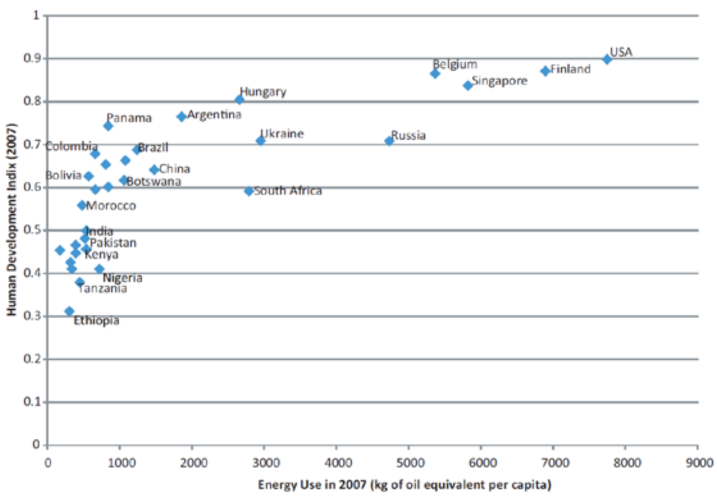
DFID launched in 2016 a five-year flagship global research programme to respond to gaps in evidence on the relationship between energy and economic growth in low-income countries, and support research-to-policy uptake. The team, composed of researchers from leading academic institutes around the world, will carry out research to identify the causal linkages between electricity supply and economic growth, and financial, policy, technological and other opportunities for development and better utilisation of large-scale power infrastructure. It will specifically look at how to incentivise renewable energy, and energy efficiency in urban areas, as well as the cross-cutting themes of climate change, gender and energy data.

Poverty reduction and social inclusion

A direct correlation exists between access to reliable and affordable electricity and poverty reduction, across and within countries – as illustrated in Figure 2.2.

- Access to electricity is vital for delivering on a range of social development goals. For example, unreliable electricity supply puts at risk safety in hospitals and the cold chain for immunisation programmes. Governments struggle to provide safe drinking water partly due to the lack of reliable electricity for pumping water. The amount of lighting in a home also impacts the number of hours that children can devote to studying.

Figure 2.2: Correlation between the Human Development Index (HDI) and electricity consumption per capita



Source: GEA (2012)

- Women and girls are particularly affected by the social development impacts of a lack of access to electricity. Without modern energy services women must spend extra time carrying out household tasks like collecting firewood and doing manual agriculture labour, which reduces their opportunity to study and earn an income. Electrification allows women to complete household tasks more efficiently and household lighting allows women to take up extra income-generating activities in the home in the evening, such as weaving.[1] Women and children are more impacted by lack of reliable power in hospitals than men, such as in relation to maternity services.

[1] A study in Nicaragua found that access to reliable electricity increases the likelihood of rural women being employed outside the home by 23% (cited in O'Dell *et al.*, 2014).

Increased security concerns due to insufficient public lighting also particularly affect women.

Environment and climate change

- To have a 50% chance of limiting global warming to a 2^0C rise, the world has a remaining 'carbon budget' of 1.1 trillion tonnes of CO_2 emissions from human activities up to 2100. However, coal reserves alone exceed this by almost a factor of two. Despite the momentum toward renewables, coal is expected to account for 35–45% of global net growth in electricity generation over the next decade, 'locking-in' carbon emissions for many decades due to the long lifetime of the infrastructure (New Climate Economy Report, 2015).
- Through its impact on livelihoods and incomes, access to electricity increases the resilience of the most vulnerable communities to the shocks and stresses caused by climate change. For example, the mechanisation of agriculture increases farmers' profits, which puts them in a better position to withstand a poor harvest due to irregular rainfall (Perera *et al.*, 2015).
- The current dominance of coal and other fossil fuels for generating electricity poses a significant risk for the local environment and public health. It is estimated that a shift to alternative energy sources could bring global average health co-benefits of US$50 to 200 per tonne of CO_2 avoided, relative to baseline development, primarily through avoided dangerous air pollution (New Climate Economy, 2015). Coal-fired power plants vary significantly in how 'clean' they are, but most are extremely water-intensive and the toxic waste produced can pose serious dangers to nearby water sources (NRDC, 2007).

Box B: The water, energy and food nexus

Water, energy and food are inextricably linked. Agriculture is the largest global user of water, and energy is required to pump water to irrigate crops and power machinery and transport crops. The food production and supply chain accounts for 30% of total energy consumption. Increasing access to electricity for farmers could provide significant socioeconomic benefits, but will also put increasingly scarce water resources at risk. Governments tend to tackle the problems of water, energy and food security in isolation, without recognising and dealing with the interconnections between them.

Source: World Water Development Report (2014)

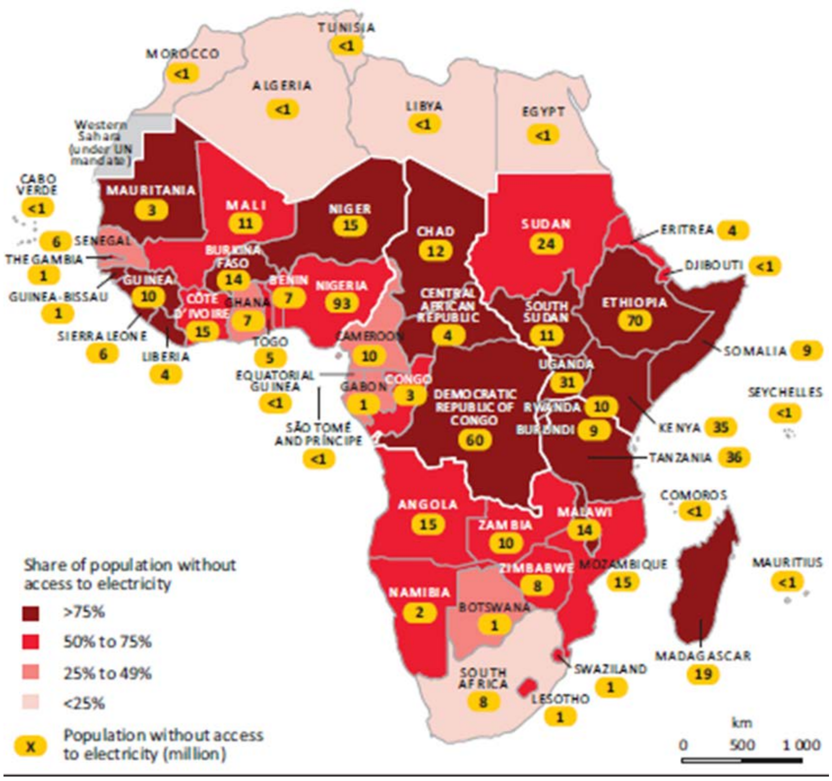
2.2 Recent trends in the power sector in developing countries

Across a number of dimensions, the power sector is underperforming in many developing countries. This section outlines general global trends in the level of access to electricity, its reliability and affordability, and the sustainability and security of its supply.

Low rates of electrification

- Electrification in many developing countries is extremely low, with 1.1 billion people without access to electricity across the world in 2012. Of this total, 88% live in Sub-Saharan Africa and South Asia, and 87% are in rural areas (SE4A, 2015). There are certain countries, particularly India, which account for a high proportion of the absolute figure of people without access, although other countries such as Kenya, Zambia and Mauritania have a much lower electrification rate but a smaller population (World Bank, 2015). Figure 2.3 below shows the status of electrification across Africa.

Figure 2.3: Share of population without electricity in Africa



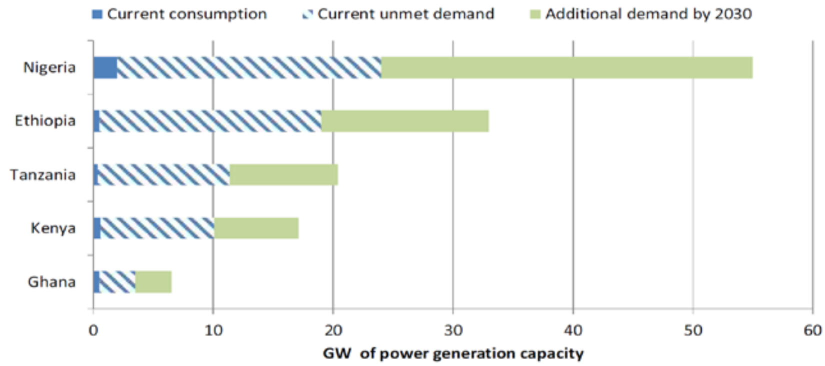
Source: International Energy Agency (IEA) (2014)

- There has been progress in addressing this electrification deficit. From 1990 to 2012, electrification rose from 76% to 85% of the world's population (slightly exceeding the population increase), with the most dramatic increase in South East Asia and South Asia. However, this growth is not uniform across the world. For example, in 2010–2012, South Asia provided electricity to 54 million people (which is higher than its population increase), mostly in urban areas, while in rural areas of Sub-Saharan Africa the growth in access fell short of population growth by 23 million (SE4All, 2015).
- Progress in electrification is partly offset by population growth and the associated increase in demand. It is projected that the number of people without access to electricity will decline to around 810 million in 2030 and 550 million in 2040 (6% of the projected global population at that time). However population growth masks the actual scale of the progress: under this scenario, 1.8 billion people would have gained access by 2030 and 2.7 billion by 2040 (World Energy Outlook, 2015).

Surging demand for electricity

- The current rapid global rise in demand for electricity is expected to continue increasing further, particularly in developing countries. It is estimated that world energy demand will grow by nearly a third between 2013 and 2040, with net growth coming entirely from developing countries. This is driven by the global economy growing by 150% during this period (World Energy Outlook, 2015), and assumes that the energy intensity of growth remains constant, which could be pessimistic given recent trends. The figure below shows current and projected future unmet demand for electricity (without factoring in energy efficiency gains) for a sample of five countries.

Figure 2.4: Consumption and demand by 2030 for five DFID priority countries



Source: DFID Energy Policy Framework (2015)

Growing momentum for renewable energy

- World electricity production relies heavily on fossil fuels. Globally, fossil fuels account for 67% of total electricity production, while 11% comes from nuclear and the remaining 22% from renewables, mostly hydropower (IEA, 2015). Historically, fossil fuels have tended to be the default option for rapid expansion of electricity supply primarily because the technology is 'mature' and enhances grid stability, thus providing reliable supply. Since the 1990s there has been aggressive growth in global coal demand, although in 2014 coal growth stalled principally because of structural and temporal factors in China (where half of global coal is used), including a diversification of the power sector away from coal (IEA, 2015).
- Momentum is growing for policies and investments into non-fossil fuels, due to various reasons, including the rapidly declining technology costs of renewables and the urgency of addressing climate change. The amount of new annual investment in renewable electricity and fuels rose from $45 billion in 2004 to $270 billion in 2014, while in the same period the number of countries with renewable energy policy targets rose from 48 to 164 (REN21, 2015). The table below compares the breakdown of global electricity production by renewable source for 2004 and 2014, based on generating capacity in operation.

Table 2.1: Global electricity production capacity by source, 2004 and 2014 (GW)

Energy source	Global electricity production capacity, 2004	Global electricity production capacity, 2014
Renewable electricity (total)	800	1,712
Hydropower capacity	715	1,055
Bio-power capacity	<36	93
Geothermal power capacity	8.9	12.8
Solar PV capacity	2.6	177
Concentrating solar thermal power (CSP)	0.4	4.4
Wind power capacity	48	370

Source: REN21 (2015)

Low electrification rate in new urban areas

- Following the sustained trend of urbanisation in many developing countries, governments often struggle to supply electricity to the additional urban population, particularly in peri-urban areas and informal settlements. By 2050 the proportion of the world's population living in urban areas is expected to rise to 66% from the current 54%, adding another 2.5 billion people to urban populations, particularly in

Africa and Asia (UN DESA, 2014). Increasing urban access to electricity is, however, something of a 'low hanging fruit' as the unit cost of connection is low.

Volatile energy security

- Energy security is affected by global dynamics in trade and rapid industrial growth in different countries and regions. The import of fossil fuels for electricity generation by many countries has contributed to a steep rise in energy trade, which has been characterised by high price volatility. For example, with China and India becoming large importers of coal, prices have doubled since 1990 (New Climate Economy Report, 2014), although over the last five years price volatility has continued, with dropping prices and major instability in the market. On one hand, a high level of dependence on imports makes countries vulnerable to commodity price volatility and exchange rate fluctuations. On the other, importing fossil fuels is still a way of securing a relatively cheap energy supply, although as countries get richer they tend to start pricing in more the externalities associated with their use (such as air pollution, environmental impact, etc.).

Technological progress

- Technological progress is triggering a growing interest in the potential for developing countries to deliver electricity more efficiently and cleanly than industrialised countries currently do. The dramatic decline in the cost of many renewable electricity technologies is driving investment in the sector, as renewables reach grid parity. The cost of the more mature renewable electricity technologies – including biomass, hydropower and geothermal – has remained stable since 2010, and these options are competitively priced compared to fossil fuels. Onshore wind is now within the cost range, and sometimes lower than for fossil fuels, while the cost of PV systems has fallen by half in four years, reaching grid parity (IRENA, 2015a).

- Technological progress has also enabled innovation in electricity supply and increased the possibilities to access power in rural areas. For example, collective and individual off-grid electricity systems are gaining momentum in developing countries due to improvement in battery technologies and mobile payments. An estimated 26 million households are now being served through off-grid renewable energy systems (IRENA, 2015b).

2.3 Evaluating the performance of a particular national power sector

The performance of the power sector varies significantly between different developing countries. To assess the performance of a particular power sector, it is therefore important to identify its strengths and weaknesses against a range of criteria.

There are various criteria and indicators available for benchmarking performance, including multi-dimensional criteria, such as the Energy Sector Management Assistance Program's (ESMAP) Multi-Tier Framework for Measuring Energy Access, the Multi-Dimensional Energy Poverty Index developed by the Oxford Poverty and Human Development Initiative and the Energy Development Index developed by World Energy Outlook. These indices capture several dimensions of performance, such as access, reliability, quality, affordability and legality, as well as health and safety issues. The table below breaks down these dimensions and suggests some performance indicators.

A combination of indicators is necessary to get a better picture of the performance of a particular power sector. For example, a high level of interconnectivity is a positive factor toward ensuring security of the supply, but only if there is sufficient reserve capacity in generation. Consumption *per capita* can also be deceptive, as it is masked by industrial use. In addition, what is a 'good' level of diversity in the electricity mix depends on the local context and resources.

Data for performance evaluation can be gathered and compared using various sources such as the World Bank Data Portal, National Energy Balance Data and World Energy Outlook. Different data sources can give different performance outcomes, due to the use of different metrics. For example, the World Bank measures access to energy in terms of number of connections to the grid, whereas the World Energy Outlook uses household surveys that include off-grid connections.

Table 2.2: Suggested indicators for assessing the performance of a power sector

Performance criteria	Examples of indicators to benchmark performance	Examples of results
Access to electricity: Universality	Percentage of population with access to electricity (rural/urban)	Sub-Saharan Africa: 35% of the total population (World Bank, 2015)
	Average electricity consumption *per capita*	Sub-Saharan Africa excluding South Africa: 150 kWh per capita (McKinsey, 2015)
Quality of supply: Reliability	Number of hours of electricity outages/average number of hours of reliable supply	South Asia: 135 hours of electrical outages in a typical month (Enterprise Surveys, 2010–2016)
	Voltage and frequency fluctuations	National grid codes specify the allowable range of parameter fluctuations by network type
	Value lost due to electrical outages (% of sales)	Power outages are responsible for a 15.6% loss in production compared to the value of sales in 2014 (Enterprise Surveys, 2014)
	Diversity of the energy mix in power generation	Bangladesh: 62% Natural Gas, 22% Furnace Oil, 7.75% Diesel, 2.03% Coal, 4.86% Power Imports and 1.86% Hydro (Bangladesh Power Development Board, 2016)
Regional trade	Size of power pool: MW of installed capacity of regional power pool	Southern African Power Pool: 49,877 MW (Igbinovia and Tlusty, 2014)
	Excess capacity within a regional power pool	Southern Africa Power Pool: -8,247MW (shortage) (Sichone, 2015).
	Proportion of electricity traded within a regional power pool	West African Power Pool: 7.5% in 2010 (Igbinovia and Tlusty, 2014)
	Number of bilateral contracts signed within a regional power pool	Southern African Power Pool: 28 bilateral contracts (SAPP, 2013)
Affordability of Supply	Share of household income spent on electricity (for different income brackets)	Bangladesh: 0.7% (rural)/ 2.2% (urban); Pakistan: 3.4% (rural)/ 4.8% (urban) (Bacon *et al.*, 2010)
Sustainability	Proportion of electricity generated from different renewable energy sources	Sub-Saharan Africa, excluding South Africa: 51% of electricity generation from hydropower, 24% from natural gas, 18% from diesel/heavy fuel oil, 5% from coal, and 1% from other renewables (Eberhard, 2016)

Box C: ESMAP's Multi-Tier Framework for Measuring Energy Access

Traditional binary measures of access to electricity, which focus on electricity connections, fail to capture the multifaceted nature of energy access, such as the reliability and affordability of the electricity. Under ESMAP's multi-tier approach, energy access is determined by examining how a household's electricity and cooking technology measure up against the following eight attributes: capacity; duration and availability; reliability; quality; affordability; legality; convenience; and health and safety. Energy access is then measured in a tiered spectrum, from Tier 0 (no access) to Tier 5 (the highest level of access).

For example, in the city of Kinshasa, Democratic Republic of Congo, traditional access indicators report 90% access to electricity due to widespread grid connections in the city, whereas the multi-tier approach puts it at only 30% due to the irregularity and frequent blackouts and voltage fluctuations (SE4All, 2015).

Source: ESMAP (2015). *Beyond Connections: Energy Access Redefined*. World Bank. Presentation available here

2.4 Trade-offs between the multiple objectives of the power sector

The power sector is expected to deliver on multiple social goods, and there are trade-offs at every level. However, new technologies and policy innovations also demonstrate the possible synergies that can be achieved.

- Traditionally, there has been a trade-off between expanding generation capacity to deliver universal electricity access and limiting GHG emissions, as fossil fuels were seen as the main option for delivering electricity at scale in many countries. However, increasingly, renewable energy sources (e.g. CSP, PV, off-shore wind, etc.) are showing the potential to deliver power at scale.
- However, the use of renewables still brings a trade-off between: (i) the challenges associated with their increasing share in the mix, such as relatively high cost and their technical integration into the grid; and (ii) the environmental, health and other benefits that domestic renewable energy resources provide.
- Sometimes expanding the electricity grid and providing reliable electricity supply are competing goals. For example, when generation capacity is limited, additional grid connections might put more strain on the system and increase the number of outages and voltage fluctuations.
- A conflict often exists between providing electricity at an affordable rate and generating sufficient revenue to invest in and expand the sector. The design of the tariff structure can balance these often competing objectives.
- In an electricity-constrained context, governments must decide between prioritising the electricity needs of industry (for economic growth) and the poorest section of society (for access purposes). However, there are possible synergies, for example industrial consumers can act as anchor customers for electricity supply to nearby households.
- There can be an over-reliance on electricity supplied from 'local' sources, which are seen as cheaper and more secure. Sometimes imported electricity from neighbouring countries would be a cheaper option. For example, in Tanzania the repeated droughts over the past decade and the overreliance on poorly managed hydroelectricity have resulted in a deterioration of the quality of the electricity supply in the country. Diversification of the energy mix and network integration between neighbouring countries can enhance energy security.

3 Grid-connected power systems: Value chain and technologies

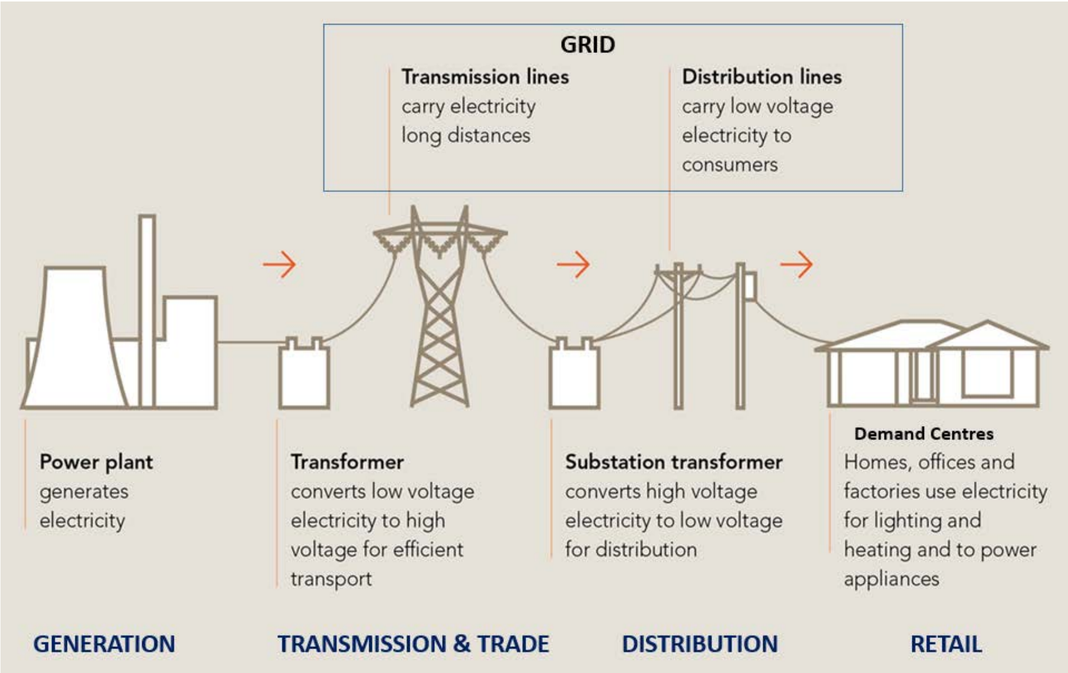
Policy-makers and donors require an in-depth understanding of the major technical and economic aspects of the power sector's processes and organisation, so as to identify the opportunities and barriers to improving the performance of the sector. **This chapter identifies the different segments and stakeholders of the power value chain. It distinguishes between grid and off-grid systems, provides an overview of the state-of-the-art technologies along the value chain, and identifies the main performance challenges facing these systems.**

3.1 The value chain and its stakeholders

Grid-connected power systems are currently the only viable option to deliver power at scale efficiently, reliably and affordably. This section explains the main technical and economic characteristics of the segments and the rationale behind best practices driving power sector reforms.

Technically, grid-connected power systems are commonly organised around five main segments of the value chain: generation, transmission, trade, distribution and retail. However, the effective structures and regulation of the sector differ widely around the globe, ranging from a traditional model consisting of a vertically integrated sector, often operated by a state-owned utility handling all functions, to an unbundled and liberalised model, where all the services in the value chain are performed by different actors.

Figure 3.1: The electricity value chain of a centralised system



Source: Amended from Energy Efficiency Exchange website (2016)

Generation

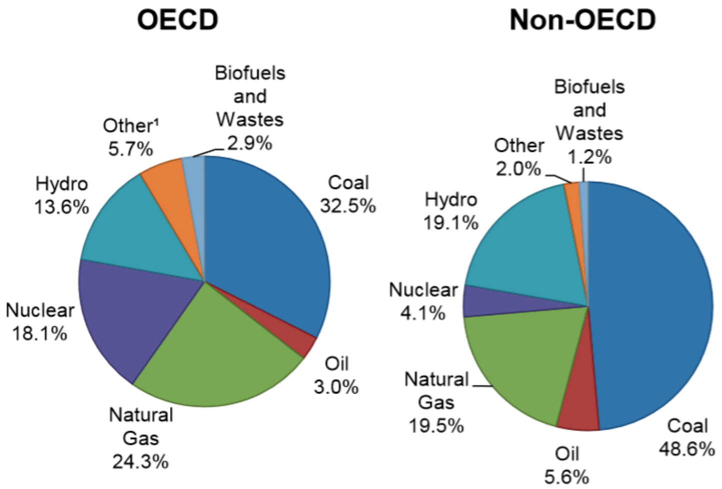
- Generation is the conversion of primary energy contained in a specific source (e.g. solar, nuclear, fossil fuels, biomass, hydro, wind, geothermal, etc.) into electricity. At a national scale, the largest share of electricity is generated from power plants that are operated either from a company engaged in generation and distribution (a utility) or by Independent Power Producers (IPPs). IPPs typically develop, finance, construct, operate and own the generation facility.

- The electricity mix refers to the share of electricity generated over the year from different sources. It is used to assess the proportion coming from renewable sources (as a measure of sustainability) and the diversity of energy sources (as a measure of energy security). The electricity mix varies significantly between countries due to the relative availability and affordability of different primary energy sources (see Box D).

Box D: Energy mix and sustainability

Globally, electricity generation is responsible for about 42% of CO_2 emissions, as fossil fuels remain the main source of primary energy in both developed and developing countries (see figure 3.2).

Figure 3.2: Average electricity mix in OECD and non-OECD countries, 2013



Sources: IEA (2015 and 2006) and IEA data

- Contracts, also called Power Purchase Agreements (PPAs), are often used as an agreement between power producers and retail suppliers or large individual customers (called 'off-takers') to purchase/sell a portion of the producers' future power production. By setting parameters such as price, volume and times of production, such contracts reduce the financial risk related to uncertainty for both sides.
- The liberalisation of the generation segment has, in many countries, resulted in substantial private investment in electricity generation and a corresponding improvement in the efficiency of power plant operations (IEA, 2005). In a competitive set-up, power producers sell their electricity on a wholesale market.

Transmission and distribution

- Once the electricity is generated, it is fed into the national grid and transported toward aggregated pools of users, typically urban areas (called 'demand centres').
- When electricity is transported 'technical losses' occur even if the system is run at optimal efficiency. These losses are reduced at high voltages. Therefore high voltages are required for efficient transport of electricity across long distances (e.g. usually 700–800kV in North America). However, technical losses are greatly increased by poor technology, sub-optimal design or poor maintenance of the network (called 'excess technical losses').
- High voltage is used in transmission networks (which link to large power plants and transport the electricity produced) and low voltage in distribution networks (which connect the grid to the demand centre or customer). As the grid gets closer to a demand centre, the voltage is lowered: industrial or commercial customers are

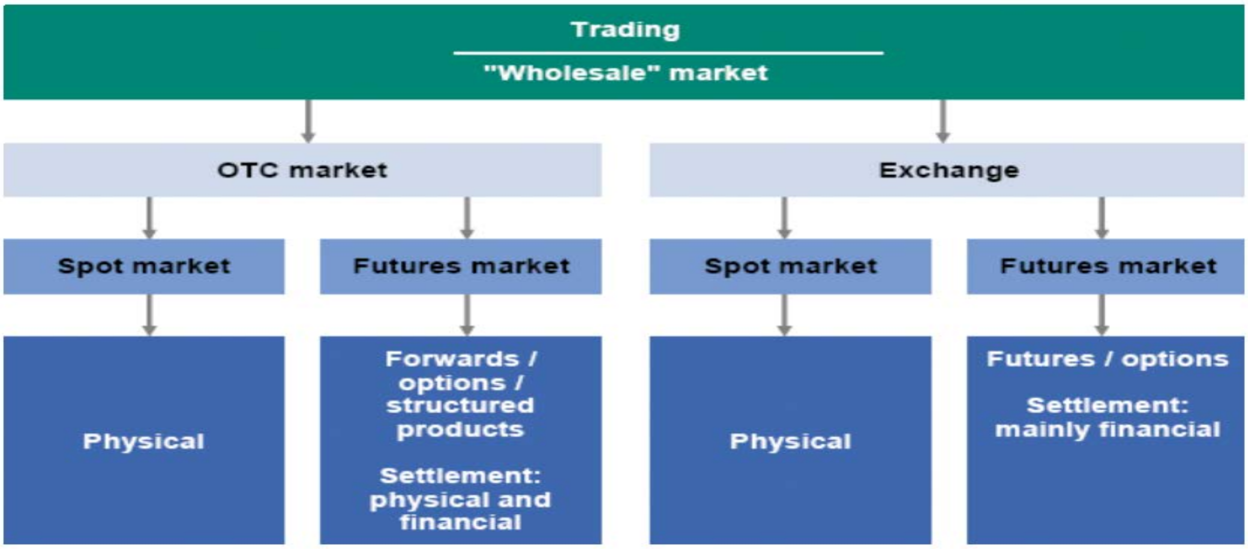
typically connected to medium voltage grids (in the range of 1 to 20kV), which then supplies a low voltage (230–400V) distribution network connecting to households (the 'last mile' connection). In addition, smaller capacity power plants (e.g. biomass or solar plants) are also typically connected to medium voltage grids.

- The grid is an extremely capital-intensive investment and presents the structure of a natural monopoly. The grid operator derives revenues from grid tariffs, which are reflected in the retail price of electricity. To prevent windfall profits originating from this monopoly, the grid operations must be carefully regulated. Box 3.A in Annex B provides a brief overview of some regulatory options.

Trade

- Liberalised electricity markets entail the existence of a central power exchange that matches demand with supply at every single point in time through an anonymous bid system. Different trading timelines exist to ensure the continuity of electricity supply: deals can be made to serve mid- to long-term forecasted demand (the 'futures market') and shorter-term demand fluctuations can be met through the day-ahead and intraday markets (the 'spot market'). The latter even allows for adjustments (turning power plants on and off) within minutes and ensures the overall reliability of the supply. The price on the spot market is determined by the so called 'merit order' effect (see Box 3.B in Annex B) and is paid uniformly to all power producers.
- The wholesale market generally consists of two main platforms, as illustrated in Figure 3.3:
  - The 'exchange' is the marketplace, where the commodity is traded anonymously. It offers a fair, low-risk and transparent trading environment, and ensures an efficient dissemination of price information and liquidity in the sector. Typically, an exchange is easy to access for power producers, entails low transaction costs, and therefore fosters private investments in generation. It also provides an indication of competitive tariffs, which can be used for 'over-the-counter' (OTC) deals and bilateral trading agreements, such as PPAs (Ecorys, 2010).
  - OTC deals are bilateral agreements whereby companies or large consumers buy their electricity directly from power producers through a broker, and usually represent a majority of the transactions on the wholesale market. OTC deals are characterised by limited price transparency as they result from bilateral price negotiations and are riskier than exchanges given that the customer may default (RENAC, 2016).

Figure 3.3: Structure of a wholesale electricity market



Source: Ecorys (2008)

- Cross-border trade and network integration create a more efficient, robust and secure system at the regional scale. Cross-border trade is usually undertaken by balancing the electrical load over several networks operated by different entities (called 'power pools'). Cross-border trade creates benefits through day-to-day trade, such as averaging out demand peaks and fluctuations in the production of renewable energy. Longer-term benefits also include the possibility to share spare capacity, thus reducing the requirement for 'emergency' power plants and increasing the ability of the pool to meet challenges (for example technical faults or extreme weather events).

Retail (or sale to end-customers)

- Retail companies sell electricity to consumers they buy from IPPs or from the wholesale market. They usually pay wiring charges to the transmission and distribution operators. Effective competition among retail companies empowers the consumer to respond freely to price signals, and encourages energy efficiency practices. This approach has been successful in many developed countries. Successful competition partly depends on allowing customers to easily switch between providers and ensuring that all retail companies have equitable access to the wholesale market.
- Usually, the price paid by customers to the retail company is a function of the total electricity quantity consumed. This is normally measured by meters connecting the private network of consumers with the distribution network and these are usually installed on the premises. In developing countries, metering programmes can help reduce theft of electricity (contributing to commercial losses) but attention must be paid to the cost-effectiveness of such initiatives (IEA, 2005).
- The price of electricity billed to the end consumer can vary, as the unit price may depend on the total consumption, the time of day and the consumption category (industrial, commercial or residential). The block tariff is one of many examples of non-linear pricing: the first tariff on the tariff scale is often a low ('lifeline tariff') so as to ensure that everyone can afford to meet their most basic needs. Lifeline tariffs are either subsidised by the government or more commonly cross-subsidised by commercial users and heavy domestic users. The tariff then increases with subsequent tranches of electricity consumed. Social tariffs also exist: they are targeted at vulnerable groups of the population and often aimed at increasing access to electricity.

Power sector reform has mainly focused on promoting the unbundling and liberalisation of the power sector, as this has yielded significant long-term economic benefits in developed countries. However, reforms pushing for a fully liberalised model have failed in many developing countries, in particularly in Africa where they have led to large underinvestment over several decades (see Box 3.C in Annex B for more details).

Evidence has shown that reforms need to be driven by the pre-existing conditions in the country and that there is no one-size-fits-all model. In recent years, partly unbundled, partly liberalised 'hybrid' models have been adopted in some countries and have proven relatively successful. Figure 3.A in Annex B illustrates different configurations that might exist. However, all hybrid models introduce some level of unbundling to create a competitive setting in the generation and/or distribution segments and rely on an independent regulatory authority to promote fair and transparent regulation of the sector. Box E provides an example of the stakeholders involved in the 'hybrid' Kenyan power sector.

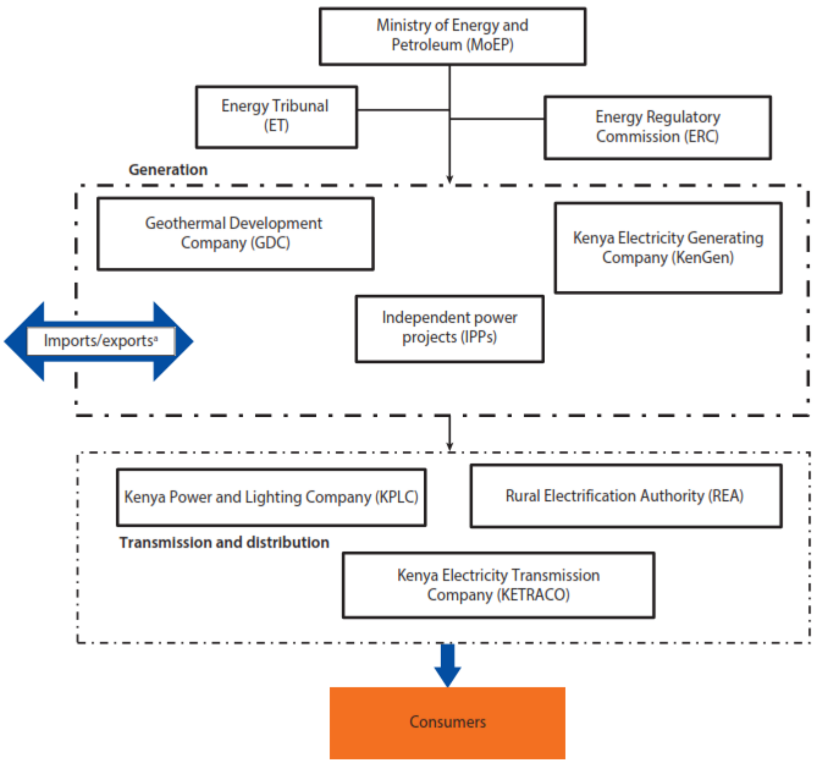
Box E: Power sector organisation: The Kenyan example

From the mid-90s onwards, Kenya implemented a series of reforms to separate the regulatory and commercial functions of the sector, facilitate restructuring, and promote private sector investment. These reforms shape the organisation of the country's electricity power today.

The institutional framework revolves around three main institutions. The Ministry of Energy and Petroleum is primarily responsible for policy formation, i.e. designing and implementing policy, strategy and plans for the sector, as well as overseeing the implementing agencies. The Energy Regulatory Commission is the regulatory body of the sector and as such has the mandate to, among other things, set tariffs, coordinate the development of energy plans, and monitor and enforce sector regulations. Appeals against the decisions of the Commission can be taken to the Energy Tribunal, which is an independent entity.

The power sector is unbundled to a certain extent: the generation segment is dominated by KenGen, a public power-producing company, which co-exists with a number of Independent Power Producers and the Geothermal Development Company, a fully state-owned entity aiming to fast track the development of geothermal resources in the country. The Kenya Power and Lighting Company (the 'off-taker') purchases the electricity from power producers and distributes it to consumers. The Kenya Electricity Transmission Company (the 'network operator') handles the transmission infrastructure. The Rural Electrification Authority designs and carries out rural electrification programmes.

Figure 3.4: Overview of Kenya's electricity sector



Source: Eberhard *et al.* (2016) and Kenyan PPP Unit website (here)

3.2 The challenge of supplying electricity

Electricity is a unique commodity, characterised by the fact that systems must accommodate the following technical challenges:

- generation must match demand at every single point in time to ensure grid stability;

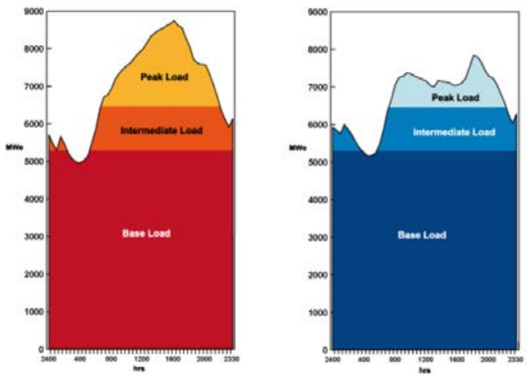
- it cannot often be stored in bulk at reasonable costs; and
- it cannot be transported without incurring technical losses.

This section will discuss these technical challenges and how they relate to some of the performance issues commonly observed in the power sector of developing nations.

Power demand and electrical load

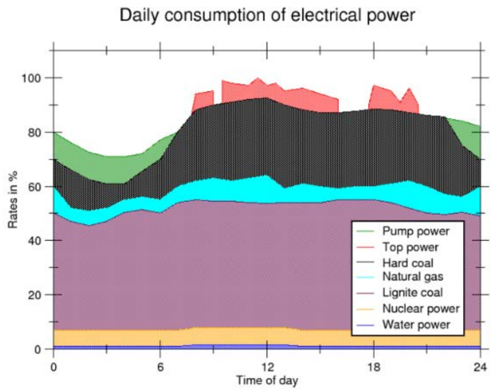
Demand for electricity is influenced by cultural and social patterns (e.g. working hours and working week), geographical location (due to climate and hours of daylight), seasons and weather conditions. Figure 3.5 illustrates that electricity demand in general fluctuates significantly within a 24-hour period (i.e. is lower at night) and that its profile changes depending on the season. For example, for temperate latitudes, demand tends to surge during the afternoons in summer, due to the use of cooling devices, while the winter peak is flatter.

Figure 3.5: Typical daily load profile in summer (left) and winter (right)



Source: World Nuclear Association

Figure 3.6: Load dispatch



Source: Energybc

Generation must constantly match demand to ensure grid stability, in order to avoid voltage fluctuations and power cuts. In many developing countries, the inability of power systems to match demand in real time is responsible for power outages and voltage surges that can damage electrical appliances and disrupt industrial and commercial activities. Empirical evidence has shown that an average firm in Africa incurs a cost ranging between $0.46 and $1.25 per kWh of unsupplied electricity. In Nigeria, an average of 32.8 outages per month disrupt the production of firms, and the associated cost of unsupplied electricity to businesses is estimated to be 15.6% of their annual sales value (Enterprise Surveys, 2014). This substantially undermines employment opportunities and creates environmental and health hazards for workers due to use of often poorly maintained back-up generators (Oseni, 2012).

A combination of technologies, especially those with dispatchable loads (those that can be increased or decreased according to demand), is important for optimising supply and for matching the demand profile. Power generation technologies are typically classified in three categories – base, intermediate and peak load – depending on the cost of running them and the ability to adjust the level of their production,. Figure 3.6 illustrates the typical role of different technologies in meeting demand.

- Base-load power plants usually operate almost all year round (80% of the time or more) and usually have high fixed capital costs and low marginal costs of production. They generally have only limited flexibility to adjust their production within small periods of time. Such technologies typically include nuclear, geothermal and coal power plants, the production from which cannot be easily or quickly increased or decreased. .
- Intermediate load power plants typically operate between 4,000 and 6,000 hours a year (i.e. 46–68% of the time) and have lower fixed costs and slightly higher marginal cost of production. Thanks to their relative responsiveness (production can be

adjusted within a few hours), their production can follow the main daily variations and meet most of the demand peaks. Typically, combined-cycle gas turbine plants and some coal-fired technologies belong to this category as well.

- Peak load power plants are switched on to serve the marginal demand. These plants have a high marginal cost of production but, due to their reactiveness, are very useful to compensate for the sudden increase in demand or decrease in generation, for example due to changes in production of renewable electricity due to weather conditions become less optimal. The most versatile technologies include open-cycle gas turbines, diesel and large-reservoir hydroelectric dams.
- Large-scale networks (e.g. national and regional grids) provide certain economies of scale, such as being able to most efficiently decide which power plants to turn on and off (load dispatch) to ensure supply meets demand perfectly, at lowest cost. They can average out demand and fluctuations in the production of renewables over a greater number of customers (or plants), and can optimise load dispatch across a larger pool of plants, thereby reducing the marginal cost of power supply. These large-scale systems involve significant centralised control and are therefore currently the best option to deliver power efficiently, reliably and affordably at scale.

Box F: The consequences of an overreliance on hydropower in Tanzania

In 2005, hydropower represented nearly 60% of Tanzania's installed power capacity. Due to repeated and severe droughts over several years and poor management of water resources, a significant share of the country's hydro capacity was often non-operational (up to 80% in December 2013). This forced TANESCO, the national utility, to rely massively on very expensive fossil fuel emergency power plants operated by IPPs which along with inadequate revenue collection, led TANESCO to accumulate considerable debt (up to $230,000 a day in 2013). TANESCO's precarious financial situation, resulted in delayed payments to IPPs, threatening further the performance of the sector and needed the intervention of donors.

To remedy this situation, TANESCO is in the process of adjusting its energy mix, using the country's resources to develop gas to power, solar, wind and geothermal plants. It is also considering importing electricity from large-scale hydropower projects in Ethiopia.

Sources: Reuters (2015) and World Bank (2013)

Storage options

Storage could dramatically decrease the cost of production of electricity, by storing excess (and cheap) base-load electricity when demand is low and releasing it to meet demand peaks. It is preferred to peak generation when the marginal cost of storage is lower than the marginal cost of peak generation. However, electricity cannot often be stored at scale at reasonable cost yet. There are currently two main types of well-established electricity storage technologies: batteries, which are appropriate for short-term storage, and pumped-storage hydroelectricity plants, which can be used for larger volumes. The latter pump water from a river up to a higher reservoir when excess electricity is available and release it during peak times, generating electricity through turbines. Many other technologies storage technologies exist or are under development, including heat and compressed-air storage but these are less common.

The current high cost of the technology has prevented many governments from considering storage as a viable option, although cost projections are decreasing and interest is growing (ESMAP, 2015). In some cases, favourable terrain conditions combined with an excess of cheap base-load power supply can make pumped-water storage economic. For example, the Guangzhou pumped-water storage facility in China was able to increase the efficiency of the nearby nuclear power plant from 66% to 85% in 2000 (Gavan-Lopez, 2014).

Significant technical innovation underway in energy storage is expected to lead to a dramatic shift in the economics of power systems in the coming years. In particular, energy storage would enable an increase in utility of distributed production of renewables. On-grid storage can also reduce costs for grid operators in some circumstances, particularly for handling variable renewable energy.

Transport and system losses

Electricity is transported through a complex network of overhead lines, transformers and cables, which result in technical losses, even when the system is operated at maximum efficiency. In the most advanced economies, transmission and distribution losses range from 4% to 12%: electricity theft (non-technical losses) is close to zero and networks are optimised to minimise technical losses. Many developing nations are faced with significant excess losses that originate from electricity theft and sub-optimal networks. In Sub-Saharan Africa, for example, technical losses have been estimated to about 23% and revenue collection rates only reach about 88%. The costs of distribution losses and uncollected revenue in Africa average 50% of utility turnover (Eberhard *et al.*, 2016).

In very remote rural areas, where individual electricity demand and ability to pay is low for socioeconomic reasons, the combination of high technical losses (even 'at efficiency'), high capital costs and low demand can make rural electrification programmes financially non-viable. For a given consumption, unavoidable technical losses increase relative to the quantity consumed as the population becomes sparser and as individual consumption levels decrease.

Decentralised systems

Decentralised on-grid systems are power systems where some of the production happens at a relatively small scale and can be fed into the distribution grid. As an example, electricity produced by rooftop PV panels or in-house generation capacity installed within an industrial plant ('captive capacity') are often connected to distribution grids. These set-ups enable individual producers to feed the electricity that they do not consume into the grid and receive financial compensation accordingly.

Distributed on-grid energy production has some advantages. When located close to population centres (such as rooftop panels) they reduce technical losses and can reduce the need for investment in network-strengthening infrastructure, such as voltage boosters and substation upgrades. Also, as they often produce during demand peaks, they reduce the need to dispatch peak load. However, they do not resolve the issues related to the limited financial viability of rural electrification programmes in remote, difficult-to-access or sparsely populated areas. In these cases, off-grid distributed power systems may be considered.

Summary

Using the technical and economic background provided in this section, Table 3.1 summarises the reasons behind the major performance issues experienced in developing nations.

Table 3.1: Factors influencing power sector performance in developing countries

Major performance issues:	Primary reason behind the poor performance:
Unreliable supply	Insufficient generating capacity and diversification of the electricity mix Inadequate load dispatch and limited storage capacity Inadequate transmission infrastructure and high excess (technical and commercial) losses Non-cost-reflective tariffs deterring investments in the entire value chain
Low rates of electrification	Uncertain returns to investment of grid expansion to rural areas due to high capital cost, high technical losses, limited consumption and ability to pay, and sometimes tariffs that are not cost-reflective Costly and difficult operation and maintenance of the network in remote rural areas (lack of local capacity and poor road network)

Unaffordable power	Theft and resulting financial burden on utility Excess technical losses Non-targeted electricity subsidies (when tariffs are not cost-reflective) that benefit those who consume the most and do not target the poor
High emissions	Limited viability of investment in renewables due to the high capital cost of renewable technologies, lack of maturity of local capital markets, fossil fuel subsidies, uncertain policy or regulatory frameworks Limited integration of renewables in the grid, caused by issues around grid stability and high technical losses when the generation site is located far from population centres
Inefficient use of energy	High excess losses (technical and commercial) Average tariffs are often non-cost reflective, and do not encourage efficient use of electricity
Limited energy security	Lack of regional trade and limited integration of networks Lack of diversification of the mix: overreliance on imported fossil fuels and limited use of locally available resources

3.3 State-of-the-art technologies

This section provides a short discussion on available power sector technologies and related technical and economic concepts.

Generation technologies

Generation technologies differ widely in their characteristics depending on the primary energy resource being converted into electricity. The main operational parameters used to classify power plants are as follows:

- **Load**: some technologies can dramatically increase their production within a short period, while others have a longer response period. Different technologies are therefore suited to serve different load requirements. Non-dispatchable technologies cannot be classified within the usual three types of loads: they rely on resources, such as wind and solar, the availability of which – and resulting production – cannot be easily anticipated or stored.
- **Capacity**: the capacity of a power plant describes the maximum power that the plant can generate at a point in time. It is typically measured in kW (for PV solar), MW or GW (for nuclear reactors or large off-shore wind farms). It should not be confused with the energy production, typically measured in kWh, MWh or GWh depending on the scale of production.
- **Capacity factor**: The capacity factor characterises the level of utilisation of a power plant compared to its maximum capacity. It is therefore lower for peak load plants than for base-load plants, as they function during shorter periods of time. This factor explains the fundamental difference between the generation capacity installed and actual amount of electricity generated. For example, in Germany in 2013 wind represented 18.8% of the total capacity installed but only 8.9% of the total energy generated. The difference is particularly high for some renewable energy sources due to their intermittent nature.
- **Efficiency**: this parameter characterises the degree to which the generation technology can convert primary energy into electricity. It is physically impossible to convert all of the energy contained in the primary source into electricity but typical plant efficiencies vary significantly between energy sources. Conventional thermal power plants, for example, typically have an efficiency ranging from 30% to 60%. Conversion efficiency also applies to renewables but has a different cost implication since the raw energy in the case of sun or wind is free (biomass usually comes at a cost).
- **Investment cost and levelised cost of electricity (LCoE)**: Renewables are particularly capital intensive but have very limited operational costs; the marginal cost of production is therefore close to zero. In order to compare the overall cost of

electricity generation with different technologies – which differ widely in their capital requirements, operational costs and operational characteristics – practitioners have created the concept of LCoE, which reflects the average cost of capital per unit of power generated depending on the capacity factor that results from market operations. The LCoE is the ratio of discounted capital and operational expenditure over the plant lifetime over the discounted electricity generation.

The LCoE figures cover only the cost of generation for a specific technology and do not reflect the cost of maintaining a reliable service and ensuring the security of the wider system. Using the average LCoE across the pool of plants as the basis for determining a cost-reflective tariff therefore means that producers and customers will receive the right pricing signals. It will also help ensure a sustainable and economically efficient long-term balance of supply and demand. Minimising the overall system-wide LCoE (subject to achieving access and service objectives) should therefore drive decision-making.

The LCoE of a specific technology (such as solar or wind) varies significantly across countries depending on the level of familiarity of investors and lenders with the technology, the maturity of capital markets, the level of development of technology-specific supply chains, the know-how of the workforce (construction and operations), the type of procurement process, the quality of the regulatory environment, etc.

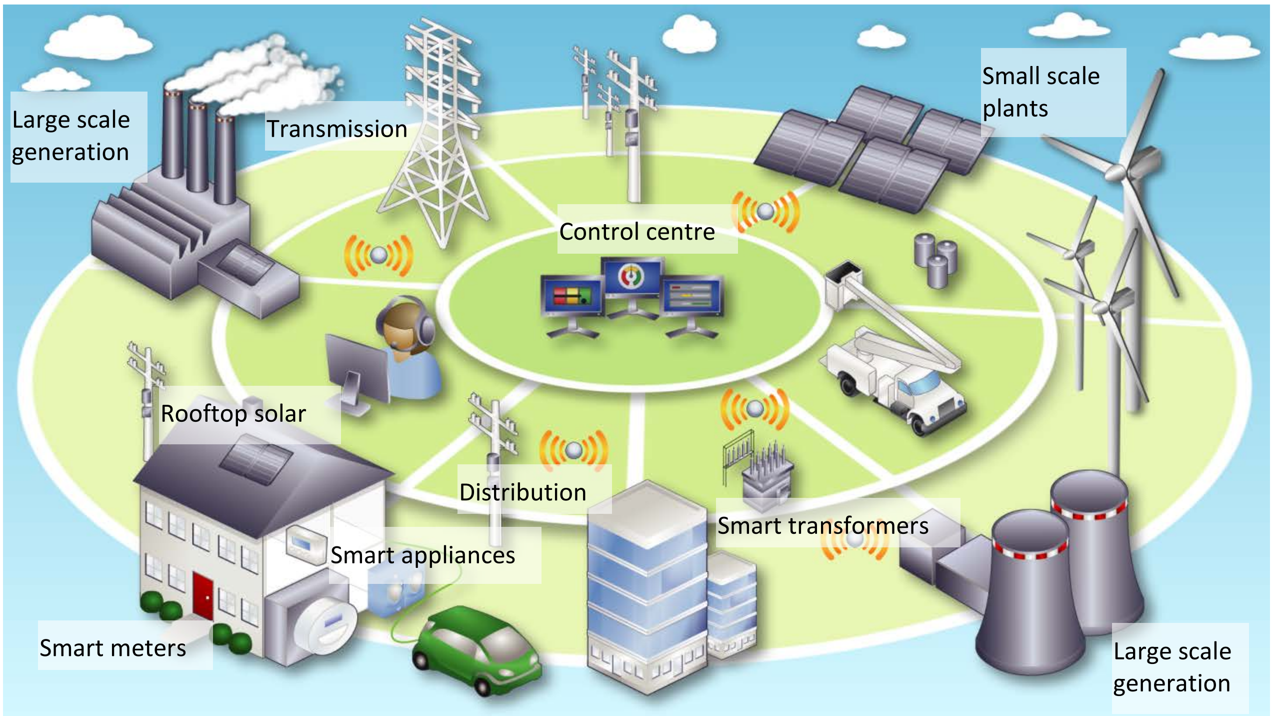
Grid-connected distributed technologies

Recent technical progress has entailed a shift away from a fully centralised grids to the inclusion of distributed generation capacity and related technology. Digital technology and related equipment (meters, transformers, etc.) can be integrated into the grid to control the performance of the system in real time, assessing changes in production (e.g. from of renewables) or consumption automatically adjusting the load dispatch within seconds. This involves two-way communication between the utility and the end-customer. The application of such technologies is often referred to as 'smart grids'.

Smart grid technologies differ in cost, technical status, applicability and market maturity. The recourse to these technologies depends on the degree of sophistication of the grid. In developing countries, well-established technologies – notably those enabling automation and demand response – may be efficiently used and are usually cost-effective. More advanced technologies, such as smart inverters and renewable forecasting technologies, are more costly but increase the efficiency and productivity of renewable power generation. They are particularly important when the capacity penetration of weather-dependent renewables reaches 15% or more. Indeed, below this threshold renewable energy technologies can be connected to grids without requiring major grid investments (IRENA, 2013). This applies to a great number of developing countries, as few rely substantially on renewables.

Smart grids are not just about new technology – they may stimulate the emergence of new business models in the future. Tariffs could reflect the real-time costs of generation, thus incentivising consumers to reduce consumption when demand and tariffs are high and to consume more when demand (and tariffs) are lower. The advantages could include more efficient transmission of electricity and better integration of all generation capacity (including small-scale distributed renewables), reduced demand peaks, quicker resolution of grid imbalances and improved reliability and reduced costs for utilities. All of these would drive tariffs down (US Department of Energy's Office of Electricity Delivery and Energy Reliability, 2016).

Figure 3.7: Smart grids for distributed power generation



Source: Adapted from Knowstartup website (2016)

Finally, grid-connected mini-grids can provide the wider grid with 'stabilisation services' and increase network efficiency, as they locally balance demand and supply and therefore reduce technical losses. However, when these systems are installed by end-users, such as anchor customers, the reliability of the supply to users is likely to drive mini-grid operations and the complicated matter of providing the wider grid with 'stabilisation services' may not be considered. More sophisticated business models, run either by a dedicated energy service company (ESCO) or the utility, could play a crucial role in unlocking these network benefits.

The donor community could play an increasing role in developing innovative business models, which will ensure a trade-off between reliability of supply to the end-user and stabilisation services to the grid. India, Ghana, Pakistan, Bangladesh, Nigeria and Nepal now have valuable experience of using grid-connected mini-grids (Vivid Economics and ARUP, 2015).

4 Barriers to and opportunities for improving performance in the power sector

The performance of the power sector in developing countries is typically poor, and is holding back economic growth and poverty reduction. The power sector is characterised by insufficient access, poor reliability of electricity supply, limited affordability for many (especially the poor), low penetration of renewable technologies and lack of security of supply.

Developing countries face a persistent and significant shortage in public and private investment in new infrastructure, across the generation, transmission and distribution segments. This results in undersized and underperforming power systems, which are unable to serve existing demand. For example, Sub-Saharan Africa needs to double its electricity production by 2030, and requires investment amounting to more than 6% of Africa's GDP, i.e. about $41bn a year (Eberhard *et al.*, 2016). This large investment deficit cannot be met by the public sector alone and private sector participation is required. However, the current reluctance of investors and very limited pipeline of projects in the sector are signs that significant barriers need to be addressed.

The barriers to attracting investment, and using it effectively, are manifold, complex and intertwined. This section gives an overview of the barriers – institutional, financial and technical – and covers both on-grid and off-grid systems.

This chapter also explores possible entry-points for addressing the key institutional, political, financial, technological and policy barriers to improving performance in the power sector that we identified in the previous chapter. It focuses on interventions which donor agencies could consider as part of their engagement and technical assistance programmes with partner governments. The final section of this chapter signposts which interventions could be considered depending on the particular performance problem.

4.1 Institutions, regulation and policy, and political economy issues

4.1.1. Institutional barriers to improving performance in the power sector

Institutional, regulatory and policy, and political economy barriers affect the performance of the power sector throughout its value chain. These factors set the enabling environment for how the sector is managed and governed, and affect the perceived risks in investing in the sector and the extent to which investment is utilised effectively and delivers the expected benefits.

The lack of effective planning (and clear communication about these plans) is a barrier to creating a conducive investment climate and coherent policy environment. When there is no strategic vision outlining industrial policy, rural electrification targets and projected economic growth or when the strategic vision is not linked to actual policy decisions, it is not possible for the government to forecast demand for electricity over the long term or decide on the best options to meet the demand and how and when these options should be procured. The lack of credible integrated planning (which takes into account wider sustainable development aspirations) is often related to broad political and macro-economic instability, and deters the participation of the private sector. It increases the risk of setting competing policy priorities and limits government ability to identify and prioritise the critical areas of reform required.

Capacity gaps in governmental institutions are at the root of governance deficiencies. There is a lack of the technical skills required to create a transparent and competitive procurement environment, as well as to put in place a functioning institutional framework with clear accountability lines and the required level of autonomy for the regulator. For example, governance of a utility depends on the capabilities of relevant individuals, including shareholder quality, managerial and board autonomy, accounting standards, and performance monitoring. Most utilities in Sub-Saharan Africa meet only about half of the criteria for good governance (Eberhard *et al.*, 2016). The capacity gaps in the sector are also related to the absence of transparent planning and to regulatory risk (AfDB, 2013a).

The structure of a country's electricity market significantly impacts the potential for private investment and thus the overall performance of the system.

For example, when the market is only partially liberalised, and a utility dominates or has a monopoly over all segments, including the load dispatch, the utility has a vested interest in using its own power plants. This undermines the financial viability IPPs and deters investments in the long term.

Barriers can also exist in a liberalised environment if the regulation is not regulation does not encourage effective competition. For example, a major constraint to effective wholesale electricity competition is often a policy and regulatory environment that ties many electricity producers to long-term PPAs, which means they are unable to sell their electricity to the wholesale market, reducing competition. In many cases, there is also an insufficient number of market players to facilitate meaningful competition.

The absence, or lack of independence, of a regulatory authority often results in politicised and non-transparent management of the sector and impedes the enforcement of rules and regulations. As a result, electricity tariffs paid by customers are influenced by political concerns and often set below cost-reflective levels. This tariff gap is an implicit energy subsidy, and in most cases governments do not allocate enough funds from the main budget to cover the entire subsidy.

Utilities therefore accumulate increasing levels of debt, which often means they can no longer pay IPPs for their production in a timely manner and that can lead to defaults. This is referred to as the off-taker or credit/payment risk, and it significantly undermines the viability of private investments in countries where the utility has low creditworthiness. As a result, developers have difficulty accessing private finance and need financial guarantees from governments or donors, such as letters of credit. All of this either deters investors entirely or pushes up the cost of delivering new projects.

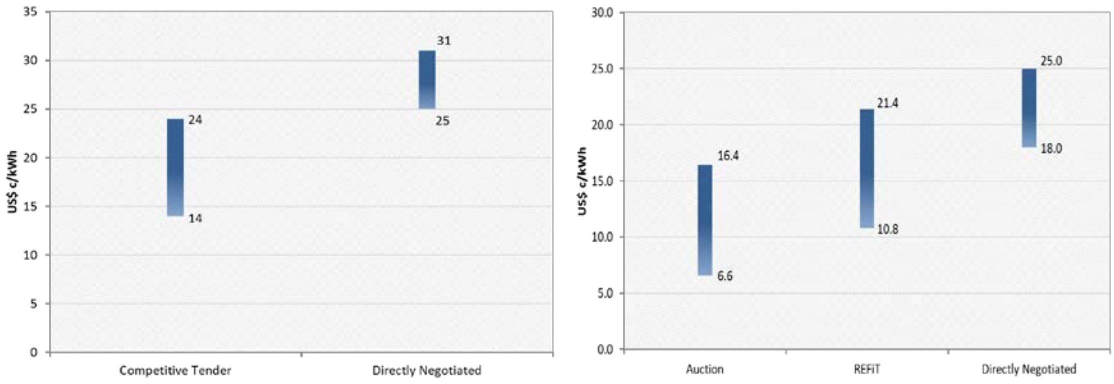
Unpredictable *ad hoc* changes in laws and regulations (often termed 'regulatory risk') are a strong deterrent to investment and result in inefficient and often incoherent regulation of the sector. Unexpected changes in regulation, such as the tariff or tax rates, and levels of government subsidies to specific technologies (often renewables) dramatically affect the long-term returns on investments and precipitate a lasting reluctance to invest. The regulatory risk is particularly high in countries where the regulatory framework is still evolving and where there are relatively few precedents for how the legal system handles conflicts resulting from changes in laws. The perceived regulatory risk is often higher in countries with unstable political regimes, as this may trigger the development of incoherent and conflicting policies.

Political risk is a major barrier, particularly in conflict-affected environments or in the case of countries with recent precedents of expropriation, arbitrary cancellation of contracts, permits or licences, restrictions on the conversion and/or transfer of currencies. Such issues can disrupt the operations of a project and again undermine the possible return on investment.

The absence of competitive tendering is a major barrier to private investment. Most IPPs in developing countries are still directly negotiated between the government and project developers, for example in the form of memoranda of understanding (MoUs) or unsolicited bids, although there is a move away from this. This lack of transparency in the procurement process has a number of negative effects: (i) it increases the risk of controversy – often these deals are struck with allegations of corruption; (ii) it yields lower price outcomes, compared to competitive tenders, as highlighted in Figure 4.1, therefore putting more strain on the utility's finances and/or the final consumers; and (iii) it does not encourage the development of a pipeline of bankable projects, which is a binding constraint in the power sector in most developing countries.

However, there is significant resistance to the adoption of competitive tendering, as many key stakeholders have different vested interests in prolonging the *status quo*. Private sector stakeholders may be reluctant as tariff outcomes (and therefore profits) from the competitive process are often lower (Figure 4.1). Also, governments often lack the capacity to design and run this type of procurement. Donors and development finance institutions often support the design of bankable projects and engage directly with the government to ensure that they are financed. While directly negotiated projects may still be appropriate in some circumstances, it is crucial that the government has the capacity and an appropriate methodology to assess value for money.

Figure 4.1: Price outcomes of different procurement processes for (left) medium-speed diesel projects in Kenya and (right) solar PV



Source: Eberhard (2016b)

The limited level of regional integration in the power sector is often driven by institutional barriers and results in incoherent national plans at the regional scale (e.g. where spare capacity for the power pool should ideally be installed). Political barriers include the reluctance of national governments to relinquish control over the power sector, governance deficiencies existing in the different power pool countries making coordination at the regional level more difficult, differing political systems, powerful interest groups, and corruption. Political will and desire for integration and trade is crucial for regional integration. Governments must be willing to coordinate power sector plans and rules at the regional level with appropriate delegation at the national level. (Economic Consulting Associates, 2010).

Box G: Powering East Africa using affordable hydropower from Ethiopia

Ethiopia is endowed with a large potential for affordable hydropower, in particular on the Omo River flowing into Lake Turkana and the Nile. In 2011, the Ethiopian generation capacity amounted to about 2 GW (REEEP, 2014), out of which 99% relied on hydro. Two major hydropower projects – the 1,870 MW Gibe III dam on the Omo River, which began operations in 2015, and the 6,000 MW Grand Ethiopian Renaissance dam (expected to commence operations in 2017) on the Nile – represent a five-fold increase on the installed capacity in 2011.

The country alone is not able to absorb the additional production. Beyond the social and environmental aspects of such large hydropower projects, affecting tens of thousands of people and flooding large areas (about 1,500 km^2 for the Grand Renaissance dam, i.e. about five times London's inner city area), they necessitate an urgent increase of regional trade. Gibe III alone could provide electricity to more than 200 million people in the region (World Bank, 2012) and, exporting the production surplus is critical for the financial viability of these investments.

Large investments in interconnectors and institutional strengthening of the regional power pools are crucial. The Nile Basin Initiative, for example, aims to develop hydropower in the Nile region in a cooperative manner, share substantial socioeconomic benefits, and promote regional stability. It includes Egypt, Sudan, Ethiopia, Uganda, Kenya, Rwanda, Burundi, the DRC and Tanzania but further integration – particularly investments in high capacity transmission lines between countries – is required. A number of donors are investing in such developments as a 1,000 km high-voltage line between Ethiopia and Kenya with a maximal capacity transfer of 2 GW (World Bank 2013 and AfDB 2013b).

Further reading: a guide to the key features of power system integration commissioned by ESMAP provides a literature review on all aspects of power sector integration (see: Economic Consulting Associates, 2010).

4.1.2. Institutional opportunities for improving performance in the power sector

Strengthening institutional capabilities

Human, organisational and institutional capacity is a prerequisite for improving performance and donors can build capacity at all levels of the individual, organisation and wider institutional set-up through technical assistance programmes (see Table 4.A in Annex B for a framework for institutional capacity building). As a starting point, it is important to carry out an institutional assessment of the underlying causes of capacity gaps, including incentives and the political economy of the institutions. The following should be the target results of any technical assistance programme that aims to strengthen institutions in the power sector:

- **Strong and independent institutions to enable effective planning and management of the power sector**, including balancing demand and supply, preparing budgets and expenditure frameworks, and reviewing performance. Even in a fully liberalised sector, the government must ensure a level playing field, regulatory oversight and transparency and accountability.
- **Coordination across agencies and organisations to manage conflicting interests**. In Ghana, the Energy Commission is an interesting institutional model, playing both a coordinating and regulatory oversight role. In Tanzania, the Government has set up a Joint Sector Working Group to carry out joint planning and performance review, although its effectiveness has been mixed.
- **Highly trained and motivated government officials for effective decision-making and management of the sector.** Donor agencies can support ongoing and sustained training and mentoring, such as by establishing centres of excellence and facilitating international skills exchange. In Angola, the Ministry of Energy has partnered with Agostinho Neto University to train specialists in pertinent technical and legal areas to reduce project delays and attract investment (AfDB, 2013a).
- A supportive enabling policy and regulatory framework, including a long-term vision for the power sector with clear targets and responsibilities. Institutions can only function effectively if there are regulations and policies to ensure transparency and accountability, as well as to provide the mandate to institutions. They also need to be empowered with sustained and sufficient finance, which partnerships with development agencies can help facilitate. Box H below provides an example from Rwanda of how development agencies can provide institutional support.

Box H: Sector-wide approach to enhance collaboration and coordination across the sector

In 2008, only 6% of Rwandans had access to grid electricity and the Government of Rwanda made the ambitious commitment to triple access over a five-year period. Development partners got behind the government's target, and collaborated under a sector-wide approach channelling all funding toward a roll-out plan and monitoring performance. The implementation included joint planning of target areas for new grid connections, redesigning the grid connection technologies so as to lower costs, and adopting a micro-hydro feed-in-tariff.

Careful analysis was carried out on households' ability to pay for electricity, balancing affordability with the financial sustainability of the programme. While there were cost-recovery tariffs, and the utility was expected to contribute 10% to capital costs, the connection cost was subsidised based on ability to pay. The analysis showed there was a $224.5 million shortfall in funding, which was raised after a donor roundtable with the government. A total of 80% of programme costs were met through government and donor grants. As a result, Rwanda exceeded its original target, and by 2012 nearly 1 million people gained access to electricity and more than 1,400km of new distribution networks were built.

This experience demonstrates the importance of collaboration and coordination across stakeholders, strong ownership and vision by the Government, and well-tailored international support.

Source: World Bank (2015)

Locally led and driven reform of the power sector

Worldwide efforts since the 1980s to promote market-based reforms and restructuring of the power sector in developing countries have been slow, difficult and without a proven or clear link to an increase in the performance of the sector.

The expected pathway to reform starts with transforming state-owned utilities into separate non-government legal entities, and passing legislation to allow private participation in the sector. An independent regulator would be established to introduce transparency and efficiency in the sector. Further stages include unbundling to separate the potentially competitive generation from the natural monopolies of transmission and distribution. Competition would be created through trading on an electricity market. Many developing countries have completed the initial stages, but few have completed unbundling, privatisation and introducing retail competition. Figure 3.A in Annex B illustrates the status of reform in Sub-Saharan Africa.

There is a clear rationale to pursuing power sector reform to the extent that it results in a better governed and more efficient sector. Moreover, there are some clear lessons from global experience in reform:

- There are a range of reform models, and countries should match what they hope to achieve with the right model. Understanding possible constraints to reform will also help set an appropriate pace and pathway.
- The reform process must be led and driven locally, as any perception that it is being imposed by external actors will be a serious barrier. An in-depth political economy assessment can identify whether there are opportunities and entry-points for reform, and the individuals who can drive the process. Funding of concrete reforms should not be attempted until there is a supportive political and economic environment – which donors can support by identifying and engaging with reform-minded local actors and supporting coalitions of reform champions.

Promoting a gender-sensitive and inclusive power sector

There are a number of practical policies that can be adopted to help ensure women, girls and other vulnerable groups receive adequate attention and have equal access to services.

- Impact assessments with a focus on gender and minorities for all power projects, policies and plans can help identify early any unintended negative consequences on vulnerable groups. For example, when building a new power plant, such an assessment might identify women as potentially losing out on resettlement options because of land ownership rights, meaning appropriate mitigating actions can be designed.
- Men and women use electricity in different ways, and this has implications for how to deliver and prioritise electricity services, such as different wattage requirements, when during the day electricity is essential, and varying abilities to pay. Understanding the different needs of women in accessing and using electricity will help governments plan and deliver a more effective and gender-sensitive service.
- **Women are traditionally underrepresented in decision-making roles in the power sector.** Improving the gender ratio within government and private agencies in the sector is of value not just for increasing social equality but also because female staff are more likely to understand and address the specific challenges facing women in accessing electricity.
- **There are a wide range of vulnerable groups, the exact composition of which depends on the local context.** In many countries, access to electrification can be politicised and electrification programmes prioritise particular constituencies –

including ethnic or religious groups – based on allegiances with politicians. It is important to assess any donor programme to ensure that it is promoting inclusion, rather than worsening it.

Further reading: The World Bank has prepared under their ESMAP programme a guide to integrating gender considerations into energy options, including check-lists for things to consider and case studies (see: ESMAP, 2013).

Efficient demand-side management

Governments are increasingly turning to demand-side management as a relatively low-cost way of balancing supply and demand and reducing stress on the electricity system.[2] Adopting cost-reflective tariffs is the most direct way of incentivising efficient use of electricity. However, given the political barriers to this, there are some alternatives:

- Many developing countries have adopted mandatory (e.g. labelling schemes) or voluntary programmes (e.g. awareness-raising) to encourage household and industrial consumers to use efficient electrical appliances, such as compact fluorescent lamps. It has been estimated that, on average, each additional $1 spent on more efficient electrical equipment, appliances and buildings avoids more than $2 in investment in electrical supply (IEA, 2006).
- **Tariffs can be designed to incentivise reduced electricity consumption** (e.g. block tariffs, as defined in Chapter 3). The price can be fixed for up to a certain amount of electricity used, a basic amount that allows the poor to have basic services at minimum cost, and then increases in progressive bands with further consumption. Rates can also be higher during peak hours to reduce demand and ensure the system is not overloaded. Such tariffs can help overcome opposition to price reform and allow equitable access to electricity based on consumer affordability and needs.
- Most utilities have incentives and targets for increasing generation capacity, reflecting that expanding generation is both a legitimate and politically popular objective. Setting performance targets on efficiency with an associated financial return could enable efficiency and supply to be put on an equal footing.

Promoting regional integration

Developing countries are increasingly pursuing regional integration of power systems to help secure their supply of electricity and balance the generating capabilities across a greater pool of plants. In Africa, there are a number of regional agreements on electricity cooperation and trade, such as the Southern Power Pool. However, given the scale of the economic and institutional challenges facing the national utilities, a significant amount of political will is required to make them work. There are some strategies for ensuring supportive policy and politics:

- There is no one-size-fits-all design for a regional power pool, and they should be carefully designed and planned to match local objectives and capacities. There also needs to be flexibility to respond to changes in the local context as the integration process moves forward and certain basic requirements before integration can happen, such as robust finances for national utilities.
- One of the most challenging aspects is for national governments to allow regional planning to supersede national plans, and to a certain extent consider the regional interest above the national. To overcome this, governments have to be convinced that they will benefit from a regional plan. Having heads of state formally adopt and launch a regional plan also helps to secure political ownership.
- Regional integration of electricity requires effective institutions at the regional level to facilitate discussion and negotiation among national power sector agencies, to

[2] One estimate states that developing countries could reduce their total energy demand growth (beyond just electricity) by more than half, and save $600 billion in avoided new infrastructure, through energy efficiency measures (MGI, 2008).

build trust and a common vision and put in place a common legal and regulatory framework. A range of institutional models are being used, including power pools and their secretariats, regional regulators (or regional associations of national regulators), and regional transmission/system/market operators. Special purpose vehicles, with a corporate structure established to execute a specific project, have also been successful for stand-alone regional projects due to their transparent nature and ability to bring on board expert staff. The strongest of the regional institutions are those that emerge and grow out of existing institutions, and where there is already a legacy of regional cooperation. For example, the Southern African Power Pool falls under the Southern African Development Community (SADC), a regional economic community with a strong integration agenda across a range of sectors. The power pool benefits from being a utility-driven institution that also benefits from the political guidance of SADC (ESMAP, 2010).

Box I: Overcoming challenges to regional integration through public–private partnership

Africa GreenCo is an innovation being designed to overcome the lack of financial and market integration at the regional level, and promote regional power pools. It aims to serve many roles, including as a credit enhancement intermediary for power projects by entering into PPAs with generators and utilities. It will act as a single point PPA counterparty, eliminating the need for power producers to negotiate multiple PPAs, and in the event that a national utility defaults it will sell to another buyer via the pool, thereby mitigating risks. This is expected to foster private sector investment, which will hopefully quickly deliver much-needed capacity additions. It will also help facilitate regional planning and decision-making, with local government and private actors as members. Africa GreenCo is currently proving its feasibility within the Southern African region, and will need to demonstrate its viability to attract significant funding – including from donors.

4.2 Finance

4.2.1 Financial barriers to improving performance in the power sector

Financial barriers in the power sector are due to a combination of the lack of track record of some technologies or business models, immature national capital markets, and the institutional, policy and regulatory barriers discussed above. All these barriers affect private sector investors, commercial banks and other financing or refinancing institutions, as well as government and public utilities, which commonly have difficulties raising capital for large-scale infrastructure.

The limited maturity of domestic capital markets, mostly in low-income countries, is a binding constraint to accessing domestic financing. Domestic commercial banks have difficultly offering large, long-term and cost-competitive loans. Investors therefore face a sub-optimal payment period, an elevated risk of illiquidity when the loan tenor runs out, and no refinancing option. They often therefore have to recourse to international lenders or to seek support through donor-supported initiatives such as the GuarantCo facility, which provides local currency guarantees for infrastructure projects.[3]

This trend is exacerbated for renewable energy technologies for the following reasons: (i) some renewables require more upfront capital than their diesel or gas equivalents and therefore entail a longer repayment period (up to 20 years for on-grid projects); (ii) they have no or limited track record in-country and returns on investment are uncertain; and (iii) domestic lenders often do not have the tools or the knowledge to assess the financial viability of these investments.

The lack of information and limited track record of some technologies in a specific country deters domestic debt financing. The limited familiarity of domestic lenders with the

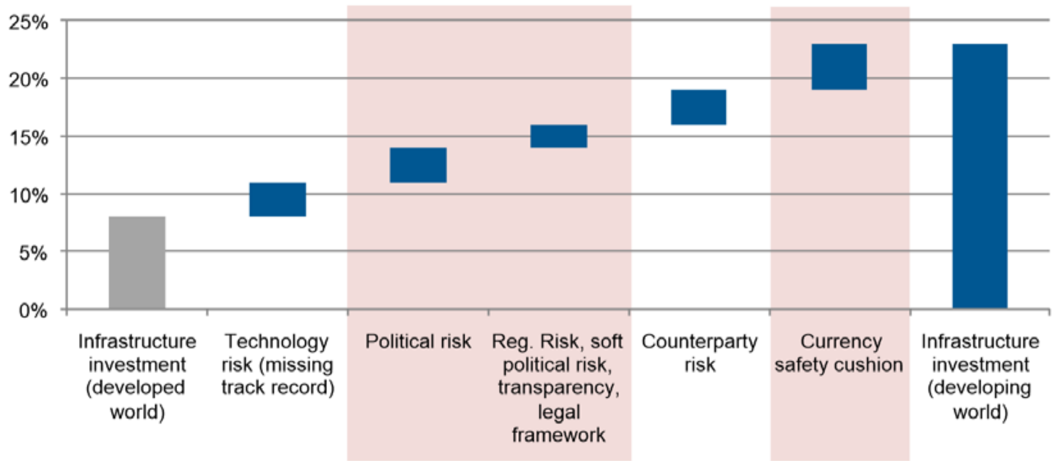
[3] See www.guarantco.com/

newer technologies or business models, such as off-grid systems or some renewable technologies, exacerbates their reluctance to finance such investments. The development of small-scale and off-grid systems particularly relies on accessing domestic financing as these investments are often carried out by small-scale entrepreneurs who cannot easily access international capital markets (DB Climate Change Advisors, 2011).

Inflation and the resulting depreciation of the local currency are major risks facing investors and lenders. Due to the lack of domestic financing, project developers often turn to international commercial banks and other lenders and acquire debt in an international currency, while, in most cases, securing a long-term PPA with the utility stipulating a fixed tariff in the local currency. Due to the nominal exchange rate depreciation over the lifetime of the investments (20–30 years or more), a mismatch between the income stream from the plant's operation and the servicing of the debt by the project operator may arise and jeopardise the operations of the IPP. This may also impact public sector investments in transmission or rural electrification when a large share of the investment has been financed through international lenders (including a donor).

The high expectations with regards to equity returns reflects the high perceived risk and are making a lot of projects financially unviable, therefore preventing investment in a pipeline of bankable projects. Equity financing (with a share of financing from a private investor) accounts for at least 25–30% of the total investment cost and equity return expectations are project specific and reflect the degree of risk associated with this investment (DB Climate Change Advisors, 2011). In industrialised countries, equity returns average about 8%. The additional challenges that investors face in developing countries (e.g. limited off-taker creditworthiness, currency risks, etc.) dramatically increase the perceived risk and therefore translate into higher return expectations. As shown in Figure 4.2, equity return expectations can be above 20% in some developing countries. The higher the expected return on equity, the less financially viable the project, as the cost of debt is also likely to rise with the perceived risk profile. The highlighted areas in the figure represent areas where the perceived risk between domestic and international lenders may differ and is likely to be higher for the latter group.

Figure 4.2: Effect of an increased level of risk on equity return expectations



Source: DB Climate Change Advisors (2011)

Fossil fuel subsidies, particularly those on diesel, can be a financial barrier to investments in renewable energy projects, as they artificially widen the gap between the LCoE of fossil-fuel-based generation and that of renewables. Additionally, fuel subsidies put a real strain on the national budget and contribute to eroding government creditworthiness, as well as being generally untargeted and accruing to those who consume the most. They are therefore considered a costly approach to protecting the poor (Arze del Granado, 2010).

A significant penetration of renewables can make the refinancing of investments difficult for all investors in a liberalised market where a significant share of electricity is traded on the spot market. The marginal cost of renewables is close to zero, and when the penetration rate of renewables is high the price of electricity dramatically drops on the spot market (see Box 3.B in Annex B).

In remote areas, the discrepancy between the high unit cost of power and the willingness to pay for services is responsible for the slow roll-out of grid-based electrification programmes in numerous countries and is mostly driven by techno-economic constraints. The cost of the physical infrastructure per household is high, as these areas are sparsely populated and the long distances that electricity has to cover results in high technical losses. Additionally, maintenance of the network infrastructure is difficult and costly due to the lack of trained staff and materials locally. These areas are often characterised by high rates of poverty and thereby the willingness of consumers to pay is a major barrier: often household cannot afford the one-off connection charge without taking up a loan. Although delivering power in these areas is costlier than anywhere else, utilities cannot charge tariffs that would reflect the 'true' cost for social equity reasons (Bhattacharya *et al.*, 2015).

Off-grid systems such as mini-grids or individual systems face significant techno-economic constraints, which translate into financial barriers. These systems can bring significant benefits, such as lowering operating costs by utilising local renewables, proximity with demand centres reduced technical losses, and more precise matching of capacity demand. Table 4.1 summarises the advantages and limitations of off-grid systems. The IEA estimates that an annual investment in off-grid systems of $26 billion will be required to meet universal access targets by 2030 but a number of financial barriers need to be overcome for investments to pick up.

One of the major threats is the uncertainty around future demand levels, as well as possible grid-extension plans, which would entail a drastic change in the operational and financial model of mini-grids. The latter could impact substantially the ability of the investor to recover the investment cost and repay the related debt. Off-grid investments are also facing 'first-generation barriers', which include low-returns on investment, high transaction costs, lack of regulation specific to off-grid investments, lack of track record, unfamiliarity of financing institutions, and unsuitability of existing credit facilities. Additionally, the limited creditworthiness of the often local investor (often a community association or an NGO) is a further barrier in accessing finance (Bhattacharyya *et al.*, 2015).

Table 4.1: Techno-economic advantages and limitations of off-grid investments

Type of off-grid system	Advantages	Limitations
Mini-grid, often based on locally available renewable resources	Higher exploitation of the local and clean energy sources Reduced transmission infrastructure, and lower system losses (as generator is close to demand centre) Independence from grid stability issues Relative (or full) independence from fossil fuels, benefitting energy security and climate change	Needs to have a threshold number of households Households needs to be concentrated within a small area Need to match capacity with load when designing Difficult to guarantee reliability of supply Lack of standardisation among local grids – limits possibility of integration Economies of scale and benefits from security of supply are not achieved
Individual systems (e.g. solar home system, solar lanterns, etc.)	Do not require coordination between stakeholders Simpler technology System can be designed to exact needs of consumer	Unit energy costs are normally higher than grid (low capacity, excess battery costs, etc.) Requires robust product and spares supply chain Finite capacity to store electricity – wastage of any excess

4.2.2 Financial opportunities for improving performance in the power sector

Attracting private investment

To meet current and future demand for electricity, huge investment in generation capacity is required. The cost of addressing the needs of Sub-Saharan Africa's power sector alone has been estimated at $40.8 billion a year – equivalent to 6.35% of Africa's GDP. However, total investment between 1990 and 2013 only reached $45.6 billion, mainly through public sector financing and development aid (Eberhard *et al.*, 2016). Governments recognise that bridging this funding gap requires attracting large volumes of private investment, primarily through privately financed and owned IPPs. There are a number of strategies for attracting private financing, above and beyond those affecting the general investment climate of a country:

- IPPs have arisen in a variety of power sector market types, suggesting that the full liberalisation of the power sector is not a pre-condition. However, reforms such as unbundling and independent regulation allowing for cost-reflective tariffs are important for improving the governance of the sector and therefore reducing perceived risks for investors.
- **Regulations need to be in place that define the 'rules of the game' for IPPs in the power sector**, giving certainty to contracts and proper transparency and accountability. These rules should then be enforced by an independent regulator.
- **An effective, efficient and transparent procurement and contracting process is very important**. Competitive bidding for IPPs increases fairness and transparency, and results in better price outcomes, compared to directly negotiated projects. However, this procurement process requires a high degree of institutional capacity and specialised staff. In recent years, reverse auctions (see Table 4.2 and Figure 4.1) have significantly contributed to bringing down the unit price of renewable electricity sold by IPPs to utilities.
- The financial health of off-taker utilities is a key determinant in encouraging IPPs and is impacted by several parameters, such as their internal management, the revenue collection rate (i.e. commercial losses being minimised), the tariff structure, and the minimisation of technical losses (Eberhard *et al.*, 2016).

Effective pricing regimes

The starting point for building a financially robust power sector is the revenue generated from consumers. However, in developing countries the amount generated often falls far short of covering the regular costs of supplying electricity, the large capital costs of investing in new generation capacity, and ongoing maintenance. The balance represents the extent to which the government subsidises the costs (either directly through the budget or indirectly through the utilities balance sheet). Subsidies can be important for making electricity affordable to low-income consumers, but they also have an important influence on the ability to attract private sector investment. This is particularly important for rural electrification programmes, which suffer from a high per-unit cost of grid expansion due to low population density, limited demand by rural consumers and high costs associated with grid expansion in remote areas.

Effective and carefully designed pricing regimes are therefore needed to ensure adequate returns to investment from grid expansion, and affordability of supply. The type and design of subsidies is crucial for delivering a range of benefits, and includes the following features and considerations:

- Subsidies can be targeted at the capital costs of projects (usually through special purpose funds), the connection costs (e.g. delayed monthly payment of the connection fee over a long period), and cross-subsidies within the tariff system. The exact size of the subsidy needs to be carefully designed to avoid price distortions and accurately reflect consumers' ability and willingness to pay.
- **The tariff or subsidy policy should incentivise utilities providing adequate quantity and quality of supply**, such as 'output-based aid' mechanisms that

provide conditions on the financial support provided. This will also increase consumers' willingness to pay for the service.

- **Subsidies can be funded from contributions from the government and development agencies, or through cross-subsidies** between high- and low-income households, or between industry and households. That said, in many low-income countries there may be insufficient existing high-income consumers to make such a cross-subsidy viable.
- Financing from the government or development agencies also has to be sustained and guaranteed, to encourage long-term capital investments. The regulatory framework putting in place the revenue model needs to be credible and long term. Subsidies need to be fiscally sustainable, which can be a major problem if the subsidy consists of a fixed electricity price while the cost of the energy source (e.g. the price of oil) fluctuates.

Box J: Using output-based aid for realising quick gains in electrification in Ethiopia

In 2008, Ethiopia's national electricity coverage was only 7% and in rural areas only 2%. The government put in place a target of increasing access by 50% in five years (totalling 228,571 rural households), under a programme implemented by the state-owned utility Ethiopian Electric Power Corporation (EEPCo). By 2015, several serious challenges had slowed and halted progress, particularly due to a shortage of supply, and the programme had provided only about 43,000 poor rural households with a grid connection. These new connections were also relatively easy and cost-effective new additions, as the infrastructure was already in place. Despite this, the programme demonstrates an interesting approach to designing electrification programmes.

In Ethiopia, the upfront cost of connection is a more serious barrier than the monthly consumption charges, and only an estimated 35–40% of households in electrified areas are usually ready to connect. As part of an 'output-based aid' approach, a multi-donor grant provided a fixed subsidy of $35 per connection to EEPCo once they had made the connection, a five-year loan to the household covering the financing of the connection fee, as well as two free compact fluorescent lamps. They targeted households in areas which had been electrified for more than a year, as experience showed that households able to pay the connection fee would do so immediately. This programme demonstrates the importance of carefully designing a subsidy package to respond to the particular local balance between costs and willingness to pay for electrification.

Sources: Maurer and Nonay (2009); World Bank (2014)

Channelling investment into renewables

For various reasons – particularly the higher technology costs, often higher risks involved, and often distorted policies in favour of fossil fuels – renewable electricity projects typically have higher investment costs. However, there is a range of policy financial instruments that can overcome these barriers and attract new investment into renewable power generation. The following table provides an overview of the different price-based options:

Table 4.2: Overview of price-based financial instruments for renewable electricity

Instrument	Description	Key considerations
Feed-in Tariff (FiT)	A fixed rate is offered to renewable electricity producers for each unit of electricity fed into the grid. In most cases, the grid is obliged to purchase all renewable electricity, irrespective of demand (the 'purchase obligation'). Depending on the maturity of the market in a given country, capacity caps and tariff benefits can be put in place with the FiT.	Very common, particularly in developed countries. Need to balance providing security to investors and setting a long-term price to avoid excess profits accruing to investors, and flexibility to respond to cost changes. Need to include 'hidden' costs, such as grid-related and administrative costs.
Preferential tariff system	Includes FiTs, but also includes regular tariffs that are not fixed but the tariff methodology is favourable for renewables.	Same considerations as FiTs, although those without fixed rates are more complex and may not be guaranteed over the long term.
Net metering	Renewable electricity generated by individual consumers (households or industries) is as a priority consumed on-site and any excess is fed into the grid, which is obliged to absorb it.	Mostly the meter turns 'backwards' as excess electricity is fed into the grid, so the producer in effect receives the retail price of electricity, for power fed in. It is commonly used for rooftop solar, but can also be used for wind generators.
Auctioning	Competitive procurement process, whereby the government puts out a target amount of generation, and sometimes a particular renewable source, and private investors bid for the projects.	Auctions have resulted in lower price outcomes than directly and bilaterally negotiated deals but still require specialised technical capacity in government. They help develop a pipeline of bankable projects.
Direct investment support	Examples include loan guarantees, letters of credit, concessional loans, grants and tax incentives.	Should be seen as separate to pricing support, and can help overcome high initial investment costs.
National funds	Used for funding investment support, research and development, etc.	Can be funded by the state budget, development agencies, charges or levies on fossil fuels.

In addition to these price-based mechanisms incentivising the production of renewable electricity, there are quantity-based mechanisms (quotas) that require a fixed amount of electricity sold by suppliers to be generated from renewable sources and that then allow the market to determine the cost. However, they rely on a well-functioning electricity market to drive down costs based on the level of demand, which in many developing countries does not exist. They vary in design, but in general each company gets a specific quota based on a number of factors, and faces a penalty if they do not meet the obligation. It is usually accompanied by a renewable certification scheme that allows trading among companies to meet the obligation, providing a double financial incentive for using renewables.

There are also indirect ways of incentivising renewable electricity generation. Using a variety of policy measures, it is possible to include the 'external' cost of using fossil fuels in the final electricity generation costs. These 'external' costs, represent the unaccounted-for damage that fossil fuels cause to the environment and their impact on climate change. These schemes usually result in electricity prices increasing for consumers, and as such have not been widely considered as appropriate for developing countries in the short term.

Prior to introducing policies specifically incentivising renewable sources of electricity, removing policies which favour fossil fuels should be considered. In 2013 it was estimated that consumer subsidies for fossil fuels amounted to US$5.3 trillion globally, while subsidies for renewable energy amounted to US$121 billion (Coady *et al.*, 2015). This includes both direct government payments for fossil fuel generation and indirect incentives such as providing land, water and infrastructure at below-market rates. However, in developing countries, there needs to be a careful balance between expanding generation capacity using what appears in the short term to be the cheapest and quickest route and promoting renewable sources of generation.

Box K: Moving from feed-in tariffs to auctioning in South Africa

South Africa relies more on coal for electricity production than any other country, but the government has made a major push to attract private investment for expanding renewable electricity generation. In 2009, it began experimenting with FiTs designed to cover generation costs plus a real return on equity of 17%. Despite being considered generous, significant uncertainty remained, particularly with regards to the legal base for the tariffs, delays in finalising PPAs, and interconnections with the national utility.

As a result, the scheme was dropped in favour of competitive tendering under a Renewable Energy Independent Power Producer Procurement Programme. Within each procurement cycle, the government offered a specific amount of new power capacity, with capacity and price caps for different technologies. Bidders had to also meet certain economic development criteria, such as percentage of shares owned by black South Africans. Bids were evaluated by a large evaluation team and in a high security environment with 24-hour voice and video monitoring. The government overcame a lack of in-house capacity in running the auctions by using local and international transaction advisers. The process was professionally run, on time, and at each subsequent bidding round was improved. By early 2016, 92 grid-connected projects had been awarded to the private sector, with $19 billion committed to projects that total 6,327 MW of renewable energy-generating capacity. Prices thus fell to among the lowest in the world, with solar PV as low as USc 6.4/kWh, and wind reaching USc 4.7/kWh. Over four bidding rounds, solar and wind prices fell by 46% and 71% respectively (in nominal, local currency terms).

Sources: Eberhard (2013); Eberhard (2016)

International climate finance offers a new opportunity to address the barriers and risks that hold back private investment in renewable electricity generation. Developed countries have committed under the United Nations Framework Convention on Climate Change to jointly mobilise $100 billion a year by 2020 to support climate action in developing countries, including for new investment in renewable electricity. There are already several existing and planned dedicated climate funds and programmes, such as the $780 million Scaling-up Renewable Energy Programme, which provides concessional financing for private sector renewable projects. The multilateral development banks, which have a long history of supporting infrastructure development, have pledged to scale up climate finance to more than $30 billion per year by 2020. There are some emerging lessons for donors in selecting the type of financial instrument or approach for supporting private investment:

- The leverage should be maximised, i.e. using a minimum of public funds for the greatest amount of private funding;
- They should address the barriers and risks that are holding back private investment rather than just funding renewable projects, which could 'crowd out' private investment; and

- It is important to match the financial instrument with the capacity of local institutions and the financial market.

Box L: Leveraging climate finance to attract private finance in renewable electricity in Uganda

An effective partnership between the Government of Uganda, KfW, bilateral development agencies including DFID, and the World Bank is demonstrating an innovative approach to using climate finance to attract private investment in renewable electricity projects. The GET FiT programme launched in 2013 is fast-tracking a portfolio of around 20 small renewable energy-generation projects with a total installed capacity of up to 170 MW, using a number of funding levers. The Premium Payment Mechanism provides a top-up payment (above the normal sale tariff to the grid) for actual delivery of electricity to the national grid over 20 years, but front loaded and disbursed during the critical first five years. A reverse auction is also used for solar projects, where the government puts forward the amount of capacity it wishes to procure and provides a defined tariff, bidders put forward the amount they are willing to be paid, and the programme covers the gap in the tariffs offered by the successful lowest cost bidder. The World Bank's Partial Risk Guarantee Facility is available for successful projects to address off-taker and termination risks. The programme also has a technical assistance facility that is standardising legal documents for IPPs, strengthening skills for tariff modelling, procurement and contracting and undertaking other actions to support the overall enabling environment for private investment.

The GET FiT programme's success in establishing a promising portfolio of projects has prompted it to be rolled out to other countries, including Ghana, Malawi and Ethiopia. However, it remains to be seen whether and how it can operate on a sustained basis, when/if climate finance is no longer available.

Source: GET FiT Uganda Annual Report 2015 (available at www.getfit-reports.com/2015/)

4.3 Technology

4.3.1 Technological barriers to improving performance in the power sector

Technical barriers affect the design and operation of power systems and hence the set of feasible options available to public and private investors. They are often technology specific, relate to environmental constraints or to the advancement of technology. Sometimes they are insurmountable given the current state of science or certain geographical features, but informed policy-makers can take better decisions if they are aware of the limitations and the possible trade-offs.

An underdeveloped grid-connected power system, typically characterised by a low total installed capacity, poses operational challenges, which in turn impacts the reliability and affordability of the system. With a limited number of power plants on the grid, the utility is unable to adequately dispatch load to meet demand peaks and effectively diversify the electricity mix, which can increase the likelihood of power outages. Also, the system may lack a critical size for realising economies of scale. In 2012 in Sub-Saharan Africa, only 14 countries out of 48 had grid-connected power systems larger than 1 GW. Twenty-seven countries had systems smaller than 500 MW, and 14 countries had systems smaller than 100 MW (Eberhard *et al.*, 2016a). There is also often a lack of diversity in the generation mix (e.g. a dominance of hydropower in Sub-Saharan Africa), which leaves the system exposed to events such as droughts and price volatility on the international commodity markets.

Issues related to the grid capacity, grid integration and grid connection are increasing the risk perceived by investors and may be responsible for poor network performance. Grid capacity is driven by the network infrastructure and therefore varies nationally, regionally and locally. It determines the maximum amount of electricity that can be fed into the grid at every point in time and needs to be considered when planning new investments. Grid integration is particularly challenging for distributed renewables (particularly in small-scale networks) due to their intermittent and unpredictable production. Grid connection relies on the grid operator's capacity to provide the necessary infrastructure for the physical connection to the grid in a timely manner. The risk is that the power plant becomes ready to operate but cannot sell its electricity to the grid due to a delay in grid connection. This impacts cash flows and the financial viability of the project.

The financial viability of some renewable technologies has not yet been demonstrated in many developing countries as their track record is limited. Additionally, these countries often do not have reliable resource mapping at appropriate spatial scale or over time (e.g. historical data of wind speed or solar irradiance at different points in their territory). This historical data over several years is necessary to build confidence in the models used to track resource availability and to design power plants optimally. Investors therefore have limited confidence in the robustness of their models, which in turn increases the risk profile of their investment. Increasingly donors are considering opportunities to support mapping exercises focused on renewable energy resources (e.g. ESMAP's Renewable Energy Resource Mapping Initiative[4]).

The integration of renewables into the grid is a major challenge, particularly when 'weather-dependent' renewables account for a large share of the generation capacity (15% or more), and requires a transition toward a smarter grid, which brings additional technical and financial challenges (IRENA, 2013).

Renewables remain an expensive option in many developing countries and this affects the average tariffs the utility must pay (Bloomberg New Energy Finance, 2015). Due to the financial barriers mentioned above, relatively high tariffs have to be paid to IPPs to ensure the financial viability of renewable energy projects. Without government support, this may directly impact the financial position of the utility. As the share of weather-dependent renewables rises, utilities have to procure spare peak capacity or additional power storage systems to compensate for the unpredictable fluctuations of the production of renewables. As highlighted in Chapter 3, these systems are costly and the tariffs paid for these back-up IPPs are high, which can further strain on the utility's finances.

A challenge facing regional integration is the need to transport power over long distances, possibly over thousands of kilometres from one end of the power pool where the generation is in excess to the other end where demand would otherwise be unmet. This process entails large transmission losses. Using a Direct Current (DC) instead of the standard Alternative Current (AC) system for transmission interconnections between countries is an option. The use of DC for interconnectivity does not require the technically challenging synchronisation of the power systems (frequency, voltage and phase angle) and results in lower unit costs, as transmission losses are reduced and the line capacity can be lowered.

However, there is a trade-off between the simplicity of implementation and lower unit costs offered by the DC option and the additional costs of conversion stations at each end and loss of flexibility to tap off power at intermediate points for electrifying rural areas on the way (Economic Consulting Associates, 2010). Other constraints to regional integration include the location of the line and the topology to be traversed as well as the capacity of the line, which will cap the maximum power flow on interconnectors.

4.3.2 Technological opportunities for improving performance in the power sector

There are a large number of well-known and nascent technical options for improving performance. Technological interventions are often attractive to policy-makers because they appear the simplest to implement. In reality, any new technology will require an accompanying policy and regulatory framework, as well as strong institutions.

[4] See www.esmap.org/RE_Mapping

Distributed systems of supplying electricity

There is ongoing debate about whether universal rural access can be best met through grid expansion or off-grid systems, or different combinations of the two. In many developing countries, there seems to be an important role for off-grid systems in supplying electricity, particularly for the most 'hard-to-reach' and sparsely populated areas where the returns to investment of grid expansion are the most uncertain. However, off-grid systems bring their own set of investment constraints that need to be overcome.

Planning for electrification in a holistic and long-term manner, including both grid and off-grid systems, provides certainty to potential investors in off-grid that they will have sufficient time to recover their costs. This includes setting a long-term pathway to either full transition to an on-grid system or allowing both to co-exist in parallel. A comprehensive policy and regulatory framework sets technical standards, prices and minimum service obligations, as well as ensuring quality and reliability in the sector, taking into account any eventual need for a transition to the grid.

Further reading: A comprehensive mini-grid policy toolkit explains how to design an appropriate policy and regulatory framework for promoting investment in mini-grids, together with support tools such as tariff calculation models, legal templates and case studies (see: EUEI PDF, 2014).

The government needs to consider the long-term financial viability of the system they are establishing, both in terms of initial capital costs and maintenance but also the subsidies required to fill the likely deficit between the true cost of the system (usually more expensive than grid electricity) and the tariff. Section 4.2 outlined some of the financial instruments for overcoming this constraint, which can also be modified and applied for off-grid systems. Box M provides an example from Nepal where development agencies have provided financial and capacity support to boost the institutions charged with developing the sector.

Box M: Using 'grid-connectable' mini-grids to increase access in rural Nepal

The Government of Nepal has made concerted efforts to increase the electrification rate, which was 40% in 2002 and with most connections in urban areas. By 2012, 76% of the total population had access to electricity, albeit with a very unreliable supply and frequent blackouts (World Bank, 2012). In rural areas, much of the new access has been achieved through off-grid systems (estimated at 30% of rural connections in 2008). This was a strategic decision by the government as nearly one-third of the population live in such remote and mountainous locations that neither a road nor the national electricity grid will reach them for the next 5–10 years or more.

The Alternative Energy Promotion Centre was established in 2000. This delivered a more coherent and donor-supported approach to establishing isolated micro-hydro mini-grids with 5kW to 1MW capacity and standalone solar home systems. These mini-grids have been designed as a pre-grid electrification option, so when/if the grid is extended to these areas, the mini-grid can be directly connected to the grid. The off-grid sector in Nepal has not expanded as quickly as it could have, due to a lack of adequate investment, political instability and changing focus of donors. However, the experience still demonstrates the potential of off-grid systems for areas not expected to receive grid connection in the short term. It also shows the importance of designing a holistic long-term trajectory for the power sector as a whole, combining both on-grid and off-grid systems.

Sources: Palit and Chaurey (2011); Bhattarcharyya *et al.* (2015)

Off-grid systems provide different options for delivery and payment of electricity, and can be designed to provide more flexibility than grid connections for low-income consumers. The table below presents some tested business models for off-grid supply of electricity.

Table 4.3: Business models for off-grid supply of electricity

Mode of delivery	Financing / delivery options	Key characteristics
Mini-grid	Private enterprise-run renewable energy-based village-level mini-grids	Fully commercial model or franchisee model
	Community-managed mini-grid systems	Cooperative models, or NGO run. Requires technical skills and strong commitment within the community.
	Supply of power from diesel generators by private entities using temporary networks that serve just an individual event	Operate on a fully commercial basis – usually high tariff rates, poor technical efficiency
Stand-alone system	Rental fee based service by an ESCO	Hirer pays rental fee for renting out an appliance
	Leasing arrangement by an ESCO	'Owner' leases out use of equipment for generating electricity for a certain period for a flat fee
	Micro-finance-based scheme	Offers loans for the purchase of equipment for generating electricity
	Village energy kiosks	Kiosk acts as centralised power generation site, where various electrical devices can be charged for a fee
	Cash sales by retailers	Consumer buys equipment for generating electricity outright from company, plus sometimes pays maintenance charges

Even in grid-connected areas, governments can harness the potential of distributed generation to supplement unreliable electricity supply. In many developing countries, individual or groups of consumers, and particularly firms, have established captive power plants that serve their own needs and in most cases supplement a grid connection. Examples of captive generation include rooftop solar panels serving individual households, diesel generators switched on in the event of a power outage, and gas engines used in industrial facilities. Depending on the primary energy source being used, the relative costs involved, and the efficiency of the plant, captive generation can make a positive or negative contribution to the overall power sector.

In many cases captive power plants are producing more electricity than is needed by their individual user. This excess power can be fed into the grid, to support the overall balance of supply and demand in the country and/or supply neighbouring consumers via a mini-grid. Regulations and the tariff structure needs to be designed to incentivise such a set-up. For example, in Ghana the grid operator allows commercial and industrial clients to feed excess electricity into the grid and use grid electricity up to the same volume free of charge in the evening hours.

Box N: Improving the quality and reliability of electricity supply in Tanzania

Since 2012, a 3.5MW hydro-plant on the Mwenga River has been supplying electricity to the nearby Mufundi Tea and Coffee Factory, as well as underpinning network extension to 14 villages involving 120km of distribution lines. Around 75% of total output is exported to the national grid. This has not only helped increase access to reliable supply but also increased the capacity of the grid. Changes to national regulations on small power producers facilitated this by leading to standardised interconnection, PPA and tariff agreements, and simplifying the process of grid connection. This case illustrates the importance of governments considering mini-grids as an important contributor to the performance of the overall power sector, and putting in place the enabling environment to leverage their potential.

Increasing network efficiency

There are a number of technological options for improving network efficiency by reducing transmission and distribution losses, including non-technical losses.

- **Grid infrastructure improvements have the potential to increase efficiency**. These involve engineering decisions on how to manage generation, the distribution network and storage assets to deliver electricity efficiently.
- **Commercial losses caused by electricity thefts, illegal connections and meter tampering are potentially avoidable.** Smart metering coupled with effective information and communication systems can help address such problems. For example, to prevent illegal connections to the grid customers can be metered at the point of connection to the grid, meaning if theft occurs it happens 'behind' the meter and therefore is charged to the customer. Remotely read meters in secure boxes also limit the amount of tampering possible. 'Master' (statistical) meters within the distribution network can monitor flows across the network, and identify where losses are occurring. All this equipment is costly, but the costs could be offset by increased revenue flows.
- To avoid a potential backlash from communities, targeting non-technical losses can be accompanied by measures to increase the affordability of electricity (see section 4.2). Additional measures to overcome local opposition to a crackdown on illegal connections could be providing 'load-limited supply', whereby households are given, for a flat affordable fee, only enough supply for covering their basic requirements. This avoids the need for a utility to install and read meters and invoice customers.

Box O: Using mobile phone payments to top up pre-paid meters

Tariff connection is traditionally a problem in rural areas of Tanzania due to limited road network, consumers having low incomes, and theft being difficult to monitor. To overcome this, residential consumers are fitted with pre-paid meters that can be charged using their mobile phone. Customers have a unique meter and top-up either by purchasing cards from local vendors and sending details via mobile phone, or paying directly via a mobile phone M-Pesa account. Tariffs are aligned to national rates, and connection charges can be repaid via a zero-interest loan in stages.

Source: Vivid Economics and Arup (2015)

Facilitating grid integration of renewables

Electricity grids are designed to accommodate a certain amount of variability and uncertainty in supply, and with some slight operational adjustments can accommodate up to around 5–10% renewable capacity without significant challenge. However, as the share of renewables increases additional measures are required.

- **There are technical options for supporting integration, which come with associated costs**. However, with careful planning and supportive regulation, in principle these can be brought down to modest incremental costs (IEA, 2014). The choice of technology needs to match the performance requirements of the system, such as the existing demand and energy mix, and opportunities for increasing flexibility on the supply side (e.g. how easily it is to stop and start generation plants) and demand side (e.g. can level of demand be forecasted and adjusted). Figure 4.A in Annex B presents the range of measures that can be considered.
- **There are operational measures that can be used in the short or medium term for facilitating integration of renewables.** These include using automated control technology, which allows easy adjustments such as ramping up or down generation to respond to variability in the system, enhanced measurement and forecasting tools for monitoring weather and predicting demand to allow for forward planning of variability, and centralised dispatch controls to balance variability across the system. Fluctuations of renewable electricity production can be compensated for by the dispatch of peak load capacity, such as natural gas generation and energy storage capacity. These measures require a high degree of specialisation and capability within national institutions.
- **There are relatively simple and low-cost actions that can be taken to facilitate integration in the medium term at least**. This includes well-designed and properly implemented national grid codes, which define the performance of generating assets, operational and dispatch rules, and technical requirements for interconnection with the grid. In many cases, there are more fundamental constraints to grid connection that need to be addressed first, particularly the state of the distribution network. Investment in this fundamental infrastructure is a priority before introducing these advanced technologies.

4.4 Summary

The possible interventions available for increasing performance in the power sector deliver a range of benefits. So far they have been organised by their type: institutional, financial, technical or policy. The following table presents the opportunities also in terms of the long-term objective they deliver.

Table 4.4: Summary of barriers and possible interventions to increase power sector performance

Barriers	Opportunities	Performance objective					
		Unreliable supply	**Low rates of electrification**	**Unaffordable power**	**Low proportion of renewables**	**Inefficient use of electricity**	**Limited security of supply**
Institutions, regulation and policy, and the political economy: - **Lack of effective planning; capacity gaps in government institutions;** - **Structure of country's electricity market; absence or lack of independence of regulatory authority;** - **Regulatory and political risk as deterrent to investment;** - **Absence of competitive tendering;** - **Limited political will for regional integration.**	**Building institutional capacity: Individual level, organisational level, institutional environment and policy level**	X	X	X	X	X	X
	Locally led and driven reform of power sector	X	X	X	X	X	X
	Promoting gender-sensitive and inclusive power sector	X	X	X	X	X	X
	Efficient demand-side management: efficient appliances, tariff incentives, utility targets	X				X	X
	Promoting regional integration	X		X		X	X
Finance: - **Limited access to domestic finance due to limited maturity of domestic capital markets;** - **Financial viability of projects: inflation and high perceived risks;**	**Attracting private investment: Effective regulation, procurement process and financial health of off-taker utilities**	X	X		X		X
	Effective pricing regimes: Targeted subsidies, cost-reflective tariffs, socially acceptable tariff structure	X	X	X			

- **Investment barriers for renewables: limited track record of new technologies; fossil fuel subsidies; significant penetration of renewables;** - **Investment barriers to grid expansion in rural areas: High cost per unit;** - **Techno-economic constraints of off-grid systems.**	**Channelling investment into renewables: Price-based incentives, quantity-based measures, use of climate finance**	X	X	X
Technology - **An underdeveloped grid-connected power system: issues with grid capacity, grid integration and grid connection;** - **Limitations of renewable technologies: limited track record; grid integration; and high cost** - **Barriers to regional integration: transmission losses over long distances.**	**Distributed systems for supplying electricity, often relying on renewables**	X	X	X
	Increasing network efficiency: upgrading infrastructure, grid-connected mini-grids, smart meters	X	X	X
	Facilitating grid integration of renewables: operational and technology options	X	X	X

Annex A Glossary of terms

Base-load power plants – power plants that usually operate almost all-year round, have high fixed capital costs and low marginal costs of production, and limited flexibility to adjust their production within small periods of time. Includes nuclear and geothermal power plants.

Capacity factor – the capacity factor characterises the level of utilisation of a power plant compared to its maximum capacity production.

Captive capacity – generation unit installed by a firm (usually industry) or household to primarily serve their own electricity needs.

Carbon price – the amount that must be paid for the right to emit one tonne of CO_2 into the atmosphere.

Carbon tax – a tax directly linked to the amount of CO_2 emitted into the atmosphere. It is one of the market-based instruments enabling a carbon price to be established.

Centralised electricity system – a system in which a small number of large electricity-generating sites supply sufficient electricity via the national grid to meet national demand.

Climate finance – funding from developed to developing countries, channelled by national, regional or international entities, to support poorer countries to adapt to the impact of climate change and reduce GHG emissions.

Decentralised electricity system – a system in which a large number of small electricity-generating sites supply electricity to nearby consumers, either via the grid or off-grid, i.e. relying on distributed generation.

Demand centres – aggregated pool of consumers of electricity, typically in urban areas.

Demand-side management – measures which modify or reduce the amount of energy consumed.

Electric utility – public or private agency that operates one or more parts of the electricity system of generation, transmission, distribution and retail.

Electrical grid – an interconnected network enabling the delivery of electricity from suppliers to consumers, consisting of power plants, high-voltage transmission lines, and low-voltage distribution lines.

Electricity distribution – the final stage of delivering electricity to consumers: electricity flows from substations into a network of low voltage lines called the distribution network.

Electricity generation – the process of producing electricity, from sources of primary energy such as steam, gas, water and wind.

Electricity mix – the breakdown of electricity produced by energy source.

Electricity retail – the final sale of electricity to households and firms.

Electricity storage – technology usually used to store excess supply of electricity when demand is low, to be released when demand increases. Includes batteries and pump-storage hydroelectricity plants.

Electricity trade – electricity can be bought, sold and traded as a commodity on an electricity market. There can be trading between generators, retailors, large consumers and other financial intermediaries both for the short-term delivery of electricity and future delivery periods.

Electricity transmission – the transporting of bulk electricity from a generating site to a substation, via a network of high-voltage lines called the transmission network.

Electrification – the process of extending the network and providing electricity connections to households and firms.

Emissions trading scheme – a market-based approach to control pollution by putting a ‘cap’ on the amount of emissions allowed in the system, and allowing trading among entities to meet this cap. Also known as a ‘cap and trade’ scheme.

Energy poverty – a situation wherein individuals or households do not have adequate access to modern energy to provide for their basic needs, such as lighting, cooking and heating.

Energy security – the uninterrupted availability of energy sources at an affordable price. This is usually defined at the macro/national level.

Feed-in tariff (FiT) – A policy to encourage the deployment of renewable electricity, which typically involves guaranteeing a higher price to the IPP and a purchase obligation, i.e. all of the electricity produced is sold to the grid.

Grid parity – is reached when the LCoE of a particular technology is lower or comparable to the average cost of electricity fed into the grid.

Grid stability – is achieved when generation (supply) and consumption (demand) of electricity are balanced. Grid instability usually leads to voltage fluctuations and in most extreme cases to power outages.

Independent Power Project (IPP) – power projects that are, in the main, privately financed, developed, constructed, operated and owned. In the absence of a wholesale market, they usually seek long-term PPAs with a utility or another off-taker.

Intermediate load power plants – power plants that can adjust their production within a few hours so as to follow the main daily variations and meet most of the demand peaks. They usually have relatively low fixed costs and high marginal cost of production. Includes some coal and gas-fired power plants.

Levelised cost of electricity (LCoE) – technical parameter reflecting the average cost of capital per unit of electricity generated over the lifetime of the power plant.

Load dispatch – allocation at every point in time of the required generation capacity to meet the level of demand, at the lowest possible cost.

Mini-grid – network comprising local generation, storage, and electrical lines supplying electricity to a group of consumers. Mini-grids are usually independent from the main network, which is typically controlled by an electric utility.

Net metering – a billing mechanism that credits consumers who generate their own electricity (e.g. through rooftop solar panels) and feeds any excess electricity to the grid.

Non-technical losses or commercial losses – loss of electricity within the system due primarily to theft or insufficient revenue collection.

Off-grid – when electricity is generated and used locally within a stand-alone system, and is not carried via the transmission and distribution network of the grid.

Off-taker – any private or public entity that agrees to buy a certain proportion of the future generation, at an agreed price, from an IPP. The contract formalising the agreement is called an ‘off-take agreement’.

On-grid – when the electricity produced is carried via the main transmission and distribution network to the final consumer.

Output-based aid – a form of results-based financing where payment is linked to the delivery of specific services or outputs.

Peak load power plants – power plants that are able to adjust production levels within up to a few minutes. They are switched on to serve the marginal demand, which cannot be forecast, and they usually have a high marginal cost of production. Includes gas, oil and mountain dams.

Power pool – An association of two or more electric networks operated by different utilities and having an agreement to coordinate operations and planning for improved reliability and efficiencies.

Purchase obligation – when the grid operator is obliged to purchase all electricity produced by a given IPP, irrespective of demand. This instrument is often used to promote renewables.

Power Purchase Agreements (PPAs) – a contract between two parties, i.e. the producer and the off-taker of electricity, setting out terms such as delivery timeline and price.

Renewable electricity – the generation of electricity from resources that are naturally replenished, such as sunlight, wind, water flow (tides, waves or river current) and geothermal heat.

Smart grid – involves a two-way communication between the utility and the end-customer through the grid thanks to the inclusion of digital technology: the performance of the system is monitored in real time, in particular local changes in production or consumption, so as to adjust the load dispatch automatically within seconds.

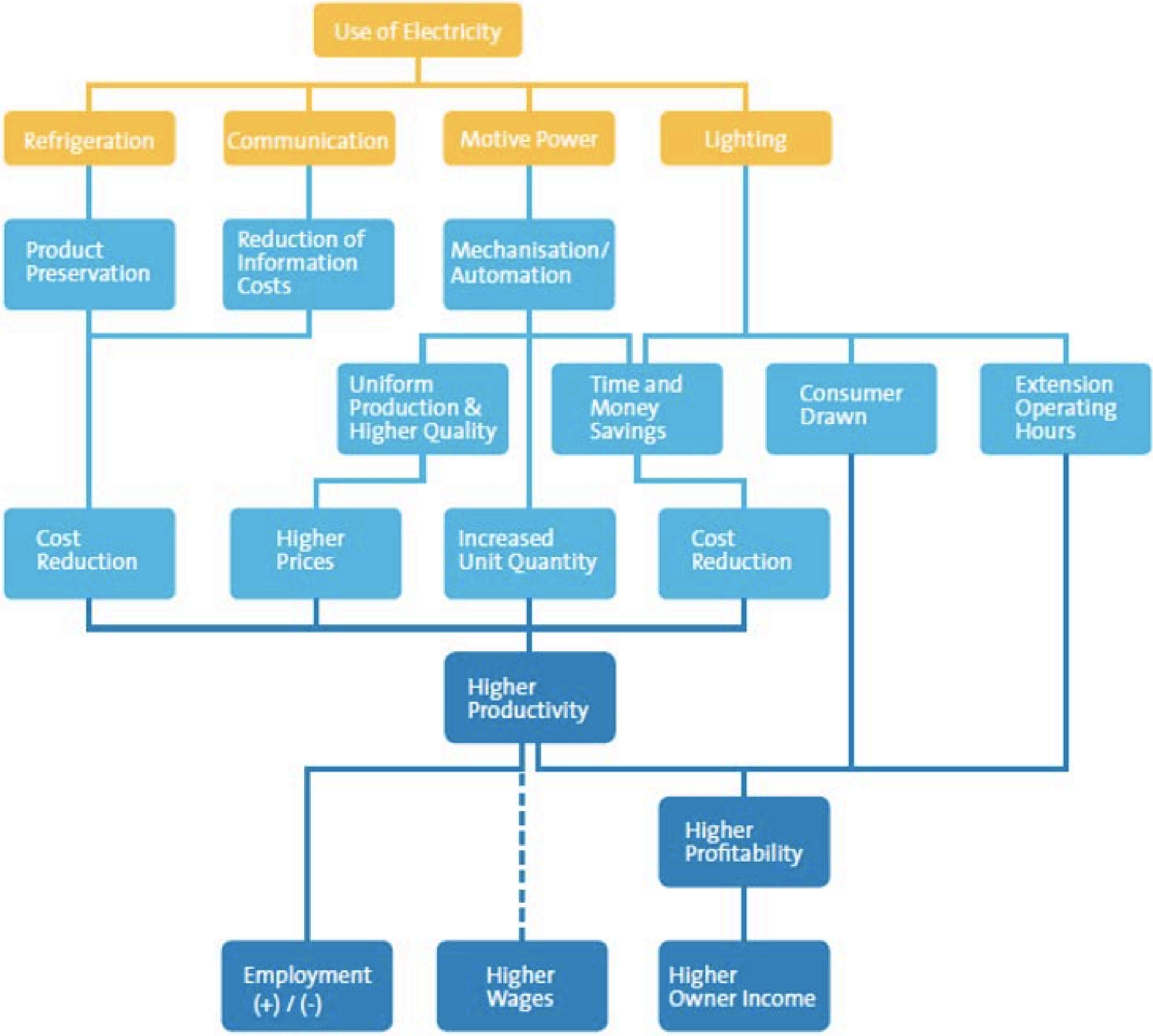
Technical losses – loss of electricity as it travels through transmission and distribution lines. Some amount of technical loss is unavoidable given the very nature of electricity. Excess technical losses arise from poor network maintenance, obsolete infrastructure or inefficiencies in the network design.

Unbundling – involves splitting the different operations of vertically integrated utilities (often controlling generation, transmission, distribution and retail) into stand-alone entities, in order to allow some degree of competition in relevant segments of the power value chain.

Annex B Supplementary figures and boxes

Section 2

Figure 2.A: Pathways from electricity to income generation



Source: Pueyo and Hanna (2015)

Section 3

Box 3.A: Comparative advantages of rate-of-return, price-cap and revenue-cap regulations

Regulating the grid must aim at providing the right incentives to reach an optimal situation between competing objectives: (1) rationalisation of costs through efficiency savings; and (2) a sufficient level of investment in the grid to ensure the quality of the service.

Traditionally, grids (as other monopolies) have been regulated through the 'cost-plus' or 'rate-of-return' approach: tariffs are set so that the regulator can cover its costs, including a reasonable rate of return on the capital invested. This reduces the risk facing the investor, which lowers the cost of capital, However, it prevents the regulator from setting tariffs, does not provide incentives to rationalise costs and make efficiency gains, and may lead to an overinvestment in the network. The latter benefits the quality of the service but may lead to high tariffs.

Price-cap regulation enables the regulator to set a cap on the grid tariffs allowed over a specified commitment period (e.g. five years). This strongly incentivises cost savings but may result in underinvestment, and entails more risk for the investor.

Revenue-cap regulation is found in many US states and in some Chinese provinces and is similar in allowing the operator to change relative prices for the electricity sold (depending on time of day, customer, etc.) as long as the percentage of change in revenues does not exceed the revenue-cap index.

In practice, these different approaches may be combined, so as to achieve the appropriate level of risk for the grid operator and accommodate the regulator's objective. This explains why grid regulatory frameworks vary significantly between countries.

Sources: FS-UNEP Collaborative Centre (2015); Crossley (2015); Jamison (2007)

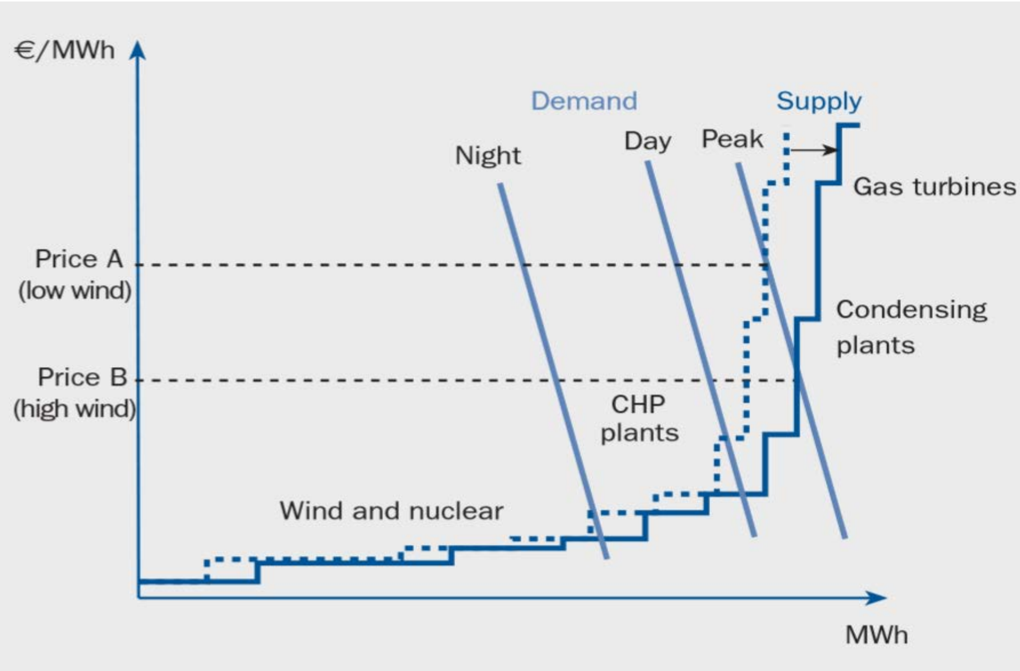
Box 0.B: The merit order effect

When there is a slight increase in demand, the power plant with the lowest short-run marginal cost (within the pool of grid-connected power plants that are not producing at that point in time) is turned on to serve the increased demand. The electricity price paid to producers on the wholesale market increases to the marginal cost of the last power plant turned on, i.e. the 'marginal' power plant.

As shown in Figure 3.A, power plants are ranked according to their short-term marginal cost of generation and only those with a marginal cost lower than the spot market price will produce. The contribution margin (green arrow) represents the additional profit that accrues to power plants with lower marginal costs and enables these plants to refinance their investment. This profit can be lost if significant renewable energy changes the 'merit order' for power.

As a rule of thumb, marginal costs are close to zero with renewables and increase with the following technologies: nuclear, coal, gas and oil. The recent high penetration rate of renewables in some countries poses a challenge to the financial sustainability of the spot market. Indeed, renewables sometimes represent a substantial share of the daily energy mix, pushing the spot market price down (dotted marginal cost curve) and making it difficult for all power producers to re-finance their investment.

Figure 3.A: Merit order effect



Source: EWEA (2009)

Box 0.C: Power sector reform, unbundling and liberalised markets

The liberalisation of one or more segments of the power sector has yielded significant long-term economic benefits in many countries and has contributed to improvement in the performance of their power systems. Below are two illustrations:

- Ensuring that the average tariff paid to the different stakeholders in the value chain is cost-reflective fosters investments in, among others: (i) new generation capacity to serve a growing demand; (ii) operation and maintenance of the existing infrastructure, thus increasing the reliability of the system and decreasing excess technical losses; and (iii) expansion of the grid through new connections and reinforcement at higher voltage levels.
- Increasing the competition among actors fosters efficiency gains that result in a decrease of the final retail price. In developing nations, where tariffs are often not cost-reflective for socioeconomic reasons, these efficiency gains can translate into a decrease of the total electricity subsidy required, which frees up resources for addressing other social issues.

Liberalisation of power markets entails the unbundling of vertically integrated (and state-owned) utilities as well as the creation of strong institutional, regulatory and legal frameworks for competitive markets. Empirical evidence indicates that a significant degree of unbundling is needed in order to ensure non-discriminatory access to the networks and to avoid conflicts of interest existing within a vertically integrated sector.

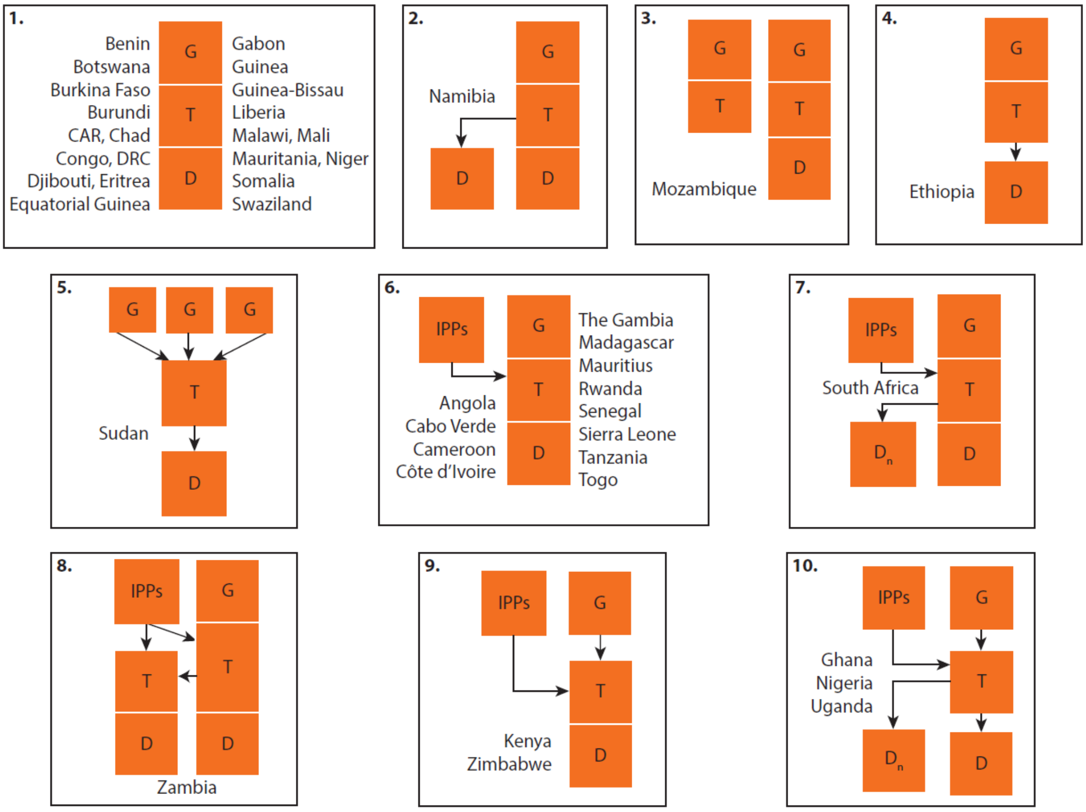
Power sector reform is a slow process, however. It can be rolled out in stages and requires continuous political will to resolve challenges when vested interests and cross-subsidies are unwound. The establishment of an independent regulator and an unbundled system operator must precede the liberalisation of the full power market, failing which subsequent power reforms can be undermined. Additionally, policies, strategies and plans for the sector must be clearly laid out and transparently communicated to lower uncertainty and thus boost investors' confidence.

Without a holistic approach, competitive markets can fail to deliver on other key policy goals, such as increased sustainability and affordability or access for the poorest. One of the most critical challenges facing policy-makers is therefore reallocating some of the benefits of liberalisation to ensure equitable access to electricity and to incentivise the power sector to deliver on environmental policy goals and trigger technical progress.

While the attention focuses on the liberalisation of the power market, substantial efficiency gains can be realised through institutional reforms even if the market is not fully privatised, unbundled or liberalised. Despite failure to implement the liberalisation model in Africa in recent decades, there are some success stories in 'hybrid' markets, such as the Ugandan 'Get FiT' and South African 'Energy Independent Power Project Procurement Programme'. These suggest that it is possible to create an environment that is conducive to private sector participation yielding substantial outcomes when the market entails a certain level of unbundling and sufficient degree of competition.

There is no one-size-fits-all hybrid model, as the new organisation of the sector needs to be driven by the pre-existing conditions in the country. The figure below illustrates the different configurations that might exist. However, all hybrid models introduce some level of unbundling to create a competitive setting in the generation and/or distribution segments and rely on an independent regulatory authority to promote a fair and transparent regulation of the sector.

Figure 3.B. Electricity sector structures: Sub-Saharan Africa, 2014



Source: Compiled by the authors, based on various primary and secondary source data.
Note: Includes vertical integration or unbundling of generation (G), transmission (T), and distribution (D) and presence of IPPs. While there are 48 Sub-Saharan African countries, the Comoros, Lesotho, São Tomé and Príncipe, and the Seychelles are excluded from figure 3.1. Thus the three island states are not included, along with Lesotho, where the national utility, Lesotho Electricity Company (LEC), has only T&D assets. A separate generation plant, the Muela Hydroelectric Station (72 MW), is owned and operated by the Lesotho Highlands Development Authority (owned by the government of Lesotho). These countries otherwise form part of the overall analysis. It should be noted that Kenya also has an unbundled transmission company, the Kenya Electricity Transmission Company Limited (KETRACO), which is responsible for new transmission assets. Furthermore, Uganda has one large, privatized distribution utility supplied from the transmission grid and some regional distribution companies not connected to the main transmission grid. Finally, some of the countries listed in model 1 can, in principle, allow private investments, but as of yet do not have IPPs. CAR = Central African Republic; Congo = Republic of Congo; DRC = Democratic Republic of Congo; IPP = independent power project; MW = megawatt; T&D = transmission and distribution.

Source: Eberhard *et al.* (2016); IEA and OECD (2005)

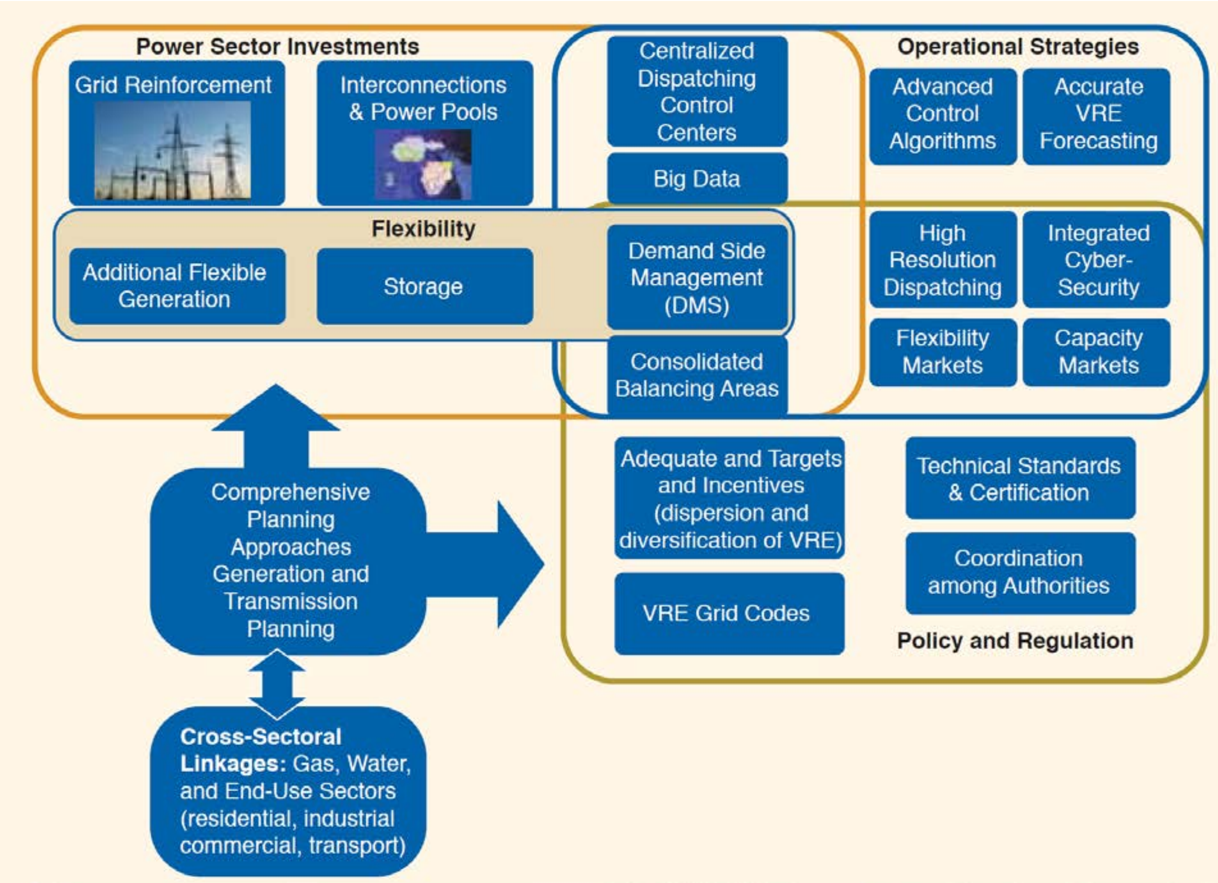
Section 4

Table 4.A: Framework for understanding capacity

	Capacity creation	Capacity utilisation	Capacity retention
Individual level	Development of adequate skills, knowledge, competencies and attitudes	Application of skills, knowledge and competencies in the workplace	Reduction of staff turnover, facilitation of skills and knowledge transfer within institutions
Organisational level	Establishment of efficient structures, processes and procedures	Integration of structures, processes and procedures in the daily workflows	Regular adaptation of structures, processes and procedures
Institutional environment and policy level	Establishment of adequate institutions, laws and regulations	Enforcement of laws and regulations for good governance	Regular adaptation of institutions, laws and regulations

Source: Oxford Policy Management (OPM)

Figure 4.A: Range of measures to reduce and manage variability and uncertainty in relation to renewable power



Source: ESMAP (2015)

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