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From electricity grid to broadband Internet: Sustainable and innovative power solutions for rural connectivity

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2023

Acknowledgements

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Foreword

Information and communication technologies (ICTs) play a critical role in achieving the 2030 Agenda for Sustainable Development.

The availability of energy is indispensable to the ICT sector, its services and applications. Electricity is needed for most ICTs, for recharging devices, powering mobile base stations, running data centres and network operations, just to mention a few. Access to reliable and affordable electricity remains a major constraint, especially in the world's least developed countries (LDCs), landlocked developing countries (LLDCs), small island developing states (SIDS), and in rural and remote areas where people stand to benefit most from the transformative power of ICTs, but where access to grid electricity is rare and incomes are low.

There is a symbiotic relationship between energy and Internet connectivity in locations that remain unconnected, particularly because off-grid business models rely on connectivity for remote management. Furthermore, connectivity business models benefit from the increased use of mobile services, especially financial services.

Electricity networks can also be leveraged to extend national and rural broadband backbones. Infrastructure sharing, and reuse can be an important tool to save costs and expand services, thus highlighting the importance of cooperation and coordination between the ICT and energy sectors to connect rural areas.

Although a wide range of renewable energy sources exist, delivering that energy by traditional methods can be expensive. The prohibitive cost of installing and maintaining electrical lines and cables often leaves many people in rural areas without a reliable power source. In such situations, space and new broadband satellite technologies, innovative solutions such as wireless power transmission systems may offer a path to cost-effective Internet connectivity.

ITU is committed to working with stakeholders on improving broadband Internet connectivity, finding innovative ways to deliver clean energy safely and efficiently to rural and remote areas, and delivering on the climate objectives set out in the Paris Agreement in 2015.

We are calling on governments, policy-makers, and regulators to review their national broadband plans accordingly. The guidelines in this document are designed to assist Member States, regulators, and private-sector stakeholders in upgrading their networks and integrating the appropriate use of modern and more energy-efficient networks, including wireless electricity (transport of electrical energy without wires) and power-line communications. In particular, the guidelines will be useful for the ITU Connect 2030 Agenda, to connect every school, every hospital, every administration, business, and community institutions to the Internet, and, with a view to supporting countries to gear up to developing greener ICTs, smart green communities and smart grids that can serve to build more controllable and efficient energy systems.

Dr. Cosmas Luckyson Zavazava
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Executive summary

Access to electricity is key to closing the digital divide in rural areas and developing an information society for all. The availability of reliable and affordable electricity remains a major impediment, especially in the world's least developed countries (LDCs), landlocked developing countries (LLDCs) and small island developing states (SIDS), and particularly in rural and remote areas. Access to electricity and broadband connectivity, including services and applications based on information and communication technologies (ICTs), plays an important enabling role in efforts to achieve the Sustainable Development Goals (SDGs) and connect the 2.7 billion people around the world currently without access to the Internet.

Without electricity, people cannot access the Internet and thus benefit from the digital transformation of the modern economy, including the education, health, agricultural and trade sectors.

This report examines the challenges of providing access to electricity, which is vital to connecting rural areas to the Internet.

Lack of access to electricity in rural areas – primary challenge

- Access to the electricity grid is:
  - unavailable
  - unreliable
  - unaffordable.
- Extension of grid into rural and remote areas is not economically viable, owing to:
  - expensive and extensive grid transmission and distribution networks
  - low population density, scattered population – dispersed homes
  - poor population – low tariffs
  - poor return on investment
  - lack of infrastructure investments and financing.

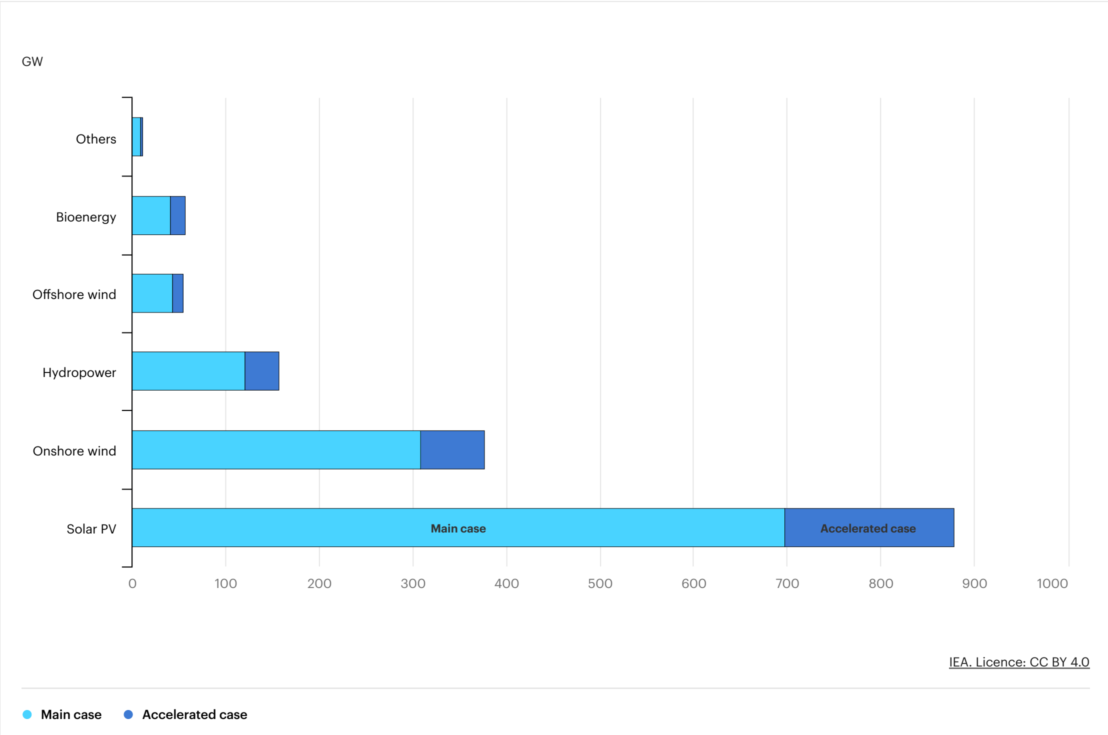
Infrastructure challenges to rural electrification

- Remote and challenging geography and terrain
- Lack of reliable, affordable and secure adjacent infrastructure, such as the electricity grid
- Lack of mobile Internet coverage or fixed broadband wireless access networks, and no access to international bandwidth
- Lack of ICT facilities in rural communities
- Limited and distant power charging locations for mobile devices and Internet ICT appliances
- Limited off-grid power solutions – unreliable diesel-generator supply, and intermittent renewable energy solutions.

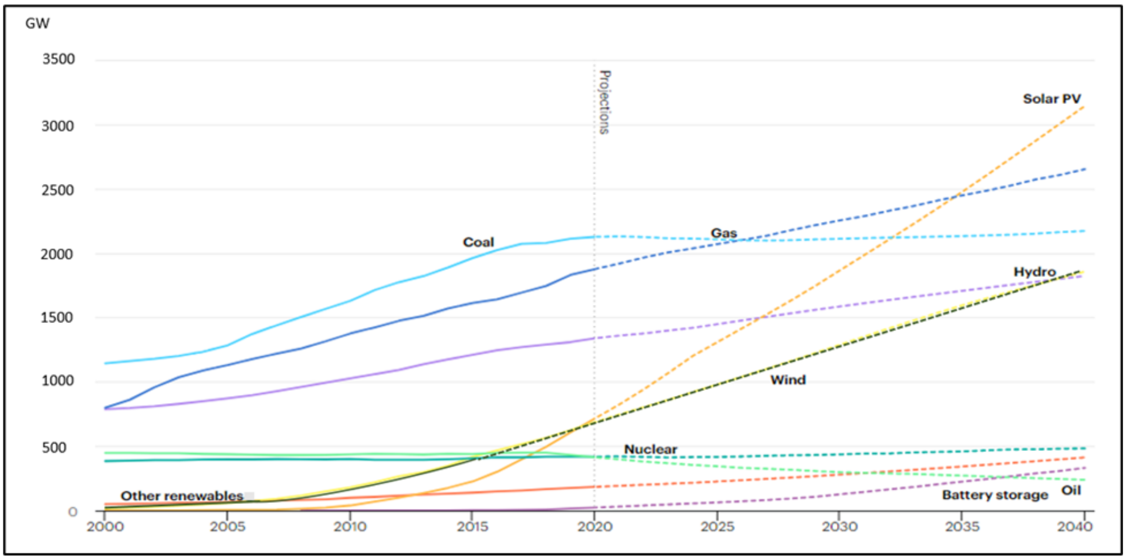
Challenges of extending the electricity grid in rural areas

- The national electricity grid can only be extended in densely populated areas
- Sufficient potential demand is needed to justify the high investment costs for transmission and distribution lines
- Grid-based retail electricity tariffs – subsidized and non-subsidized tariffs.

To improve access to electricity, sustainable and innovative power solutions for rural connectivity are needed that focus on renewable energy sources for rural electrification, lowest-cost sources such as solar power (photovoltaic cells) and wind, as well as other sources of clean energy (hydroelectric power, geothermal energy and biomass). The graph below shows projections of the world's renewable energy capacity growth between 2019 and 2024.



Source: IEA, Renewable capacity growth between 2019 and 2024 by technology.
Installed and projected power generation capacity, by source, 2000-2040



In this context, new technology such as wireless power transmission (WPT) can be considered for providing cost-effective Internet access. ITU standards for smart energy solutions, such as Recommendation ITU-T L.1380, focus on smart energy solutions for telecommunication sites, in particular the performance, safety, energy efficiency and environmental impact of systems fed by energy from sources such as photovoltaic (PV) cells, wind turbines, fuel cells and the grid. The Recommendation also considers smart energy control; for example, if the grid is off, ways of managing energy flows to achieve higher energy efficiency and sources of green energy.

Recommendation ITU-T L.1210 sets out power-feeding solutions for 5G, converged wireless and wireline access equipment and networks, taking into consideration their enhanced requirements relating to service availability and reliability, and new deployment scenarios, along with the environmental impact of the proposed solutions. This Recommendation applies to means of powering mobile and fixed access network elements, in particular equipment with similar configurations and needs.

Recommendation ITU-T L.1382 aims to accelerate network deployment, reduce capital expenditure (CAPEX) and operating expenditure (OPEX), optimize investment efficiency, and guide ICT industry transformation and optimization. The new networking architecture, power supply technologies and specifications contained in the Recommendation will also effectively promote the upgrading of industry technologies.

Last but not least, multiple energy inputs such as PV panels, wind, fuel cells, the electrical power grid, power generators and batteries can be connected to a single system. Recommendation ITU-T L.1381 considers smart control solutions for these different energy inputs to increase energy efficiency and decrease carbon emissions. In addition, for smart cooling systems, the Recommendation considers the use of external air for cooling purposes and ways to optimize cooling solutions for ICT equipment, including ICT rack cooling, row cooling methods and liquid cooling.

1 Background

The World Telecommunication Development Conference 2022 (WTDC-22), held in Kigali, Rwanda, adopted "Affordable connectivity" as priority number one for the ITU Telecommunication Development Sector (ITU-D). The focus of this priority is on the use of modern, available, secure, accessible and affordable connectivity through deployment of telecommunication and information and communication technology (ICT) infrastructure and services for bridging the digital divides. The priority aims to foster the development of infrastructure and services by utilizing existing as well as new and emerging telecommunication/ICT services and technologies and new business models. In this process, assistance is provided to Member States to enhance and strengthen confidence and security in the use of telecommunications/ICTs.

As the world welcomed its 8 billionth inhabitant on 15 November 2022, an estimated 5.3 billion people – around 66 per cent of the world population – were already using the Internet. But that leaves some 2.7 billion people worldwide totally offline, with universal connectivity still a distant prospect in least developed countries and landlocked developing countries, where, on average, only 36 per cent of the population is online, according to the ITU Facts and Figures 2022 edition, released on 30 November 2022.

And while data show slow but steady growth in fixed-broadband subscriptions, mobile continues to dominate as the platform of choice for online access, particularly in low-income countries where wireline connections can be scarce and costly, notably for those living outside major urban centres.[1]

Connectivity is energy-intensive and will not develop without access to power, in particular affordable, reliable and scalable sources of power. According to the United Nations,[2] the world continues to advance towards sustainable energy targets. But the current pace of progress is insufficient to achieve Goal 7 of the Sustainable Development Goals (SDG 7), which seeks to ensure access to affordable, reliable, sustainable and modern energy for all by 2030. A major push is, therefore, needed.

Target 7.1 of SDG 7 aims to ensure universal access to affordable, reliable and modern energy services; Indicator 7.1.1 focuses on the proportion of the population with access to electricity. Target 7.2 aims to substantially increase the share of renewable energy in the global energy mix. Target 7.3 aims to double the global rate of improvement in energy efficiency by 2030.

A concerted global effort will be required to achieve the goal of affordable universal connectivity, particularly in developing countries. The world's focus is now on efforts to promote "meaningful universal connectivity", which seeks to promote the benefits of online participation while mitigating the potential disadvantages of digital connectivity. In its 2019 report, the United Nations Broadband Commission for Sustainable Development recognized broadband access as critical to efforts to achieve the SDGs. In addition to simply being available, broadband access needs to be accessible, relevant and affordable, and must also be safe, trusted, empowering to users and deliver positive impacts. [3]

1 ITU, Measuring digital development: Facts and Figures 2022.
2 United Nations, The Sustainable Development Goals Report 2022.
3 ITU/UN, ITU/UNESCO The State of Broadband: Broadband as a Foundation for Sustainable Development, ITU/UNESCO, 2019

The uptake of broadband services is predominantly constrained by the fact that most of the unconnected population live in rural and remote areas without access to the electricity grid, which would provide an affordable source of power for mobile base stations. ITU has determined that the expansion of digital telecommunication services in rural and remote areas is primarily driven by technological and economic considerations relating to the provision of mobile services.

Furthermore, beyond economic and technological considerations, the expansion of digital penetration is key to achieving several of the SDGs, such as those relating to education, health, financialization, empowerment of women, access to knowledge, services and goods. Technological innovation in the information technology and clean technology fields aims to close the digital gap.

2 Introduction

Access to broadband Internet has the potential to transform lives and create opportunities, with a positive economic and social impact on communities and families.[4],[5] High-quality, high-speed data transmission can foster structural change in vital sectors of the economy. It is not merely a convenience: broadband access can provide underserved and unserved communities with access to vital information and services, and create opportunities that benefit community businesses, education, health and livelihoods.

The Broadband Commission for Sustainable Development views broadband as fundamental to addressing the global challenges highlighted in the SDGs. The Commission considers broadband to be one of the strongest and most effective tools to implement transformative solutions to promote sustainable development, address gender equality and foster a low-carbon economy.

ITU estimates that 66 per cent of the world's population, or 5.3 billion people, were using the Internet in 2022[6] (see Figure 1). At the regional level, in the countries of Europe, the Commonwealth of Independent States (CIS) and the Americas, between 80 and 90 per cent of the population uses the Internet. In the countries of the Arab States and Asia-Pacific regions, around two-thirds of the population (i.e. 70 and 64 per cent respectively) uses the Internet, while the average for Africa is just 40 per cent of the population.

When grouping countries by their level of development, universal connectivity remains a distant prospect in LDCs LLDCs, where only 36 per cent of the population is currently online (see Figure 2). Inequalities in access to fixed connections across countries are far higher than for mobile connectivity. While fixed connections are common among households in upper-middle-income and high-income countries, they are nearly non-existent in low-income countries, because of high prices and a lack of infrastructure.

Governments, industry and communities recognize that the lack of affordable access to electricity poses a major barrier to the further penetration of broadband services into rural and remote areas in developing countries.[7] As a result, providing access to affordable energy in these underserved and/or unserved communities is a crucial step to ensuring universal access to broadband services.

The growth of the renewable energy sector is creating tremendous opportunities to implement off-grid, locally sourced, clean energy solutions using solar power, wind and other renewable sources. Access to these reliable and affordable forms of energy not only reduces the operating costs of telecommunication sites and ICT facilities, but also contributes to alleviating poverty and promotes the social and economic development of rural communities.

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4 OECD, *Broadband and The Economy, Ministerial Background Report* DSTI/ICCP/IE(2007)3/ FINAL
5 World Bank, *Connecting for Inclusion: Broadband Access for All*, September 18, 2015
6 ITU, Measuring digital development: Facts and Figures 2022.
7 http://broadbandcommission.org/Documents/ITU_discussion-paper_Davos2017.pdf

Figure 1: Individuals using the Internet, 2005-2022

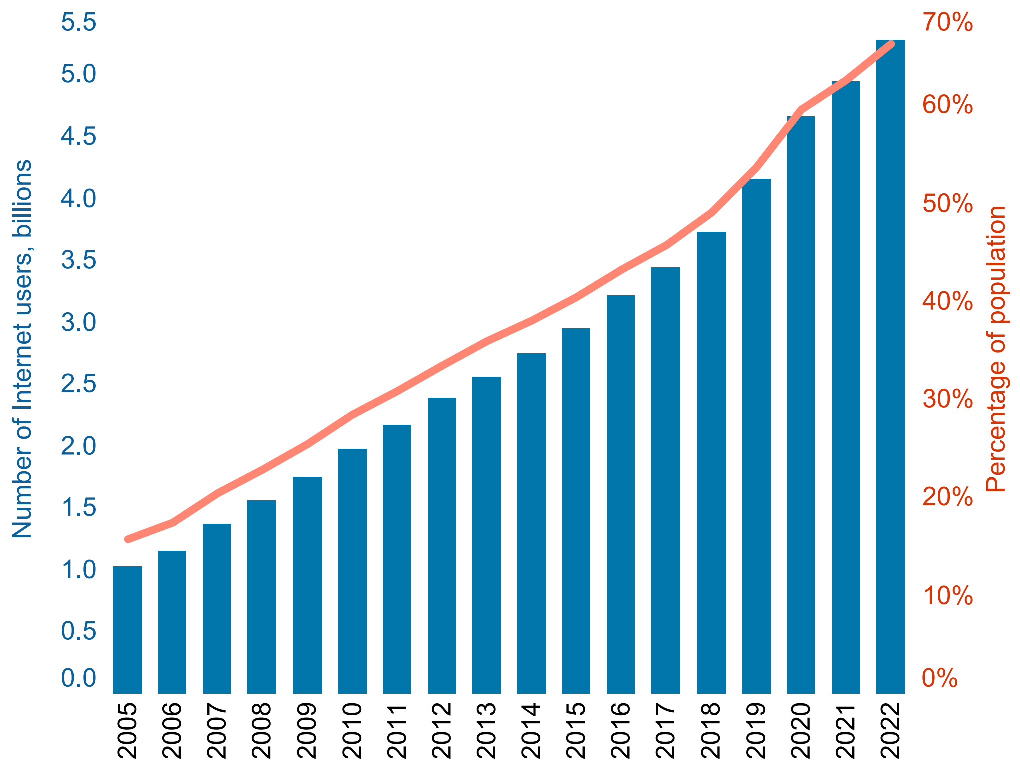
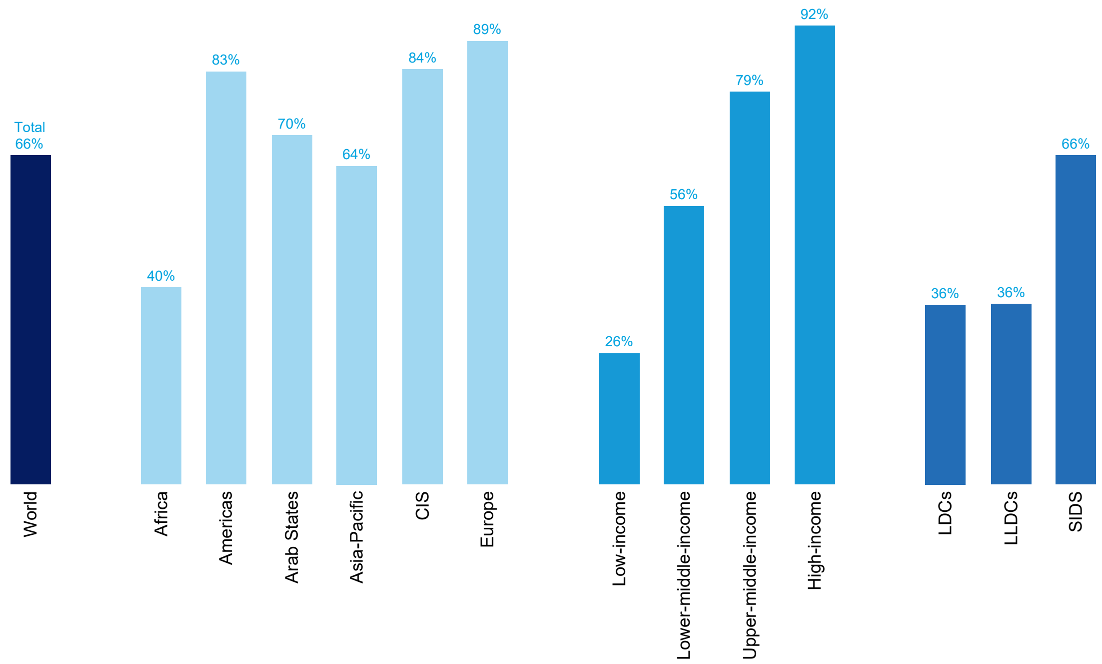


Figure 2: Percentage of individuals using the Internet, 2022



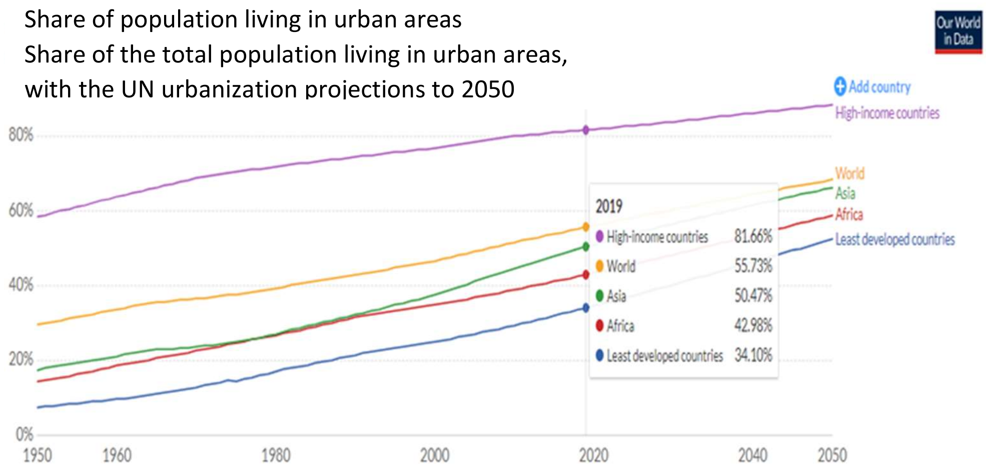
3 Status of broadband access in rural areas

3.1 Urbanization – migration of the population from rural areas

According to United Nations statistics, 4.2 billion people, or 55 per cent of the world population, lived in urban areas in 2018. The level of urbanization in Asia stood at about 50 per cent, while Africa remains mostly rural, with 43 per cent of its population living in urban areas (see Figure3)

UN projections predict a gradual population drift from rural to urban areas, which could result in an additional 2.5 billion people moving to urban areas by 2050. Most of this increase (estimated at 90 per cent) is predicted to take place in Asia and Africa. Globally, the rural population grew to 3.4 billion in 2018; after several more years of growth – as shown in Figure 4 – it is projected to decline to 3.1 billion by 2050.

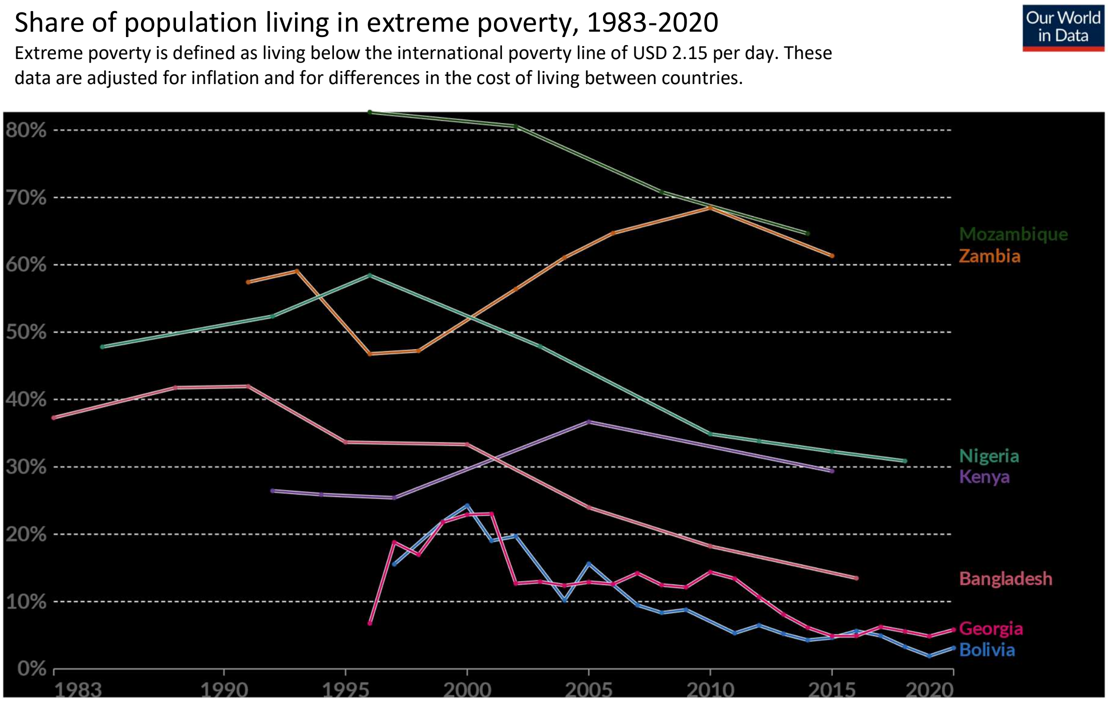
Figure 3: Share of population living in urban areas



Source: Our World in Data (https://ourworldindata.org/)

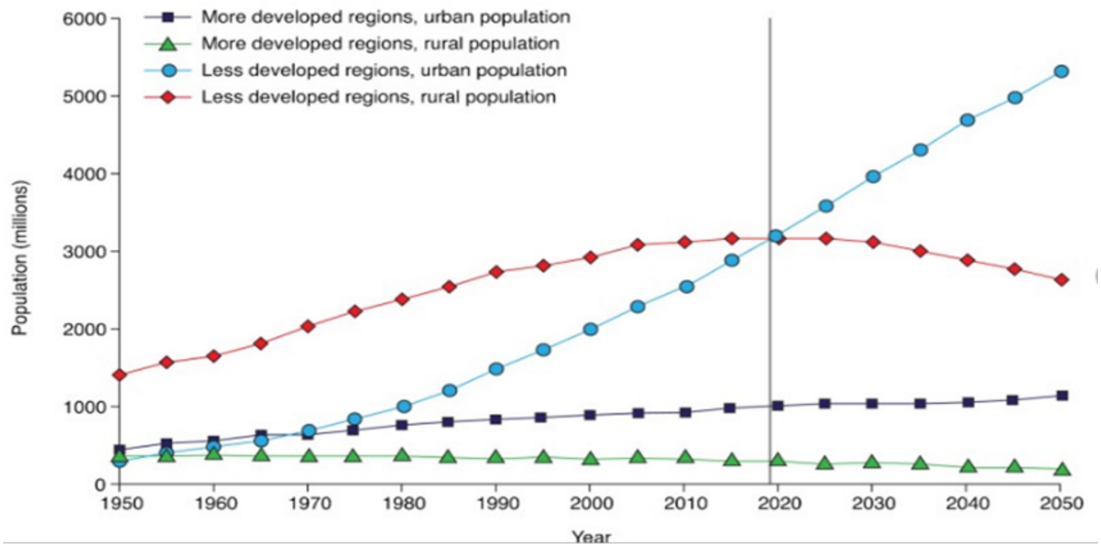
Share of population living in extreme poverty, 1983-2020

Extreme poverty is defined as living below the international poverty line of USD 2.15 per day. These data are adjusted for inflation and for differences in the cost of living between countries.



Source: World Bank Poverty and Inequality Platform
Note: These data are measured in international USD at 2017 prices. They relate to disposable income or expenditure per capita (exact definitions vary).

Figure 4: Share of population living in urban areas



Source: Our World in Data, based on UN World Urbanization Prospects 2018 and historical sources. Urban areas are based on national definitions

3.2 Infrastructure in rural areas

Investment in infrastructure plays a major role in economic development: roads, electricity generation and supply, other utilities, communications and digital broadband infrastructure all underpin sustainable development efforts and the economic transformation of emerging economies. In order to foster shared prosperity, it is essential that the social and economic benefits enjoyed by urban dwellers are equitably shared with the rural population to reduce drift from rural to urban areas. To ensure that the benefits of economic development and the digital society are available to all citizens, whether they live in urban, rural or remote island communities, it is crucial to develop an interconnected and integrated urban-rural infrastructure that bridges the divide between a higher-earning urban population and poorer rural communities.

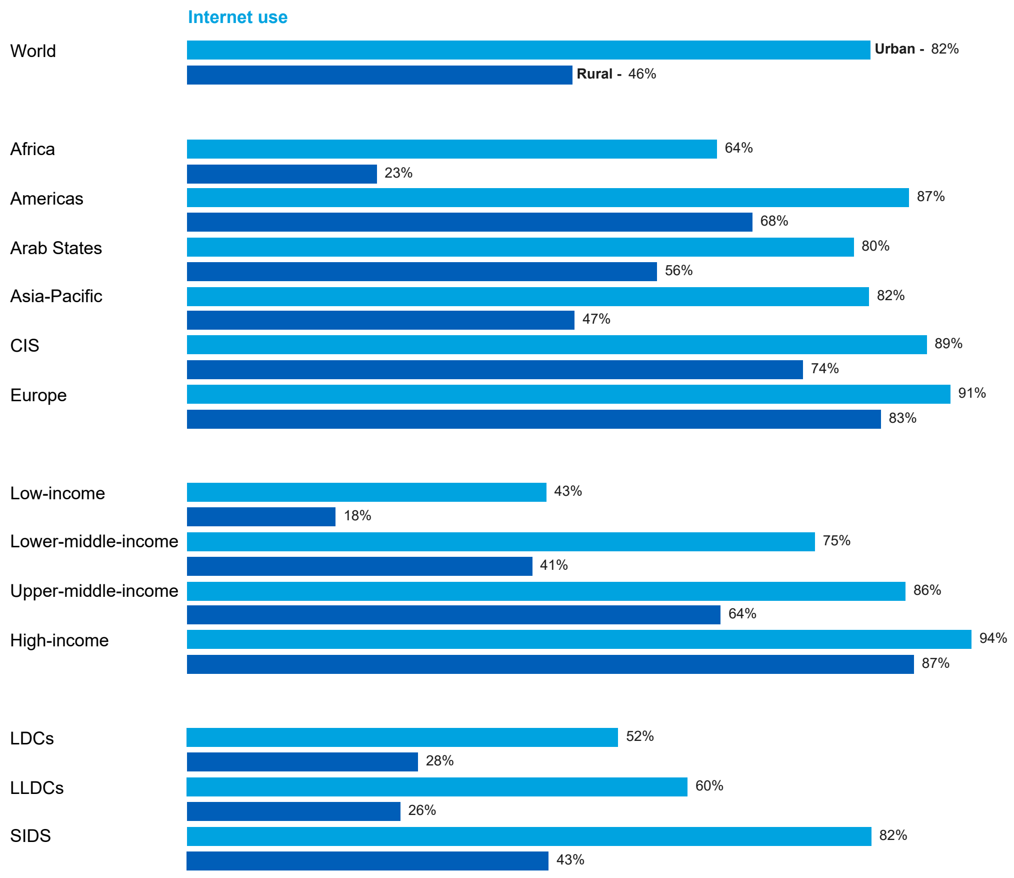
Lack of access to electricity in rural areas has a detrimental impact on economic and social development, resulting in a dearth of opportunities. Access to affordable electricity and broadband infrastructure will bring the transformative power of the digital economy to rural, remote and island communities.

As an illustration, 620 out of a total of 900 million people in Africa currently have no access to electricity. This translates into two percentage points of growth lost each year and billions of dollars spent on fossil fuels to power polluting generators. The necessary expansion of electricity networks across Africa would cost USD 63 billion per year up to 2030. However, only USD 8 billion is being spent per year. Without the progressive implementation of innovative power solutions, there will soon be 300 000 towers in Africa relying on diesel.

3.3 Urban-rural gap in Internet access – the offline population in developing countries

In 2022, two-thirds of the global population had access to the Internet, enabling them to participate in the global digital economy and benefit from the transformative social and economic opportunities of the digital ecosystem. However, one-third of the world's population is still not connected to the Internet and is denied the benefits of the digital age.

Figure 5: Percentage of individuals using the Internet in urban and rural areas, 2022



Access to broadband digital services in underserved communities will mitigate some of the economic and social disadvantages experienced by offline communities. Rural enterprises and cottage industries will thrive: they will be able to access and deliver a wide range of services more efficiently and effectively, thus making them better equipped to compete in the wider marketplace.

The expansion of mobile network coverage throughout the world has led to an upsurge in Internet data services, driven by the availability of affordable devices, cheaper data plans, and an increase in Internet usage by a growing middle class that can use and afford the services on offer.[8] Closing the urban – rural digital divide by connecting the unconnected is a priority of the Broadband Commission for Sustainable Development.

8 McKinsey&Company, 2014, offline-and-falling-behind-barriers-to-internet-adoption

3.4 Achieving universal connectivity

The Broadband Commission for Sustainable Development predicts that it will take well over two decades to achieve full Internet adoption. During this period, a large-scale "Internet of Things" will be developed that will herald what Klaus Schwab described as the fourth industrial revolution – where a range of new technologies fuse together the physical, digital and biological worlds, impacting all disciplines, economies and industries.[9] These advances will rely heavily on expansion of the Internet network to ensure universal access.

Broadband has become the cornerstone for smart infrastructure and national governments are setting targets to achieve universal access to broadband services.

3.5 Rural broadband infrastructure

Effective strategies and policies are needed to narrow usage gaps across developing regions of the world, particularly in rural areas. Successful solutions can be replicated and scaled up to improve the connectivity of large rural offline populations at minimal costs.

The major challenges to providing telecommunication services in rural areas relate to technological and economic considerations. The main transmission technologies for Internet broadband services are: optical fibre systems; copper DSL (xDSL)/ coaxial cable networks; terrestrial cellular mobile broadband networks; terrestrial microwave – fixed wireless access networks and satellite networks. Each of these technologies has specific strengths and limitations which, coupled with the regulatory environment, business objectives and financing regime, influences where they are best deployed.

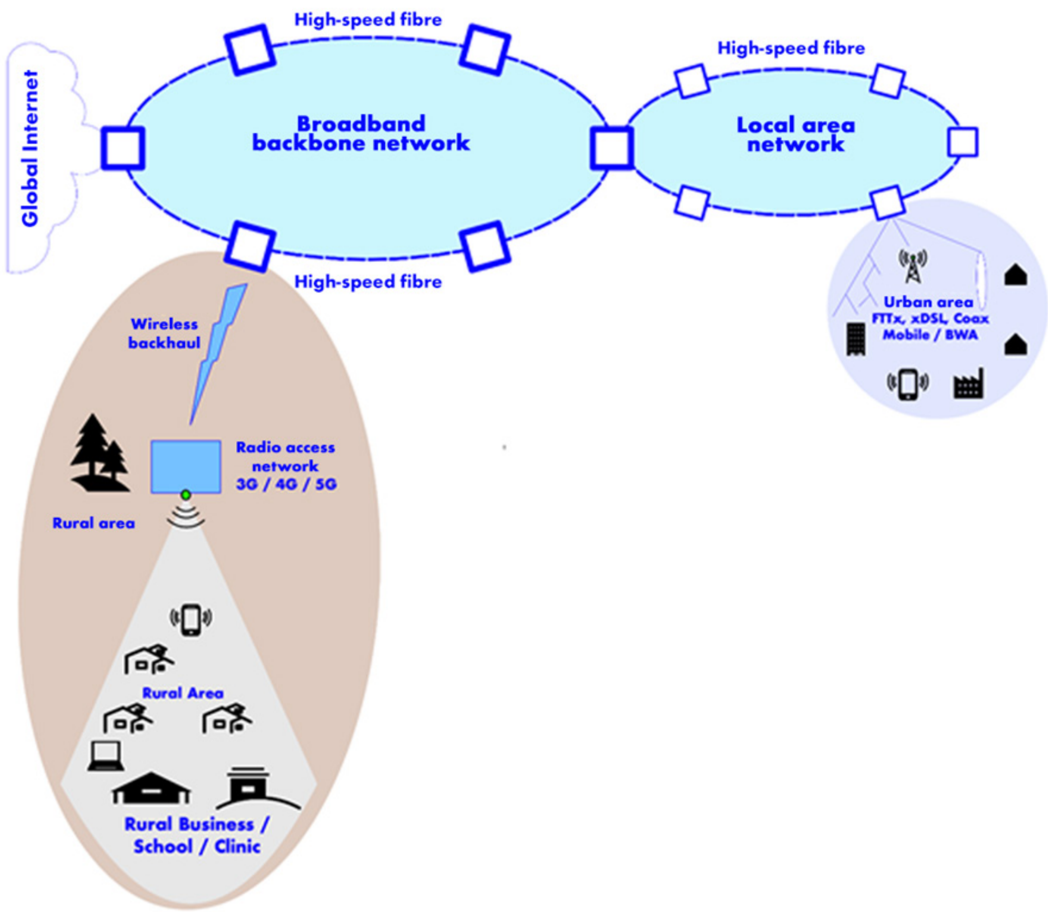
In urban areas, wired infrastructure solutions such as optical fibre, coaxial ("coax") cable and copper DSL are the broadband technologies mostly chosen to provide Internet services to homes and business premises.

In rural areas, wireless technologies, including cellular mobile networks, fixed wireless access networks and satellite technologies are often more cost-effective and permit the faster roll-out of more affordable broadband access services.[10] Backhaul connectivity solutions, utilizing microwave and millimetre wave radio technologies, are the most cost-effective and efficient technologies to connect rural and remote communities to the core network (see Figure 6). Backhaul links connect several geographically dispersed access nodes, aggregating local town or rural traffic further up towards the core network.

[9] https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab

[10] ITU-D webpage on rural initiatives: http://www.itu.int/en/ITU-D/Technology/Pages/RuralCommunications.aspx

Figure 6: Telecommunication network layout



Although optical fibre technology provides the highest capacity over long ranges, the high set-up costs (trenching, planning and permits, etc.) and long lead-time it requires make it impractical as an affordable rural infrastructure solution. However, optical fibre technology can be utilized to extend very high-capacity, shared broadband infrastructure, from the core network – over a significant distance – to regional centres and aggregation points in the country. It is often used for backbone networks to connect different core segments, municipalities and regional areas.

3.5.1 Wireless access networks

The advantages of using fixed wireless access and mobile technologies in rural areas include:

- fast time to market – as deployment is less complex and costly than wireline and subscribers can be brought onto the network more quickly than with fibre technology, and wireless networks can deliver a rapid return on investment;
- ease of deployment – wireless access is suitable for sparsely populated or remote areas, as well as urban and suburban environments, and can be used in a variety of deployment scenarios;
- plug and play – fixed wireless access terminals are simple to install;
- low cost – existing cell towers can be adapted to offer both fixed wireless access and mobile antennas.

Table 1: Typical speed comparison for fixed broadband service

Technology	Peak rate	Average user rate
VDSL2	200 Mbit/s	30 Mbit/s
LTE FWA	600 Mbit/s	50 Mbit/s
Fibre (FTTH)	1 Gbit/s	100 Mbit/s
Source: Ovum		

3.5.2 Mobile cellular coverage

Mobile broadband (3G or above) is the main way – and often the only way – to connect to the Internet in most developing countries. Today, 95 per cent of the world population is covered by a 3G or above network.

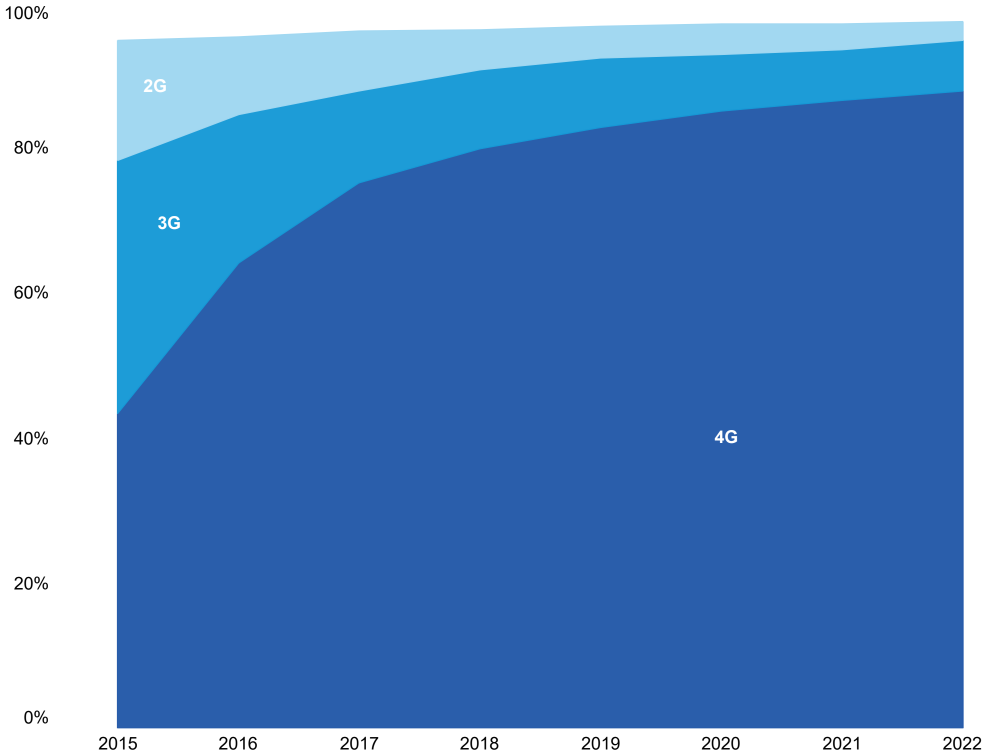
Between 2015 and 2022, 4G network coverage doubled to reach 88 per cent of the world's population (see Figure 7). At the regional level 4G technology is now available to more than 90 per cent of the population in the Americas, the Asia-Pacific, the CIS and Europe. In the Arab States, one-quarter of the population still cannot access a 4G network, while in Africa that is true for half the population.

In many countries in Europe and the Asia-Pacific region, older-generation networks are being switched off in favour of networks that allow the development of a digital ecosystem compatible with 5G. This is particularly the case for 3G, which is often shut down, while keeping 2G for older legacy devices.

The path is less clear in other regions of the world, mainly because 2G and 3G networks retain a significant presence.

Almost all urban areas in the world are covered by a mobile broadband network. But many gaps persist in rural areas. In the Americas, for example, 22 per cent of the rural population is not covered by any mobile signal at all, while an additional 5 per cent only have access to a 2G network, meaning that 27 per cent are unable to access the Internet. In Africa, those figures are 15 per cent (no coverage whatsoever), and 14 per cent (2G only).

Figure 7: Mobile population coverage, by type of network, 2015-2022



Source: ITU, Measuring digital development: Facts and Figures 2022

3.5.3 Rural broadband access infrastructure

Rural and remote sparsely populated areas lack access to affordable broadband networks. The high cost of extending the high-speed infrastructure, the low return on investment and the lack of access to the grid are major obstacles to developing a rural broadband infrastructure.

The challenge of introducing broadband Internet services in rural areas without access to the grid can be better understood by looking at the architecture of broadband access networks serving those areas.

A wired (copper and fibre cables) and high-speed fixed wireless infrastructure is widely used in major urban centres to deliver broadband services to business and residential customers, while mobile networks readily deliver broadband services to individual customers in both, urban and rural areas.

3.5.4 Mobile cellular networks

The majority of people in developing countries connect to the Internet using mobile cellular networks; operators acquire mobile spectrum licences, use networks of base stations/cell towers, and sell prepaid airtime voice and data services predominantly.

In sparsely populated rural regions, it is cellular mobile networks that are mostly used for broadband access, operating over a well-established broadband spectrum using 3G, 4G LTE and, in few cases, emerging 5G technologies (see Figure 8).

Table 2: Evolution of mobile networks

	1G	2G	3G	4G	5G
Approximate deployment date	1980s	1990s	2000s	2010s	2020s
Theoretical download speed	2 kbit/s	384 kbit/s	56 Mbit/s	1 Gbit/s	10 Gbit/s
Latency	N/A	629 ms	212 ms	60-98 ms	< 1 ms

Source: ITU – Setting the Scene for 5G: Opportunities and Challenges, 2018.

From a business point of view, expanding broadband coverage into rural regions is challenging due to high capital expenditure (CAPEX) and operating expenditure (OPEX) associated with setting up and operating base stations, including the provision of power, in remote areas that lack or have unstable access to the power grid. Broadband providers need to generate their own power locally to operate repeater stations and remote substations.[11]

A 2016 report from the GSM Association (GSMA) estimated that, compared to urban cellular sites, rural and remote cellular base station/cell tower sites could cost up to 30 per cent more

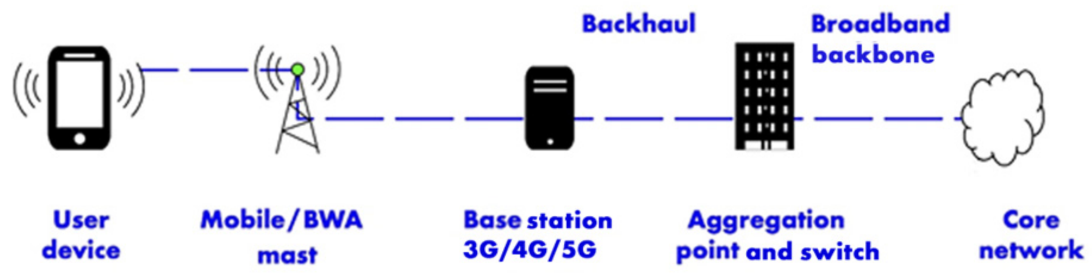
[11] Broadband Situations in Rural and Remote Areas, ITU-D Technology Document Rural Communications, https://www.google.com/search?q=rural+areas+suffer+lack+from+affordable+broadband&rlz=1C1GCEU_en-GB___GB862&oq=rural+areas+suffer+lack+from+affordable+broadband&aqs=chrome..69i57.19862j0j8&sourceid=chrome&ie=UTF-8

in CAPEX and up to 100 per cent more in OPEX (arising from energy and backhaul costs), while serving 80 per cent fewer users per site, and therefore generate less revenue.[12]

Fixed wireless access (FWA) technologies are also used to deliver a higher quality of service, based on international standards such as Wi-Fi, WiMAX/IEEE and other proprietary fixed broadband wireless access technologies. In developing countries, high-capacity microwave and millimetre wave radio technologies are usually provided as backhaul links, connecting rural communities to the core network. Satellite solutions are increasingly used to provide broadband access in more remote and isolated communities.

The development of high-capacity, wireless access solutions that are more spectrum- and energy- efficient, and are powered using renewable energy, will accelerate the roll-out of affordable broadband services in rural and remote areas.

Figure 8: Mobile network architecture



Source: Adapted from ITU

Box 1: The anatomy of a mobile network

In general, mobile phone and Internet networks feature core, backhaul, and last mile portions.

Core networks (including the national backbone and international connectivity) encompass the high-capacity fibre-optic infrastructure that delivers traffic to and from aggregation points (e.g. Internet exchange points and IXPs), peering connection points between tier 1 service providers and submarine cable landing stations for international connectivity.

Backhaul (or middle mile) technology refers to the infrastructure carrying voice and data traffic from an operator's core network to an aggregation site, such as a base station. Backhaul is often the key barrier to providing coverage, particularly in sparsely populated areas or those with challenging topography, such as islands or rural areas.

[12] GSMA. Unlocking Rural Coverage: Enablers for commercially sustainable mobile network expansion. http://www.gsma. com/mobilefordevelopment/programme/connected-society/unlocking-rural-coverage-enablers-commercially-sustainable-mobile-network-expansion. July 2016.

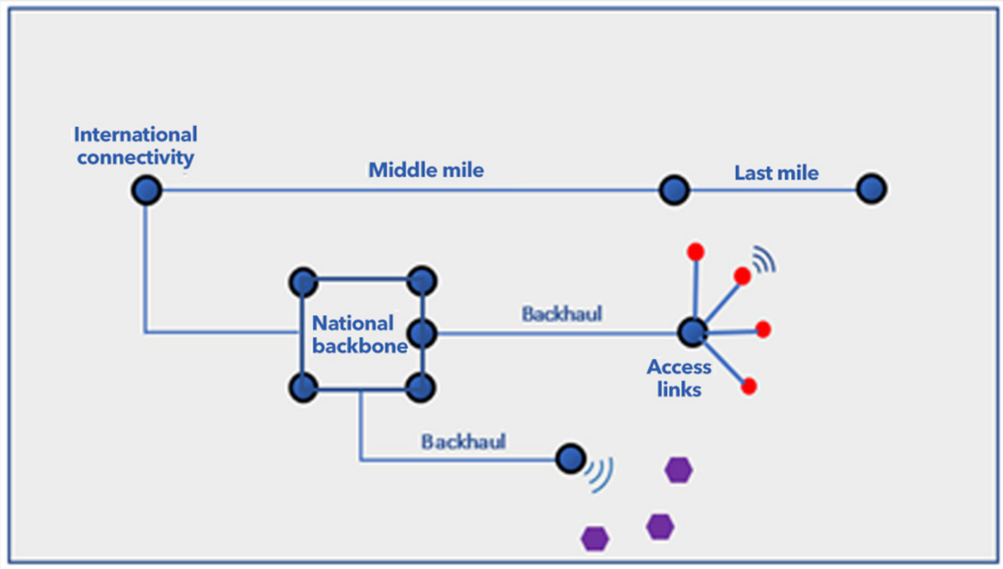
Box 1: The anatomy of a mobile network (continued)

Fibre is the most common form of backhaul, offering the highest capacity and best quality of service. However, it is often prohibitively expensive to roll out in rural or topographically difficult areas, given the costs associated with obtaining rights of way and construction permits.

Microwave technology is often used in areas where fibre is too expensive or impractical. However, it requires a clear line of sight between transmitters, so it may also be prohibitively expensive in very remote areas.

Satellite backhaul technology overcomes the rural challenges of distance and topography but has high operating costs and often lower quality service than traditional fibre.

Network infrastructure



3.5.5 Future 5G networks – innovative services

The fifth-generation technology (5G) network is evolving as a platform for delivering advanced communication services to enable governments and policy-makers to transform their national infrastructure to deliver enhanced digital services that support and empower citizens, communities, and businesses.

5G will deliver an enhanced end-user experience, improved performance, low latency, and high reliability; ultimately, it is envisaged that 5G networks will deliver gigabit speeds. Demand for these services will be highest in densely populated urban areas. As delivering these enhanced services to rural areas will not be economically viable, a lower capacity 5G service may be more appropriate in these areas.

The adoption of 5G, using terrestrial or satellite networks, will facilitate the roll-out of a new range of innovative services, including a large-scale Internet of Things and applications, such as remote manufacturing, which require time-critical process control with automation, robotics that embrace e-health and smart medication, automated transport with vehicle navigation and control, smart grid monitoring and immersive virtual reality experiences, including in the field of education and tele-medicine.

5G networks may facilitate the expansion of broadband services into rural and remote areas through the use of the sub-1 GHz frequency spectrum (the UHF frequency bands at 450-800 MHz) and will allow service providers to cover wide areas at a lower cost.[13]

5G radio systems are being designed to be more energy-efficient than 3G and 4G, so that they can be powered using small-scale renewable energy systems. The propagation characteristics of the UHF spectrum allow links to operate over longer ranges, with better penetration of geophysical obstructions than current systems in the 3-6 GHz and higher frequencies and millimetre wave bands. 5G base stations can therefore be located closer to renewable energy sources and provide wider coverage to more effectively reach remote communities, at a lower cost. Mid-band spectrum is required to support the effective operation of 5G mobile networks. Most of that spectrum is currently being used for 2G and 3G, thus driving telcos to explore refarming to free up spectrum for 4G and 5G services (e.g. 1800 MHz, 2.1 GHz, 2.3 GHz and 2.6 GHz). But spectrum availability is increasing globally, in the 3 300-4 200 MHz and 4 400 MHz bands used for mobile services, and satellites services may be integrated to augment the 5G service capability to address some of the major challenges of delivering multimedia services, ubiquitous coverage, machine-to-machine communication and critical telecommunication missions across the country.

Box 2: Huawei – Muti-layer spectrum approach

- Coverage layer – exploits spectrum below 2 GHz (e.g. 700 MHz) providing wide-area and deep indoor coverage.
- Coverage and capacity layer – relies on spectrum in the 2-6 GHz range to deliver the best compromise between capacity and coverage.
- Super data layer – relies on spectrum above 6 GHz and millimetre wave bands to address specific use cases requiring extremely high data rates.

Source: https://www.huawei.com/en/public-policy/5g-spectrum

5G improvement in energy efficiency by carrier aggregation

Spectrum availability for IMT (International Mobile Telecommunications) in the 3 300-4 200 MHz and 4 400-5 000 MHz ranges is increasing globally. The 3 400-3 600 MHz frequency band is allocated to the mobile service on a co-primary basis in almost all countries.

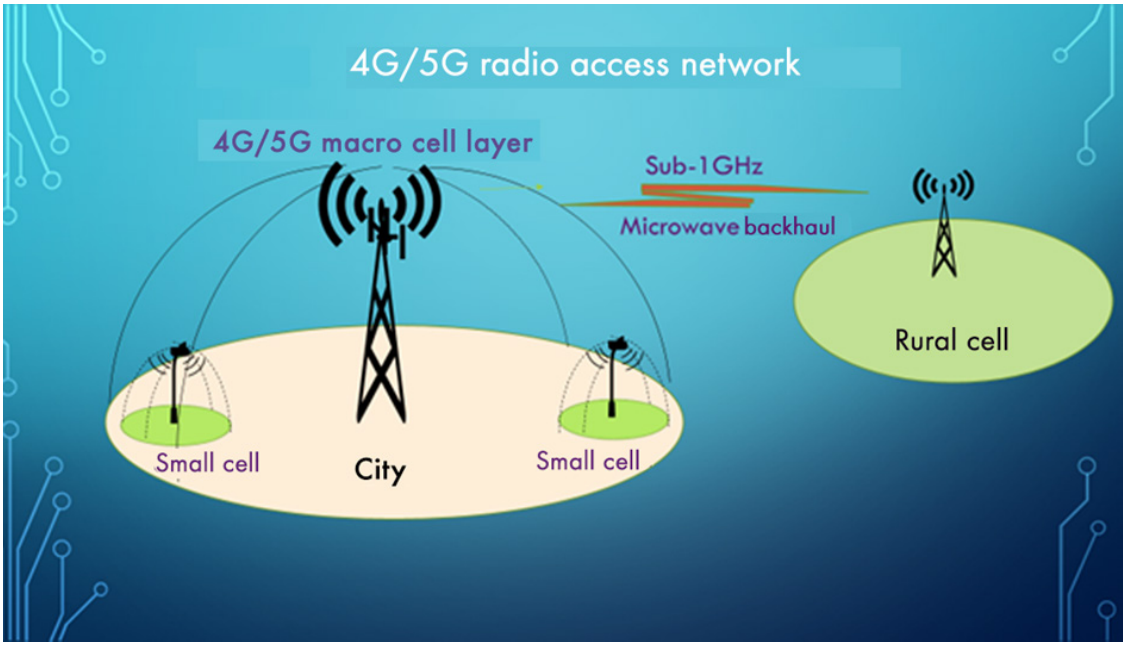
Bands below 6 GHz are crucial to support most 5G use scenarios in a wide geographical area. The 3 300-4 200 and 4 400-5 000 MHz frequency ranges are suitable for delivering the best compromise between wide area coverage and good capacity.

Dynamic spectrum access (DSA) uses a database to identify unused spectrum at any time and location by the licensed incumbent, with a view to making it available to other users without

[13] McGuire et al. EURASIP Journal on Wireless Communications and Networking 2012, 2012:112 http://jwcn.eurasipjournals.com/content/2012/1/112

causing interference to existing services. DSA may provide opportunistic access to spectrum for existing and new users by making unused 5G spectrum available, where possible, while giving priority to the principal licensee. DSA techniques are sometime being used in the TV white space UHF bands.

Key findings: Policy-makers may consider making available different portions of the 3 300-4 200 MHz and 4 400-5 000 MHz ranges to build large, contiguous blocks while also making available spectrum in the 700/800 MHz band to ensure mobile broadband delivery in rural areas.



3.5.6 Low-earth orbit satellite technologies – underserved rural areas

A new generation of low-earth orbit (LEO) satellite technologies could revolutionize broadband extension into underserved rural areas.

Communication satellites are often placed into geosynchronous, geostationary orbit, about 36 000 km above the equator, to orbit the earth in 24 hours in a stationary position. However, these satellites are very expensive to design, build, test, launch and deploy. Moreover, the round trip from the ground for signals emitted by these satellites takes more than half a second.

The LEO range satellites are smaller, orbit faster and combine more powerful capabilities with lower launch and operating costs. These satellites offer Internet latency periods of about 35 milliseconds, comparable to many cable and DSL systems serving individuals, small businesses and rural communities.

Several companies are developing and planning to launch LEO satellites during the period 2020-2030. SpaceX has commenced launching its new Starlink constellation of satellites. The Starlink project is to include about 12 000 satellites operating at an altitude of about 1 000 km, with a coverage radius of about 1 000 km, thus requiring a large network of satellites.

3.5.7 High-altitude platform systems

High-altitude platform stations (HAPS), filled with helium and operating in the stratosphere at altitudes of about 20 km, and satellite systems (including non-geostationary constellations) can potentially deliver very high data rates (100 Mbit/s to 1 Gbit/s or more) to complement fixed or terrestrial wireless backhaul networks outside major urban and suburban areas. HAPS and satellite systems can deliver video transmission to fixed terrestrial systems in rural and very remote locations, such as islands. They can be integrated into other networks, such as fixed wireless access and mobile solutions, thereby augmenting 5G service capabilities, in order to tackle major challenges relating to multimedia traffic growth, ubiquitous coverage, the Internet of Things, machine-to-machine communication and critical telecommunication missions.[14]

Sub-1 GHz frequencies will be more suitable for HAPS long-range, low-bandwidth applications to offer broad coverage in rural areas, particularly in developing countries, including in Africa, to enhance 4G and 5G coverage. This approach is to be addressed by the World Radiocommunication Conference in 2023 (WRC-23), considering the use of high-altitude platform stations as IMT base stations in the mobile service in certain frequency bands below 2.7 GHz already identified for IMT.

Key findings: Policy-makers may consider making available low-frequency spectrum (e.g. in the 700 MHz band) to ensure mobile broadband access in rural areas.

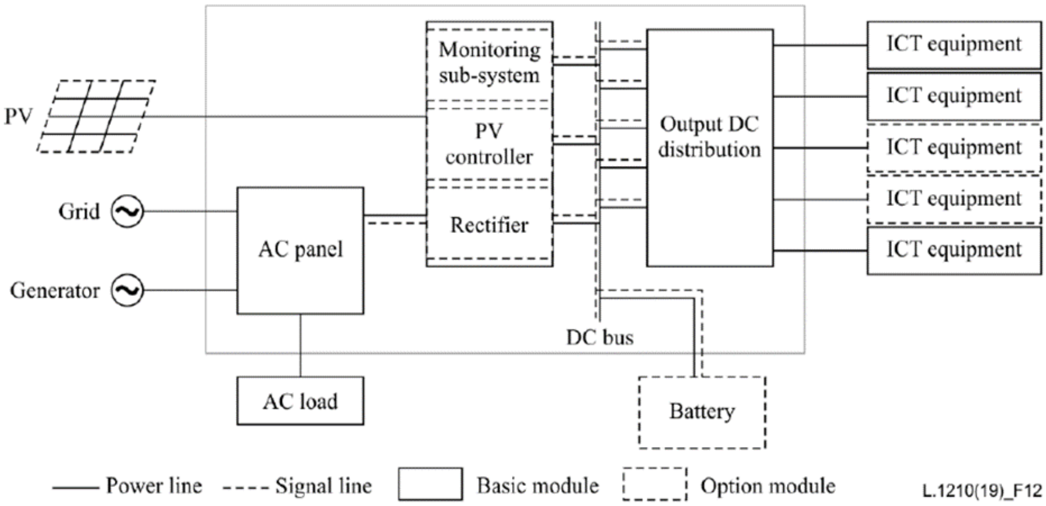
It may be expected that the 3.3-3.8 GHz spectrum could be the basis for a range of initial 5G services.

3.5.8 Renewable energy solution for 5G base stations

This solution involves connecting different energy sources such as the grid, renewable energy and generators to the input power panels of base stations. In order to maximize the utilization of renewable energy, the system applies smart technology to use renewable energy preferentially, and otherwise selects the grid, a battery storage system or a generator based on the operational cost in different conditions. Below is an example of the basic structure of the system.

14 ITU: High-altitude platform systems, https://www.itu.int/en/mediacentre/backgrounders/Pages/High-altitude-platform-systems.aspx

Figure 9: Multiple energy source input system for 5G base station, including renewable energy



When grid capacity is insufficient due to the increasing power needs of the 5G base station, renewable energy from solar photovoltaic (PV) cells, wind turbines and fuel cells could be a very good choice to increase the available power capacity, in order to ensure that the whole system continues to operate smoothly and without interruption. This is described in Recommendation ITU-T L.1210 on sustainable power-feeding solutions for 5G networks.

4 Lack of access to electricity

4.1 Energy challenges limiting broadband expansion

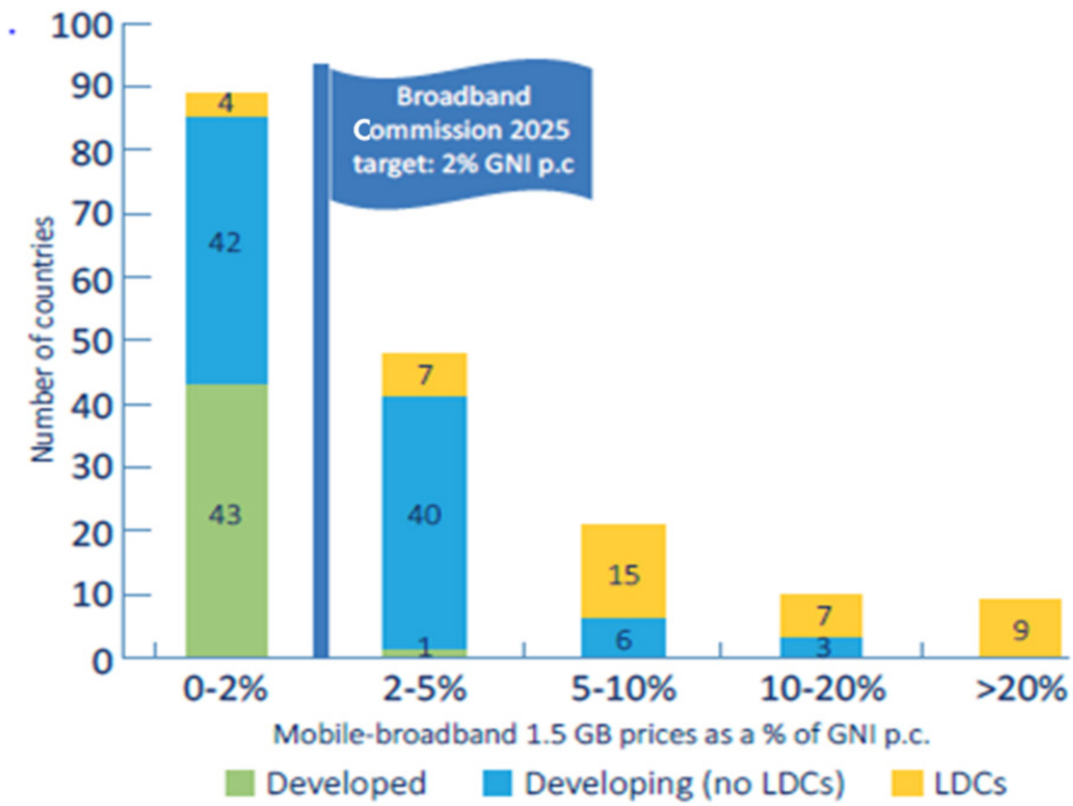
Access to reliable and affordable electricity is a prerequisite for developing broadband access infrastructure in rural areas. Without it, the social and economic benefits that will lead to shared prosperity and transform the lives of low-income families in rural communities cannot be fully realized.

The global ICT ecosystem consumes a significant amount of energy, estimated at about 10 per cent of all the electricity generated globally each year, to power the data centre cloud, the Internet broadband infrastructure, IT networks/software and end-user devices. If affordable access to the electricity grid is not available, broadband infrastructure in rural areas needs to have access to reliable off-grid sources.

The lack of grid power is a major challenge for telecommunication operators, who have to provide their own power solutions to expand cellular or fixed wireless broadband infrastructure in rural areas.

Although considerable progress has been made in recent years, affordability remains a major challenge in many developing countries, especially LDCs, as shown in Figure 10.

Figure 10: Broadband still expensive in LDCs



In order to make entry-level broadband data packages (1.5 GB) affordable in developing countries, the Broadband Commission for Sustainable Development set a target for broadband prices to come down to no more than two per cent of monthly gross national income (GNI) per capita by 2025.

The absence of a grid infrastructure in rural areas drives up the cost of building broadband Internet networks to serve remote communities, which may represent a significant proportion of the investment required to establish and operate a broadband infrastructure (backhaul systems, mobile base station systems or fixed wireless access last mile connections).

Standalone diesel power solutions, when used as the primary energy source in rural areas, involve high capital and operational costs. The return on investment for operators is poor, due to the high cost of maintenance, security and fuel for diesel-generators in rural and often remote areas.

As a result, innovative energy solutions for rural areas need to encompass measures to improve the availability and reliability of the electricity supply for the active components of the rural telecommunication network infrastructure, as well as for access to terminating equipment (e.g. CPEs, devices, computers, phones, smart TV) for end users, community services and local business customers.

In rural communities without electricity, local people have to travel to the nearest battery charging points, which may be located several miles away, to recharge their handheld devices or other battery-operated ICT appliances. This results in extra costs and service disruption, further reducing demand for Internet services and ICT adoption among the rural poor. Generally speaking, without access to electricity, ICT equipment and facilities will not be deployed in rural and remote island locations, other than held-held devices. In specific situations, temporary emergency power may be provided by batteries.

The first of the above-mentioned barriers can be described as the "broadband supply gap", namely the lack of broadband service in an area where people live and work. The second barrier, the "broadband demand gap", is understood as the proportion of the national population that could potentially have access to broadband, but do not acquire the service.

The broadband supply gap is particularly acute in rural and remote areas with a population density significantly lower than in urban and peri-urban areas. The main challenges to the roll-out of broadband services in rural areas and island communities in developing countries are:

- remote and challenging geography and terrain;
- inadequate access to reliable, affordable and secure infrastructure, especially the electricity grid and roads;
- lack of mobile Internet coverage or fixed broadband wireless access networks and no means of accessing international bandwidth;
- lack of ICT facilities;
- limited and distant power charging locations for mobile devices and Internet ICT appliances;
- limited off-grid power solutions – diesel-generator supply is irregular, while renewable energy is intermittent.

In recent years, operators of mobile networks and fixed wireless broadband services have been penalized for failing to deliver on performance targets agreed with regulators due to a deteriorating quality of service and for missing availability targets. Unfortunately, one of the most common reasons for network failure and downtime events is the lack of a reliable power supply; even as a standby source (let alone the main source), a diesel-generator set is a poor substitute for access to the national grid.

4.2 Sustainable energy for all

The electricity market is currently undergoing a process of transformation, as renewable energy technologies begin to displace fossil fuels, and as traditional power and broadband industries – previously dominated by incumbent operators – are disrupted by more decentralized, innovative business models.

Achieving sustainable energy for all is one of the SDGs. As one of the strategies to attain this objective, the Broadband Commission for Sustainable Development has set a series of targets, to be met by 2030, aiming to:

- ensure universal access to affordable, reliable and modern energy services;
- increase substantially the share of renewable energy in the global energy mix;
- double the global rate of improvement in energy efficiency;
- enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced, cleaner fossil fuel technology, and promote investment in energy infrastructure and clean energy technology;
- expand the infrastructure and upgrade technology to supply modern and sustainable energy services for all in developing countries, particularly LDCs, SIDS, and landlocked developing countries (LLDCs), in accordance with their respective programmes of support.

Goal 7 of the Sustainable Development Goals also calls on Member States to "ensure access to affordable, reliable, sustainable and modern energy for all."

The rapidly decreasing cost of renewable energy technologies such as solar and wind power, coupled with measures to improve efficiency and innovative delivery mechanisms for energy services, should accelerate strategic initiatives to achieve universal electricity access goals.

Infrastructure represents a substantial part of the cost of access to electricity. Urban populations generally have access to electricity via the national power grids. In developing countries, however, delivering electricity to rural and remote regions via an extensive transmission and distribution infrastructure requires a substantial investment that is prohibitive for many incumbent power companies and generates very poor returns. Off-grid electricity generation using mini-grid and micro-grid architectures combined with lower-cost, cleaner renewable energy sources that are available locally, can offer reliable and affordable power for rural and remote installations.[15]

4.3 Rural power deficit in developing countries

Unreliable and inequitable access to electricity is one of the main barriers to increasing economic activity and extending the broadband infrastructure in rural areas. It is a major deterrent to private investment.[16]

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[15] UNCTAD - THE LEAST DEVELOPED COUNTRIES REPORT 2017 - Transformational energy access, https://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=1902

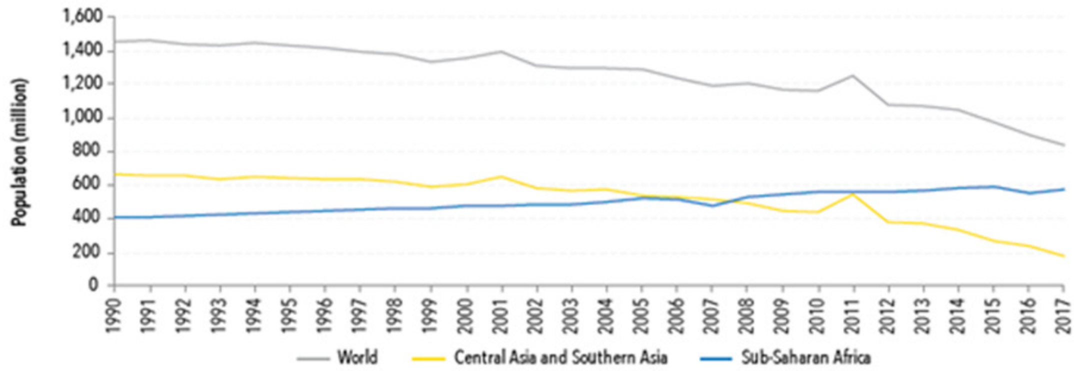
[16] The G-20 Compact with Africa A Joint AfDB, IMF and WBG Report G-20 Finance Ministers and Central Bank Governors Meeting March 17-18, 2017 Baden-Baden, Germany

In 2017, 14 per cent of the world's population (about 1 billion people) still lacked access to electricity. This figure has fallen sharply, except in sub-Saharan Africa (see Figure 11). Asia and Africa accounted for 95 per cent of people without access to electricity, 84 per cent of whom lived in rural areas (see Figure 12).

Global electrical power generation capacity increased by 4 per cent in 2018, with renewable energy accounting for 45 per cent of this increase. In 2017, at the global level, the electricity access rate stood at 79 per cent in rural areas, lagging far behind the urban access rate of 97 per cent. Underserved rural populations account for 87 per cent of the global access deficit. In 2017, 66 per cent of the global rural population without access to electricity lived in sub-Saharan Africa, as illustrated in Figure 11.

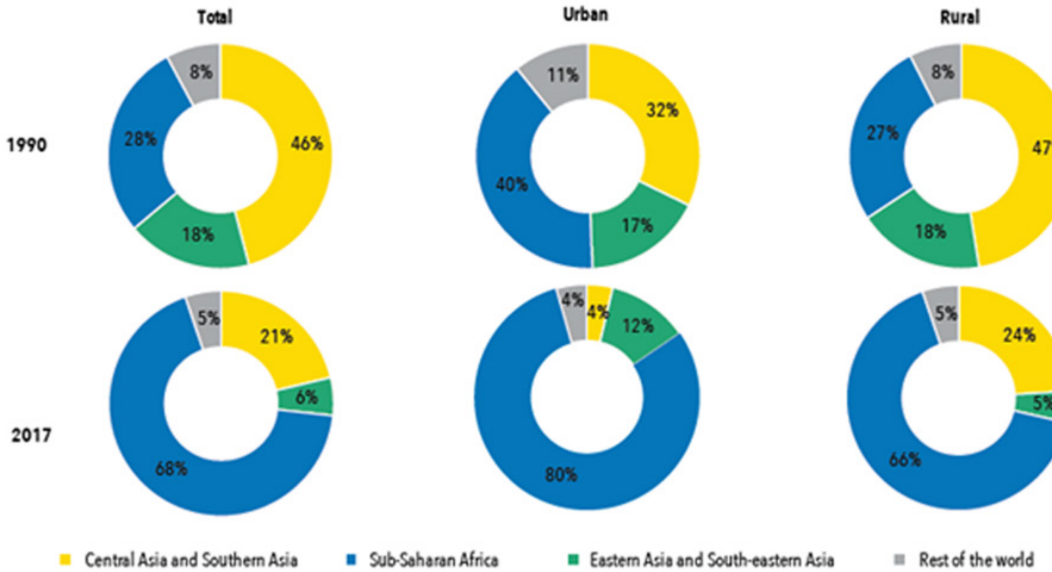
Figure 11: Rural population without access to electricity

Evolution of electricity access deficit (millions of people), 1990-2017



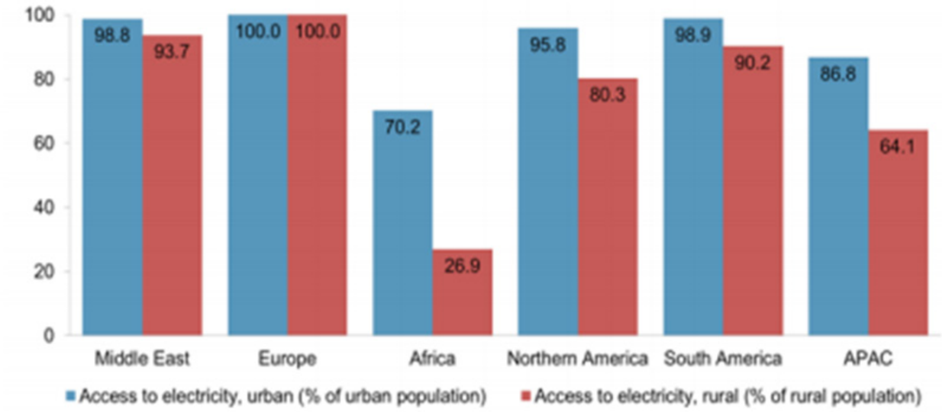
Source: World Bank.

Regional shares of the global electricity access deficit, in total and along the urban/rural divide, 1990 and 2017



Source: World Bank.
Note: Based on population without access to electricity

Figure 12: Population with access to electricity (urban and rural) in %



Source: World Bank (2017)

Without affordable energy, it is difficult to promote economic growth, overcome poverty, deliver high-quality education, boost local business and industry, expand employment opportunities and support human health and development.

Inadequate infrastructure, particularly in terms of access to electricity, is limiting the roll-out and affordability of broadband services, thereby contributing to increasing inequality.

Technological developments and the falling cost of renewables and digital technologies have created opportunities to transition away from a high-carbon world reliant on fossil fuels towards a sustainable, low-carbon economy. Global policy studies suggest that wind and solar PV will provide more than half of the additional electricity generation capacity to be brought online by 2040.

4.4 Transition to a renewable energy infrastructure

The traditional model of grid-based electricity distribution – which relies on incumbent electricity suppliers extending their national transmission distribution networks over long distances into rural areas – has failed, given that most rural populations in developing regions of Africa and Asia do not have access to the grid.

Renewable energy has enabled communities to leapfrog fossil fuels to affordable, clean energy, thereby contributing to the global drive to minimize greenhouse gas emissions to protect the environment. Thanks to technological innovation, the most reliable model for expanding the supply of affordable electricity depends on decarbonized, digitalized and decentralized power solutions.

Over the past decade, the cost of renewables has fallen dramatically. A 2019 study by the International Renewable Energy Agency (IRENA) concluded that the price of renewable solar and wind energy had fallen to a level equal to or even lower than coal and other fossil fuels. Broadband service providers can overcome energy challenges and barriers to investing in rural broadband infrastructure by generating their own clean energy from cheaper, clean, renewable sources or by collaborating with community energy development projects. An industry is also being created around providing storage solutions, which are key to promoting the penetration of renewable energy. Moreover, IT innovation also plays a key role in optimizing the production and consumption of electricity.

4.5 Improving energy efficiency – optimizing consumption

"Energy efficient appliances will help to reduce the energy investment costs required to stimulate electricity access programmes. By reducing power by a single watt from an off-grid appliance's load, this would result in lower initial solar systems costs, improved service, or both." (Van Buskirk, 2015.) Similarly, energy efficiency can make larger off-grid solar powered installations more affordable.

Analysis done by Van Buskirk in 2015 indicated that "the upfront cost of a typical off-grid energy system can be reduced by as much as 50 per cent if super-efficient appliances and right-sized solar PV and batteries are used, while delivering equivalent or greater energy service." Efficiencies can be gained by redesign of base station radio equipment (the module of digital signal processing, the power amplifiers of transceivers, the radio frequencies, and connecting wires). Optimization of the power consumption of base transceiver station (BTS) systems and of digital signal processors is being achieved by using integrated circuits architectures such as ASIC, FPGA or DSP, which are combined to obtain better efficiency.[17]

Power consumption can be further optimized by:

- switching off systems during certain times to match load[18]
- managing network resources dynamically
- sharing mobile base station, wireless transceiver and repeater station resources among different operators.

Also, extending the range of operating temperatures will eliminate or reduce air-conditioning power needs. This leads to a significant reduction of energy demand and costs at remote sites.

17 S. Zoican, "The role of programmable digital signal processors (dsp) for 3G mobile communication systems," Acta Technica Napocensis, vol. 49, pp. 49–56, 2008.

18 L. M. Correia, D. Zeller, O. Blume et al., "Challenges and enabling technologies for energy aware mobile radio networks," *IEEE Communications Magazine*, vol. 48, no. 11, pp. 66–72, 2010. View at: Publisher Site | Google Scholar

5 Renewable energy sources for rural electrification

Renewable energy solutions are the lowest-cost source of new power generation today in all regions of the world. The last decade has seen the cost of electricity generated from solar PV, wind, hydropower, geothermal and biomass decrease considerably to the point that it is within the cost range of fossil-fuelled power generation.[19]

5.1 Renewable energy more competitive than fossil fuel sources

The cost of electricity generated by recent large-scale solar PV projects has fallen below the price of electricity from fossil-fuelled generating plants (IRENA 2018). The falling costs of onshore wind and concentrated solar power have also resulted in the increased competitiveness of other renewable sources by comparison with electricity generation by means of coal or other fossil fuels.

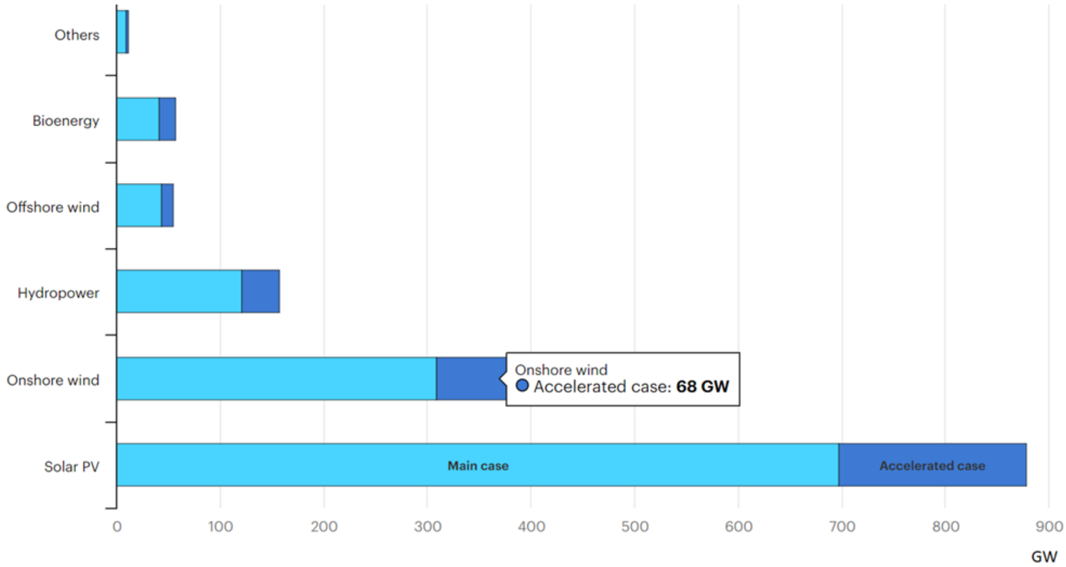
Renewable energy solutions can be used in a variety of configurations, from grid-connected to off-grid networks and standalone domestic solutions.

In rural locations without access to the grid, off-grid energy networks will emerge as the network of choice for powering broadband infrastructure components and for providing electricity for the rural economy, offering advantages of scalability, flexibility and modularity.

According to the International Energy Agency (IEA), generating capacity from renewable energy sources is predicted to expand by 50 per cent (an increase of 1 200 gigawatts) between 2019 and 2024 (see Figures 13 and 14).

[19] IRENA RENEWABLE POWER GENERATION COSTS IN 2018. https://www.irena.org/publications/2019/May/Renewable-power-generation-costs-in-2018

Figure 13: Renewable capacity growth between 2019 and 2024 by technology (GW)



■ Main case ■ Accelerated case

Source: IEA, Renewable capacity growth between 2019 and 2024 by technology.

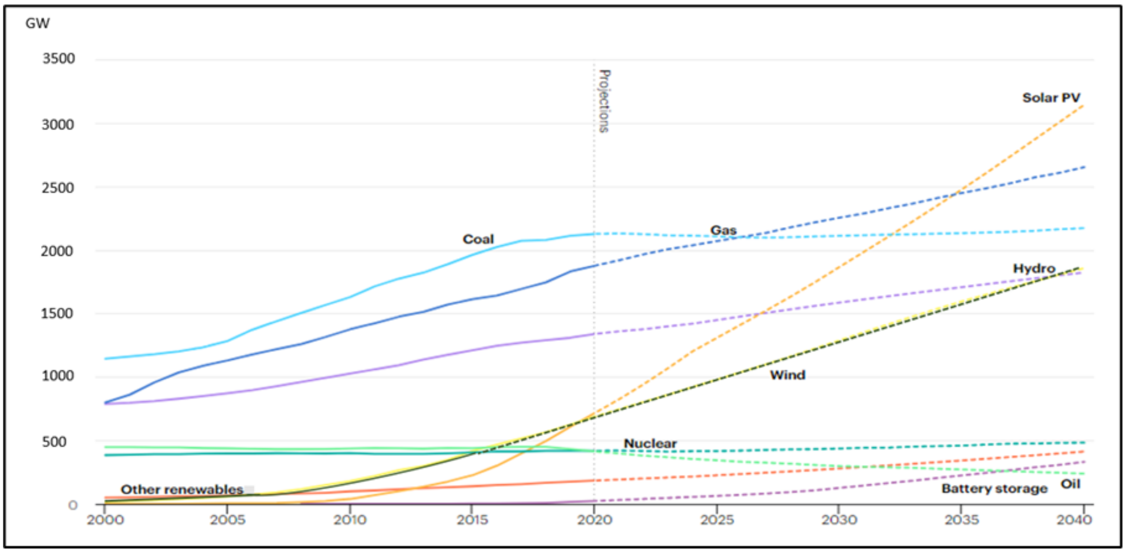
Renewable energy has become the technology of choice. By 2040 it will contribute about 66 per cent (two-thirds) of all new power generation capacity in the world, and its share of total electricity generation will rise to over 40 per cent (see Figure 14).

Mini-grid and micro-grid renewable solutions that are not connected to the primary grid must employ hybrid configurations that combine solar or wind systems, with energy storage solutions to handle the variability and intermittency of these types of many energy sources. This makes it possible to ensure high availability and reliability of electricity distributed on the mini or micro-grid network.

Where applicable, hybrid mini-grids may use a renewable energy source combined with standby diesel-generators, an attractive option for operators who already possess parks of such legacy generators. These solutions can be optimized to minimize the length and frequency of use of the diesel-generators, achieving significant savings on fuel consumption, maintenance and OPEX.

Significant advances in energy storage solutions have had a positive impact on the reliability of the energy supply and led to increased use of renewable energy solutions in rural areas. In solar PV systems, energy storage solutions are mainly used to supply evening peaks and to regulate and smooth out the power delivered on mini-grid network. Where the mini-grid is connected to the main grid network, excess power can be sold to the grid operator, helping to reduce carbon dioxide emissions.

Figure 14: Installed and projected power generation capacity by source 2000-2040



(Installed power generation capacity by source in the New Policies Scenario, 2000-2040)

Source: IEA World Energy Outlook 2019 https://www.iea.org/reports/world-energy-outlook-2019

Tremendous progress has been made on energy access in recent years, with the global electrification rate reaching 89 per cent globally in 2017. However, this development has to a great extent bypassed the LDCs, particularly in sub-Saharan Africa, where 580 million people, mainly living in rural areas, still lack access to electricity.

Combined wind and solar PV capacity is projected by IEA to exceed 38 per cent of all energy mix by 2040, compared to about 18 per cent in 2018. This presents significant opportunities for rural Africa and Asia, with some of the richest solar radiation resources in the world, to deploy solar PV solutions as their cheapest source of electricity.

The cost of renewable power plummeted 77 per cent to just under USD 0.03/kWh, making electricity generated from renewable energy sources more competitive when compared with fossil fuel energy alternatives (see Figure 15).[20]

The competitiveness of renewable energy provides vast opportunities for private companies and energy companies to engage in new business models for implementing innovative renewable energy solutions to close the rural urban electricity gap, minimize fossil fuel use, thereby reduce greenhouse gas emissions.

> "Electrification on the basis of cost-competitive renewables is the backbone of the energy transformation and a key low-cost decarbonization solution in support of the climate goals set out in the Paris Agreement" (IRENA 2019).[21]

Advances in renewable energy and innovations in digital technologies, supported by a strong national political commitment to the energy access agenda, combined with financing and local entrepreneurship, can dramatically accelerate the expansion of rural electricity access.

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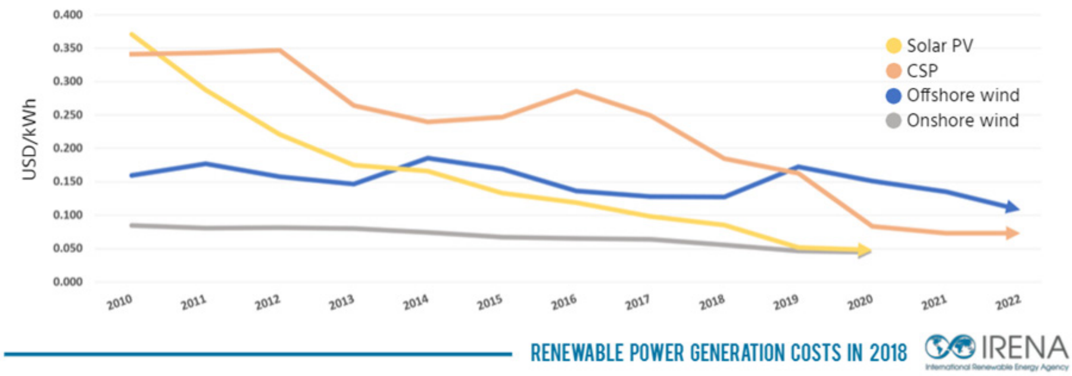
[20] IRENA (2019) – Future of Solar Photovoltaic, https://www.irena.org/publications/2019/Nov/Future-of-Solar-Photovoltaic

[21] Falling Renewable Power Costs Open Door to Greater Climate Ambition https://www.irena.org/newsroom/pressreleases/2019/May/Falling-Renewable-Power-Costs-Open-Door-to-Greater-Climate-Ambition

Figure 15: Renewable power generation costs in 2018



Source: https://www.irena.org/newsroom/pressreleases/2019/May/Falling-Renewable-Power-Costs-Open-Door-to-Greater-Climate-Ambition

Electrification rates in rural areas, where most of those without access to electricity live, have been growing rapidly and, in 2018, were estimated at about 76 per cent, according to data from the World Bank Group.[22]

5.2 Solar power

Solar energy is the most ubiquitously available source of clean energy and the most suitable for distributed power for rural telecommunication facilities, owing to the modularity of the technology: it can easily be scaled to match power needs.

Accelerated deployment of renewable energy solutions, particularly solar technologies, will significantly reduce carbon dioxide emissions. The installed capacity of solar PV cells is expected to increase almost six-fold over the next decade, and prices are expected to decline by about 0.08/kWh (installed costs) by 2030.[23] Technological advances in the field of solar energy, the competitiveness of solar, and targeted investments in rural electrification projects, supported by sound policies, will deliver considerable socio-economic benefits to both urban and rural communities.

Solar photovoltaics grew faster than any other energy source in 2016, mainly as a result of the successful deployment of solar PV in China. The increased volumes and improved economies of scale have led to a major decrease in costs. Renewables now represent almost two-thirds of new net electricity capacity additions in 2016, with almost 165 gigawatts (GW) coming online (see Figure 14). There has been a dramatic and sustained decline in the cost of electricity from utility-scale solar PV, which plummeted by over 77 per cent between 2010 and 2018 (global weighted average, "Levelised Cost of Electricity" – published by IRENA in 2019). This significant reduction in solar prices has been experienced in all regions of the world (see Figures 16 and17).

In developing countries, particularly in Africa and Asia, IEA predicts a three-fold increase to 3 000 MW in off-grid solar PV electrification programmes with private sector investment and other financing programmes. However, the most significant technical constraint affecting deployment

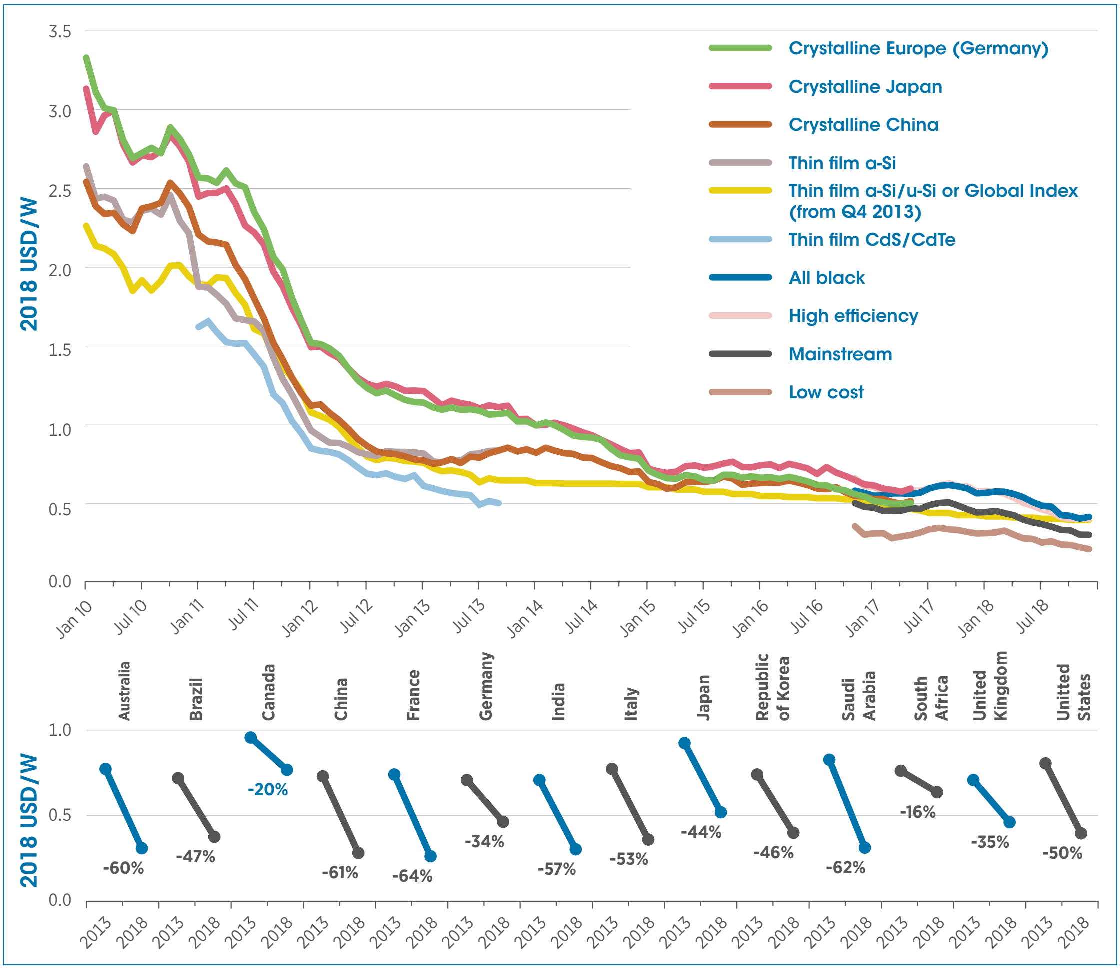
[22] IRENA, Off-grid renewable energy solutions to expand electricity access; https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_Off-grid_RE_Access_2019.pdf

[23] IRENA 2019: Future of Solar Photovoltaic, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Nov/IRENA_Future_of_Solar_PV_2019.pdf

of solar cells is the physical space requirement, which is inversely related to the efficiency of the panels. The higher the efficiency of the panel, the less space it requires.

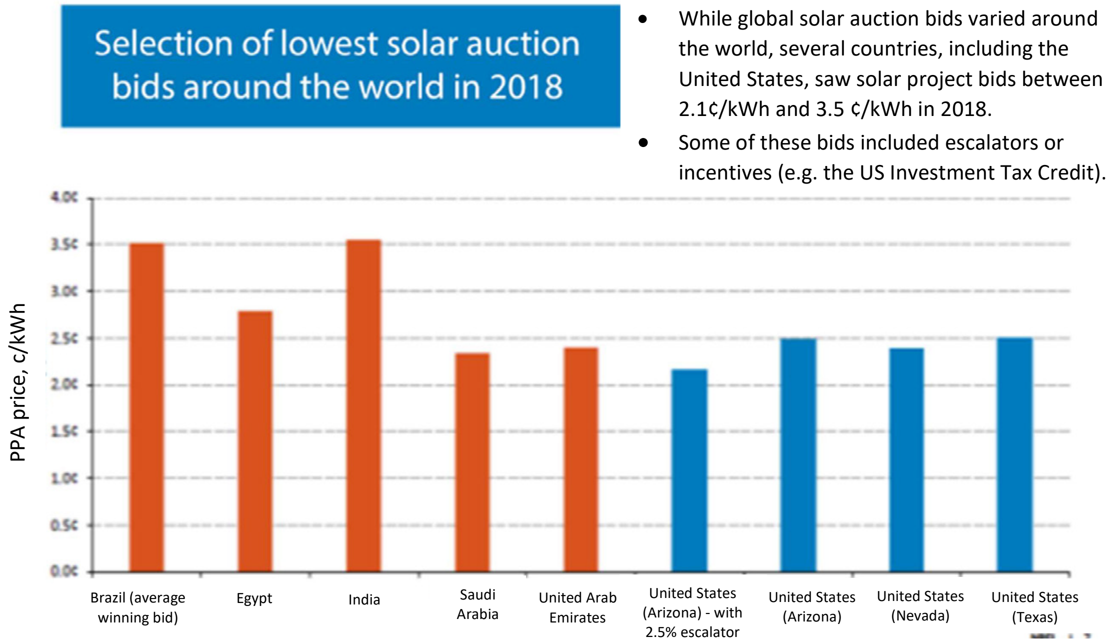
Figure 16: Solar PV energy price reduction

Average module prices by type and market from 2013 to 2018



Sources: Based on GlobalData, 2018; IRENA Renewable Cost Database, 2019; Photon Consulting, 2018; and pvXchange, 2019.

Figure 17: Lowest solar auction bids in 2018



Note: PPA = Power purchase agreement
Source: Solar Power Europe - "Global Market Outlook for Solar Power, 2019-2023"

5.2.1 Solar technology overview

A PV module is the basic building block of a solar energy system array, comprising several small photovoltaic cells that are electrically connected. It uses a semiconductor-based technology which converts sunlight into direct current (DC). PV modules are designed with electrical output that ranges from a few watts to 100 watts.

Crystalline silicon (c-Si) panels are first generation solar PV panels but still hold 95 per cent share of the global PV production market (Fraunhofer ISE, 2019), such economies of scale make them more affordable than other technologies. Crystalline panels are highly efficient, up to 17 per cent for multi-crystalline PV, and 18 per cent for monocrystalline PV panels. Further improvements in costs, purity of materials and yield are expected over the next few years (GlobalData, 2019).

Second generation "Thin Film" solar PV technologies are cheaper to produce but have generally had lower efficiency levels. Other promising devices are being researched such as Perovskites cells which have high efficiencies up to 24.4 per cent, however, are not market ready.

A new cell technology is based on the use of passivated emitter and rear contact (PERC) cells. These have an advanced silicon cell architecture that is similar in construction to conventional monocrystalline PV cells. PERC is becoming the new industry standard for monocrystalline cells, thanks to improved reliability, performance and throughput of production tools.

The choice of solar PV technology that would be suitable for a specific installation is therefore determined by the trade-off between panel investment cost, module efficiency, space availability and local factors.

5.2.2 Solar array arrangements

Fixed arrays are designed to ensure that the mounted solar modules are oriented towards the sun's rays (in the direction of the equator) to provide the optimum annual power output profile. The alternative is to use a design that can track the sun, such as dual-axis tracker systems; however, these are considerably more expensive. Optimal inclination, to maximize the intensity of direct radiation, will depend on local climatic and topographical characteristics and must factor in installation costs.

The performance of photovoltaic modules is affected by temperature conditions. When combined with modern charge controllers employing maximum power point tracking the performance of solar panels is improved in cold weather, while traditional charge controller designs, transfer the current from the solar cell directly to the battery without taking account of the change in performance of the solar cell due to environmental conditions.[24] Charge controllers equipped with maximum power point tracking can optimize the current transfer resulting in significant overall performance improvements.

Solar PV modules can be mounted on the ground, building/roof or pole/tower, with fixed tilt or single/dual axis solar tracking systems.

5.3 Considerations for sizing solar PV arrays

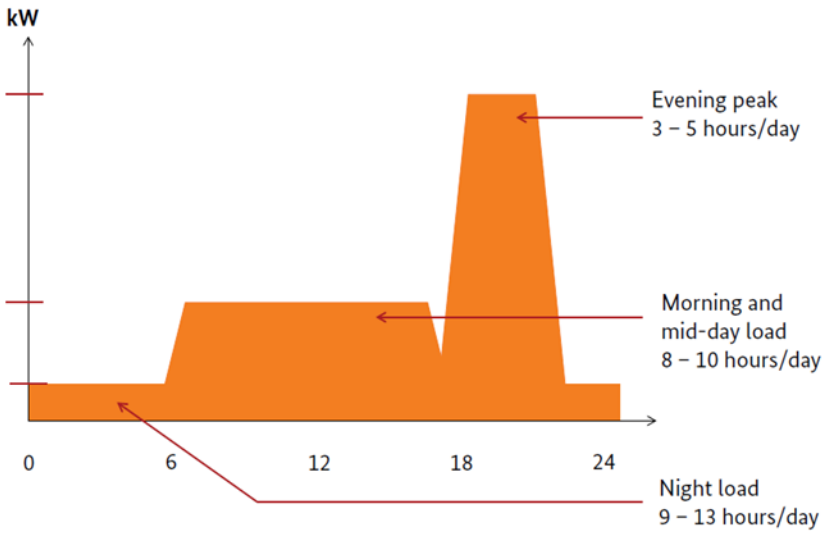
The first stage in computing the requirements for an off-grid system, having done a full survey at the location and estimated the need, is to forecast the demand, which has to take into account anticipated future increases.

A typical load profile is generated, to give the average hourly load demand over a 24-hour period, along with the worst-case planning period over a year, which may be determined by cloud cover and precipitation in tropical areas, or by snowfall in temperate regions.

An example of a load profile is shown in Figure 18.

[24] For a technical discussion on MPPT – please see Home power Magazines, issue 72, September 1999 http://www.homepower.com.

Figure 18: Typical daily load profile in a rural area



Source: Typical daily load profile in a rural area (IEA 2013)

Having calculated the hourly load demand, the peak load in kW is calculated. It must include the energy required to charge the standby batteries, as well as the forecast electricity demand. The total peak demand is assessed taking into account the "Derate Factor", the losses or inefficiencies of all sub-systems. These system components include:

Solar charge controller – regulates the voltage and current coming from the PV panels going to the batteries. It prevents batteries from overcharging and prolongs battery life.

Inverter – converts the DC output of PV panels into a clean AC current for an AC bus or to feed AC appliances.

Battery or energy storage – stores energy, which is then supplied to electrical appliances when there is demand.

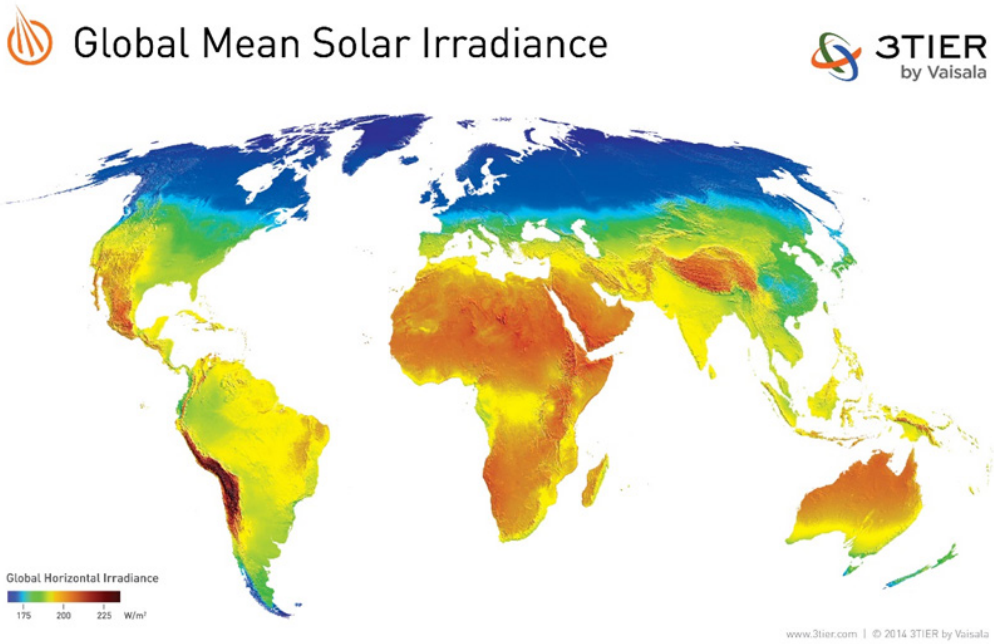
Load – the combination of all electrical appliances that are connected to the solar PV system, such as lighting, radio, TV, computer, refrigerator, etc.

Auxiliary energy sources – can be a diesel-generator or another renewable energy source.

Irradiance data

The appropriate climatic data for the locality concerned is obtained, which provides the average daily solar irradiance values from maps (see Figure 19) or from other accurately measured and assessed data sources.

Figure 19: Global mean solar irradiance



https://www.researchgate.net/figure/Global-mean-solar-irradiance-10_fig3_275922125

5.3.1 Solar inverters – voltage converters

Several solar PV panels are connected in series to form an array. The array is then connected to a centralized inverter to convert the DC generated by the array to AC. The nominal rating of the DC output is about 300 to 600 volts, which is converted to the appropriate AC voltage of the territory (the standard voltage for Europe is 220-240 VAC at 50 Hz, whereas for North America it is 120VAC at 60 Hz).

5.3.2 Advantage of solar over diesel-generators

Although the up-front costs of solar systems are significantly higher than those of a diesel-generator set, solar power is a cheaper option in the long run, because diesel-generators need regular fuelling and maintenance.

For rural telecommunication installations that lie far from the national grid, the traditional approach has been to provide self-contained generators to provide electricity. Solar power is a viable alternative.

Solar installations have very low running costs for rural telecommunication applications, with warranty periods exceeding 15 years, but manufacturers often offer lifetime warranties of 20 to

25 years with an anticipated tapering of the output to about 80 per cent of the original yield at the end of this time.

5.4 Wind power

Small wind turbines (SWTs) have a generation capacity of less than 100 kW and can be an excellent solution for rural electrification and for powering telecommunication facilities. The turbines typically have a diameter of between 7 and 15 m, with a power output generally below 50 kW.

A typical wind turbine can generate electricity at a wind speed of 3 to 5 metres per second, reaching maximum power at about 15 m/s and generally cutting out at about 25 m/s (depends on design).

Wind turbine design and elements

Horizontal axis is the most common design for wind turbines, providing higher efficiency and reliability compared with vertical axis designs.

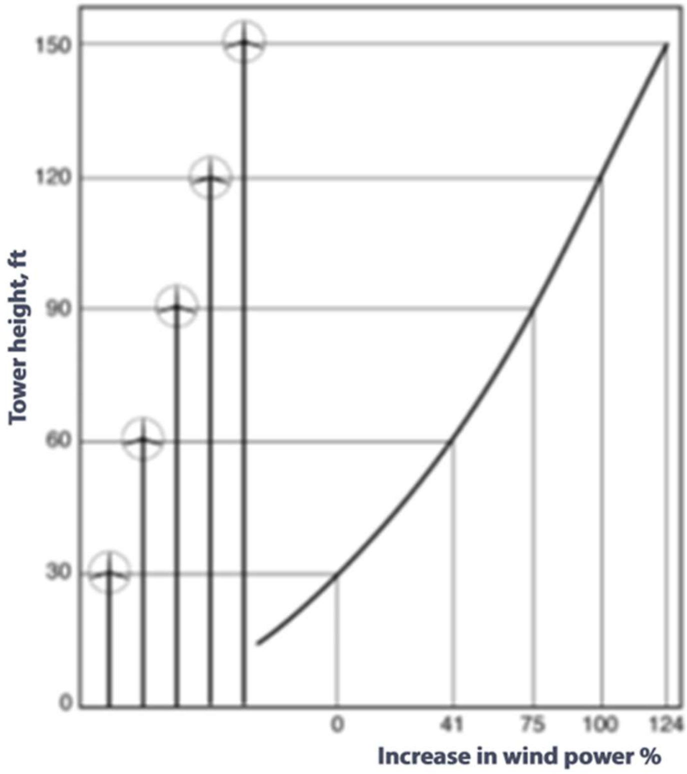
- Blade designs – integrated 1 to 3 blades mounted on a mast.
- For very small installations, e.g. a household, wind turbines will have a diameter of less than 2 m and output of approximately 1 kW.
- An average wind speed of 5 m/s or more can support the annual production of some 300 kWh per square metre of rotor surface.
- A 20 m, two-rotor swept area generates about 6 000 kWh, increasing to 8 500 kWh with 6 m/s wind speed.
  Blades must be mounted at a height greater than 15m away from ground turbulence.
- The wind turbine generators can be fixed or variable speed.
- Tilt-up poles, masts or towers are very popular in developing countries as they are easy to install and offer easy access for maintenance and repairs.
- Most SWTs have a permanent magnet generator (no need for a gearbox).
  The generator produces alternating current (AC), which is rectified to DC by bridge rectifier to produce an output that is similar to that of PV systems.
  The charge controller for in-battery charging systems prevents over charging, protects the battery and prevents the turbine from over-speeding.
  Where local data is not available, there is a need to make extensive wind measurements over an extended period of time prior to installation, as the specific location of the turbine is very important and must be carefully studied to avoid wind interferences.

Wind power has the following disadvantages:

- Unstable output, highly dependent on local topography and geography.
- Reliable wind speed data is rarely available for all candidate locations, so special tools are needed to identify the best position in an area.
- Higher structural requirement in tower design, and higher costs than traditional telecommunication towers, which do not need to carry the same high loads as wind turbines.
- The higher the power output required, the higher and more complex will be the tower design, to meet the structural demands.

The variation of power output with varying wind tower heights is illustrated in Figure 20.

Figure 20: Wind turbine power output versus tower height



Note: Indicative figure to illustrate the impact of tower height on wind turbine power output.

5.5 Fuel cells

There have been considerable advances recently in the development of fuel cell technology with regard to types of fuel and generation technology.

Fuel cells which use hydrogen as the fuel are the most popular. Hydrogen is the cleanest fuel due to its 100 per cent oxidation characteristics, emitting no pollution (produces only water). However, the adoption of fuel cells is hindered by the high initial CAPEX, the high replacement cost of the fuel and the lack of infrastructure to support the supply chain ecosystem for the fuel.

5.6 Biomass

Biomass is an interesting alternative form of green technology that is ideal for small-scale distributed energy generation. Fuel is widely available in the rural areas of developing countries and the technology has been increasingly adopted for community-based mini-grid power applications.

In telecommunication applications, however, biomass presents significant challenges in terms of scalability, operational complexity, supply chain reliability, and sustainability. Any fluctuations in the availability of the biomass source such as wood chips, agricultural waste, etc., will affect the viability and long-term sustainability of the power plant.

5.7 Micro-hydropower

Hydropower systems generate electricity using the same principles as wind turbines. The force of the water flow turns a propeller or water wheel which is connected to a generator. This produces an electric current.

- Micro-hydropower systems produce less than 100 kilowatts (kW) of power.
- Pico-hydro systems produce less than 1 kW.

The capital costs of micro-hydro systems are affected by site selection and basic layout.

System configuration is designed according to the available head of water.

Most micro-hydro installations are of the run-of-river type.

- Do not have any sizeable reservoir.
- Produce electricity only when sufficient water is flowing in the river.
- Electricity generation ceases when the water level is low or flow is inadequate.
- The environmental impact is minimal.
- Micro-hydro can be a least-cost source of electricity when the water body has sufficient head and flow is available.
- Serves community mini-grids and individual facilities.

Other advantages of micro-hydropower systems include:

- safe and secure investment over several decades;
- potential for individual, cooperative or communal ownership;
- requires only semi-skilled labour and cooperative administration for maintenance and construction;
- rapid deployment if local materials and skills are available;
- flexibility in adapting to quick load variations;
- long lifespan (decades).

Micro-hydropower systems can be used where rivers or falls are available and can be used in rural areas that cannot easily support solar or wind energy systems. They are reasonably simple to maintain and cost less to deploy than either solar or wind systems. Micro-hydro systems represent an attractive option for powering rural telecommunication systems.

Installation and maintenance of micro-hydro systems

Micro-hydro systems are not technically complex and can be implemented and managed by the local community.

- Require more frequent maintenance than comparable wind or photovoltaic systems.
- Bearings and brushes of generators require regular maintenance and replacement.
- Turbine must be protected from debris.
- Power is being generated all the time, therefore batteries are constantly recharged, hence, suitable for use with shallow-cycling batteries, such as automotive batteries, without undue performance constraints. Deep-cycle batteries offer similar system performance. The length and diameter of the feeder pipe are specified to suit the water situation and the turbine, otherwise the installation will be inefficient.

Key challenges:

- The availability of a suitable water body near the telecommunication tower site.
- Uncertainty of supply (water flow, head) at different times of the year.

Recommendation: rather than providing their own mini-hydro scheme, broadband service providers may consider a service model based on procuring electricity from hydro-based power suppliers on an agreed business model such as a power purchase agreement (PPA) or fixed costs.

5.8 Comparison of renewable energy sources – summary

The key advantages and disadvantages of various renewable energy sources that are suitable for off-grid rural and remote installations are outlined in Table 3. Energy produced from these sources will primarily serve the broadband systems and their ancillary support services but may be enhanced to provide electrification services to nearby communities.

Table 3: Advantages of renewable energy sources

	Pros	Cons
Solar	Renewable and sustainable ubiquitously available solar resource. Widely scalable owing to its modular technology – commercial scale or very small-scale applications. Suitable for distributed power generation. No maintenance cost of solar panels, except for some occasional unskilled labour to clean the panels. Cost-competitive compared to other green technology options. Stable electricity prices. Lifespan 20 to 25 years emission-free operation.	Large space requirements for higher capacity deployments. Intermittent as depends on sun, but predictable. High up-front CAPEX compared to traditional diesel-based solutions. Theft and vandalism of panels leading to high risk to investment (fencing). Low power-density compared to fossils. Long-term return on investment.
Wind	Suitable for small-scale distributed power generation. Significantly less space required, compared to solar. Low maintenance costs. Cost-competitive against fossil fuel options but less so than solar. Electricity prices more stable than with fossil fuel options.	Low reliability – due to the variability of wind speed, unpredictable, intermittent. High up-front costs. Break-even after 10 to 20 years. Low scalability and high investment. Need tall towers, 20-40 m for optimum power generation. Reliability of wind equipment varies widely. Noisy operation. High regular maintenance costs. Can be hazardous to flying birds.

Table 3: Advantages of renewable energy sources (continued)

	Pros	Cons
Micro-hydro	Efficient and reliable when water resource is available and flow is stable, particularly in rainy or winter seasons (if not frozen). Low flow-rates or low drop (or head) heights adequate to generate electricity. Low capital costs for small-scale systems. Function as run of the river system – dam not necessary. Low maintenance costs. Versatility for production in developing countries.	Site location and availability of suitable streams/rivers may be distant from the community to be served. Not easily scalable, size and flow of stream/river may restrict expansion. Lower power in dry season and summer months. Civil structure and stream diversions may be problematic.
Fuel cells	Reliable technology. Compact system and requires less space. Suitable for rooftop and urban contexts. Low maintenance. Low emissions and low noise. Less prone to theft and vandalism.	High up-front investment and cost of technology makes for a less cost-effective green choice. Highly dependent on fuel supply ecosystem and logistics. Need to build fuel reformer plants and reliable supply chain. Low range of capacities for distributed generation.
Biomass	Abundant biomass potential. Wide range of plant capacities. High reliability can be achieved with strong supply chain integration. Technology is widely available.	Operational complexity. High resource and operations costs. Biomass feed supply challenges and dependence on unreliable supply chain ecosystem. Sensitive to cost of inputs due to fluctuating feed prices.

Source: adapted from GSMA, Green Power for Mobile

5.9 Off-grid renewable energy

The investments needed for a programme to expand broadband access to rural areas are large, while the possible revenues are insufficient to cover costs without subsidies or other forms of financial support.

Expanding electricity access of a conventional electricity grid infrastructure into sparsely populated rural areas would be uneconomic as it would require high investment costs to extend high-voltage transmission lines and distribution networks into remote locations.

According to IRENA[25], off-grid renewable energy solutions, including standalone systems, micro-grids and mini-grids as viable electrification solutions, have emerged as mainstream, cost-competitive options to expand electricity access into unserved or underserved communities. Off-grid systems operate independently of the national electricity grid and are run by private

[25] Off-grid renewable energy solutions to expand electricity access: https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_Off-grid_RE_Access_2019.pdf

companies, sometimes in partnership with local community groups or in collaboration with incumbent national operators.

Figure 21 illustrates the segmentation of grid and mini-grid networks, showing that mini-grid is most appropriate for sparely populated rural electrification solution. In this segment, mini-grids offer the lowest cost, unsubsidized electricity retail price when compared to grid extension.

While urban areas have been served to varying degrees of success in the developing world by the national electricity grid, the vast majority of customers in rural areas of LDCs, in particular, are continually plagued by problems with capacity and coverage.

Off-grid solutions are deployed to generate electricity in unserved communities that have no access to the national grid, or in underserved areas where the power grid supply is unreliable or unaffordable. Off-grid power networks support household electrification, but most of the capacity is dedicated to commercial uses (e.g. powering telecommunication infrastructure), industry end-uses (e.g. cogeneration), public services (e.g. street lighting, education, health-care centres, water pumping) and livelihoods (e.g. fishing, agriculture).

The regional deployment of these systems should be based on local economic, geographic and social factors.[26]

Off-grid solutions are adaptable to local conditions, scalable, environmentally sustainable, and can empower rural communities and support digital public services in education, health care etc.

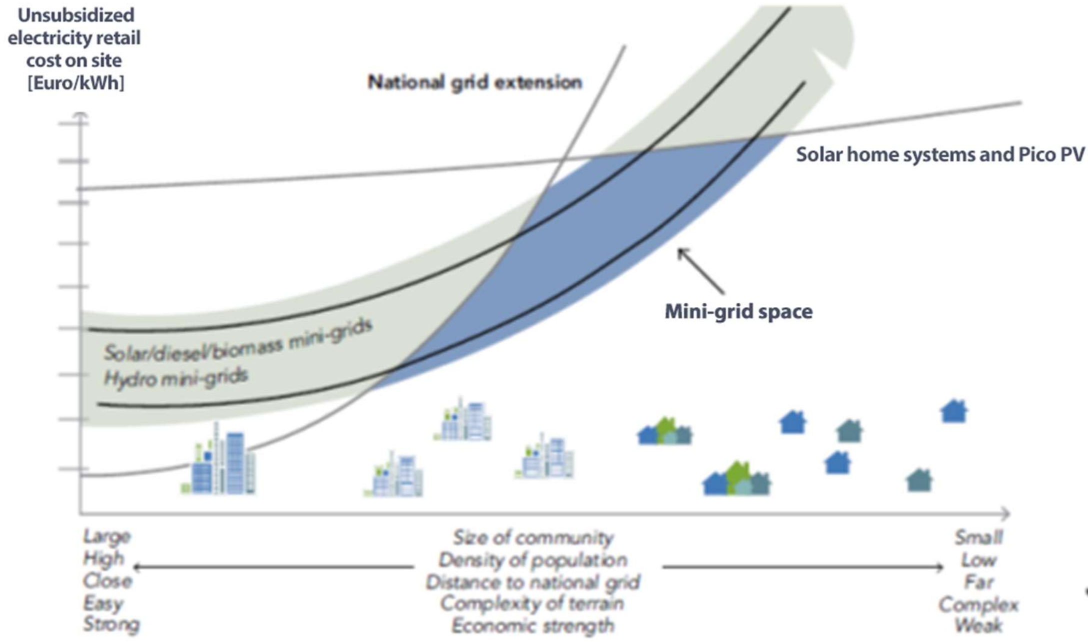
IEA estimates[27] that providing electricity for all by 2030 would require annual investments of USD 52 billion per year. Detailed geospatial modelling suggests that decentralized systems, led by solar PV in autonomous mini-grids, are the minimum-cost solution for three-quarters of the additional connections needed in sub-Saharan Africa.

[26] https://www.ren21.net/Portals/0/documents/Resources/MGT/MinigridPolicyToolkit_Sep2014_EN.pdf
[27] Energy Access Outlook 2017, www.iea.org/reports/energy-access-outlook-2017

Figure 21: Mini-grid segment (a growing role for mini-grid and renewables)

An illustration of the window in which mini-grids are the most suitable rural electrification solution.

(Opportunities for grid extension, mini-grids, and distributed renewable energy systems)



Source: EUEI PDF/REN21 2014.

5.9.1 Mini-grids

A mini-grid is a power distribution network which can operate in isolation from the national grid electricity transmission networks to offer small-scale electricity generation, typically between 10 kW and 10 MW, to a limited number of consumers via a local distribution network.[28] Mini-grids are the most appropriate option for powering remote installations and rural communities for which the cost of grid connection is prohibitive.

Micro-grids are like mini-grids but smaller, with a generation capacity between 1 kW and 10 kW. Micro-grids can be customized more readily to serve dispersed communities with isolated or smaller clusters of buildings.

Mini-grids can be tailored to more economically provide electricity for concentrated settlements, including domestic premises, cottage industries, businesses, institutions, telecommunication operators and remote utilities sites with power delivered at grid quality level or above. Mini-grids can be operated by telecommunication operators, utilities, other dedicated private companies, community-based organizations or some combination of these.

Mini-grids in many parts of the world still use diesel for electricity; however, using renewable energy solutions such as solar, hydro, biomass, or wind energy reduces cost, increases energy security and reduces environmental pollution.

[28] Africa-EU Renewable Energy Cooperation Programme (RECP). Mini-grid Policy Toolkit http://www.minigridpolicytoolkit.euei-pdf.org/policy-toolkit

In rural areas that are remote from the national grid electricity network, mini-grid operators can sell electricity to anchor customers such as telecommunication operators and local industries and can gain extra revenue by also distributing electricity to consumers in local communities. Tower operating companies (TowerCos) that generate electricity and provide services to core telecommunication operating customers may also deliver service to the local community, thereby increasing the return on their investment.

Table 4 shows the application and classification of mini-grid networks and technical characteristics of each type of network. The United Nations SE4ALL tier system is a measurement and evaluation system for electricity access used for global comparisons.

The evaluation of electrification solutions can be classified by a number of applications and quality metrics as shown in Table 4.

Table 4: UN SE4ALL – Global Tracking Framework 11

Energy access according to the SE4ALL Global Tracking Framework	No	Basic	Advanced			
Attributes	Tier-0	Tier-1	Tier-2	Tier-3	Tier-4	Tier-5
		Task light and phone charging	General lighting and television and fan	Tier-2 and any low-power appliances	Tier-3 and any medium-power appliances	Tier-4 and any higher -power appliances
Peak available capacity 12 (watts)	-	> 1 W	> 20 W/50 W	>200 W/ 500 W	> 2,000 W	> 2,000 W
Duration (hours)	-	> 4 hours	> 4 hours	> 8 hours	> 16 hours	> 22 hours
Evening supply (hours)	-	> 2 hours	> 2 hours	> 2 hours	> 4 hours	> 4 hours
Affordability	-		√	√	√	√
Formality (legality)				√	√	√
Indicated minimum technology		Nano-grids/ micro-grids, pico-PV/ solar lantern	Micro-grids/ mini-grids, rechargeable batteries, solar home systems	Micro-grids, mini-grids, home systems	Mini-grids and grid	Mini-grids and grid

Source: Adapted from The World Bank, 2014

Renewable energy sources such as solar, hydro, wind, biomass and fuel cells are utilized in clean energy mini-grids (CEMGs) with battery backup to balance demand and supply throughout the day. Diesel-generators can also be used in mini-grids as backup.

Some of the advantages of implementing mini-grid or micro-grid networks are as follows:

- Grid-quality power.
- Rapid deployment of service to telecommunication facilities and communities (weeks or months, not years).

- Can be tailored to local demands, scalable and flexible.
- Closer to the community being served, therefore reduced transmission costs.
- In the case of micro-grids, opportunities for private-sector/community partnerships to serve the off-grid community – operators, households and businesses – from local sources via low-voltage distribution lines.

Mini-grids are particularly appropriate and cost-effective for remote base stations and for mid-density communities with dispersed populations that are located far from the national grid, or that reside in areas which have unreliable power, or where grid electricity is unaffordable.

Standalone solar home systems are suitable where the local population is dispersed and households are far from the grid and require modest amounts of electricity.

Solar and wind technologies predominantly power telecommunication installations in rural and remote areas. They are predicted to make up more than 80 per cent of global renewable capacity growth over the next five years.

Table 5: Energy access interventions and indicative energy efficiency benefits – The EA+EE opportunity in context

Access tier	Technology or mode of delivery	Energy efficiency's value proposition
Tier 1	Solar portable lanterns/Pico PV	Energy-efficient light emitting diodes (LEDs) radically reduce the size and costs of the solar PV and batteries needed to provide service, making these technologies affordable for vast new markets segments.
Tiers 2, 3, 4	Off-grid systems	Energy-efficient appliances radically reduce energy supply needs, allowing a given off-grid system size to provide greater service and smaller, more affordable systems to provide equivalent service.
	Micro- and mini-grids	Energy-efficient appliances and devices can increase the number of connections a mini-grid can support, and can reduce a system's capital cost requirements, potentially improving financial viability.
	Industrious/community uses	Energy efficiency reduces the energy costs and/or extends the run time of motorized products such as mills, grinders and pumps. Efficient solar LED streetlights increase public safety and facilitate after dark commerce. Efficient solar pumping systems for irrigations have been found more cost effective than the average electric pumps. Efficient medical applications operate more reliably in under-electrified rural clinics or require smaller and more affordable off-grid energy systems.

Table 5: Energy access interventions and indicative energy efficiency benefits – The EA+EE opportunity in context (continued)

Access tier	Technology or mode of delivery	Energy efficiency's value proposition
Tier 5	Grid electrification/power sector reform	Supply- and demand-side efficiency improvements can enhance power sector reliability and financial performance, lowering prices for consumers and increasing the likelihood of energy bills being paid. In sectors with subsidized tariffs, efficiency can lower government costs.
Note: SE4All has developed a multi-tier framework for global tracking of energy access. Tier 1 represents very low energy service and Tier 5 includes full grid connectivity with higher-power appliances.		

Source: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2014/11/Africa-Market-Report-GPM-final.pdf

5.9.2 Standalone systems

Standalone systems are small-scale electricity systems that include solar home systems and pico-pv systems which are not connected to a grid electricity distribution network. A standalone system can serve the needs of individual customers, a home, a small cottage industry or business unit in areas which are sparsely populated and the potential demand is weak. Solar home systems up to 150W, can be used to power solar lamps, room lighting, mobile phone recharging, computers and small devices. Pico-PV systems provide up to 10W of power for items such as solar lamps, radios and for phone charging.

Standalone off-grid systems utilize locally available renewable energy resources including biomass, wind, hydro, and solar power. These systems often include storage systems which are typically a battery pack that permits the low-voltage DC devices to be directly powered from the battery or used for lighting and small DC appliances. AC low voltage can be produced using an inverter to power standard AC appliances.[29]

Standalone systems are most appropriate for communities where homes are dispersed and far from the grid and demand for electricity is modest.

Standalone solar system categorization

Pico-PV systems (PPS)

- Small solar home system - power output of 1 to 10 W
  - mainly used for lighting, mobile phone charger, small IT appliances, radio
- Small solar panel with battery and lamp. The PV panel can be fixed on the product itself (e.g. solar lanterns)
- Easy to install (plug and play), user-friendly application, low investment cost, little maintenance, high degree of expandability and flexible use.

[29] Rashid Al Badwawi et al. A Review of Hybrid Solar PV and Wind Energy System, https://www.tandfonline.com/doi/pdf/10.1080/23080477.2015.11665647?needAccess=true

Classic solar home systems (SHS)

- Classic solar home system – peak output up to 250 W.
- Composed of several independent components:
  - modules, charge controller, battery and loads
- Energy management is done by the charge controller
- Advantages of classical SHS are the DC loads:
  - DC-powered energy saving lamps, radios, TV and refrigerators

SHS are very energy-efficient systems without any conversion losses.

Solar residential systems (SRS)

- Larger standalone PV systems (SRSs)
  - For solar pico systems, peak output 2 to 10 W.
  - Ideal for rural or domestic applications
- Electricity for large individual installations like hotels, hospitals, schools, factories etc.
- Easy to operate and maintain
- Off-grid applications
- Classic elements of a standalone PV system include solar module, charge controller, lead-acid battery/lithium storage, inverters and loads (appliances).

Solutions of solar kits with combined connectivity are coming out, offering at minimal cost of double solution.

5.9.3 Comparison of renewable and fossil fuel sources for mini-grid applications

Due to their modularity, renewable energy technologies can be rapidly deployed and customized to meet energy demand using locally available resources and capacities.

Energy-related carbon dioxide (CO_2) emissions from fossil sources can be immediately and substantially reduced by switching electrification to renewable sources. Not only will air pollution levels be lowered, with benefits for public health, but considerable socio-economic benefits will also become possible thanks to the development of an interconnected, digitalized economy.

Table 6 describes the technical characteristics of various renewable energy and fossil fuel-based solutions that can be used in off-grid and grid-connected systems.

Table 6: Renewable mini-grid and off-grid, characteristics 2012/13

	Grid connected	Minigrid <50 MW/ own consumption	Standalone systems/ Individual electrification systems	Productive use
Gas	~ 1 500 GW			> 1 GW Gas-fired CHP systems
Diesel		5–10 GW 50 000–100 000 systems		

Table 6: Renewable mini-grid and off-grid, characteristics 2012/13 (continued)

	Grid connected	Minigrid <50 MW/ own consumption	Standalone systems/ Individual electrification systems	Productive use
Hydro	Large >10 MW 10 000-50 000 systems >1 000 GW	Small < 10 MW 100 000-150 000 systems 75 GW	Micro-hydro 0.1-1 MW Pico-hydro <0.1 MW	
Wind	310 GW 250 000 turbines	Diesel-wind hybrid <1 000 village/ mining systems	Small wind turbines 0-250 kW 806 000 turbines	Wind pumps > 500 000
Solar PV	50 GW/0.5 mln large systems >50 kW 80 GW/10-20 mln rooftop systems 1-50 kW	Diesel-PV hybrid <10 000 village systems	SHS <1 kW 5–10 mln systems	Solar lighting 5 mln; Telecom towers 10 000; Solar water pumps; PV Fridges/refrigeration; Street lighting systems; Traffic signs; Phone recharging stations
Biogas/biodiesel to power	14 GW 30 000–40 000 systems	< 100 kW biogas plants > 1 million biogas systems Gasification/rice husk etc. 1 000–2 000 systems		Livestock farms Back-up biodiesel generators
Biomass cogeneration	20 GW pulp, sugar/ ethanol 1 000–2 000 systems 20–30 GW steam cycles/ CH 1 000–2 000 systems 5–10 GW cofiring coal plant 250–500 systems			

Source: IRENA: Off-grid renewable energy systems

5.10 Basic components of a mini-grid installation:

A mini-grid renewable electricity system has several basic features, as shown in Figure 22.

1. Renewable power generators/source:

   Electricity can be produced from the following sources: solar photovoltaic modules, wind turbines, mini-hydro turbines from nearby streams or rivers and biomass power conditioners.

2. Inverters:

   DC to AC inverters are used to convert power from solar panels to AC voltage to power AC devices at the site. String or micro-inverters are options that are available; DC to DC converters adapt the solar array's DC output voltage to the level required by equipment and appliances.

3. Rectifiers:

   Convert AC voltage from wind, hydro turbines etc. to DC for equipment that requires it.

4. Energy storage – batteries and higher-capacity storage systems:

Mini-grids utilizing renewables (solar and wind) that deliver variable energy throughout the day will require optimally sized battery storage to provide electricity continuously. Excess electricity generated by these systems will be stored and delivered when required, thus compensating for fluctuating availability. In smaller mini-grids (i.e. under 300 kW) battery banks are typically used, while larger systems use other forms of storage systems such as lithium batteries.

5 Distribution network:

The type of distribution system used depends on the service to be provided over the network and the types of appliances that will be used. The network can be designed as a DC bus, or a single-phase or three-phase AC bus, to suit the systems or network characteristics. For networks that deliver services to individual customers, businesses or industries, consumption needs to be metered and recorded for billing purposes.

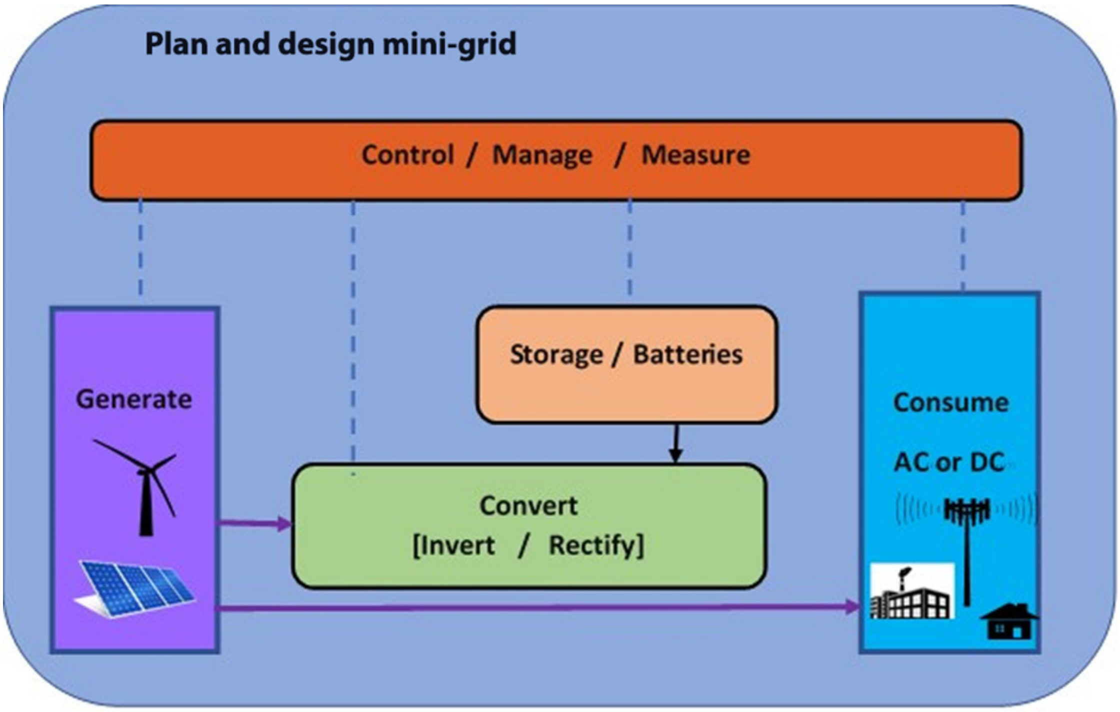
6 User/application subsystem:

For operators delivering services to end users, this could include the equipment located on the customer side, including internal wiring, meters, grounding, ICT equipment and electric appliances.

7 Smart management systems:

Perform such tasks as system control, management and optimization of the network, tariff collection, improved network energy efficiency measures and eventual grid connection. ICT may also be used for smart metering and billing/payment automation via mobile phones.

Figure 22: Mini-grid functionalities



The control functions of mini-grid networks include protection strategies and intelligent decision-making. Artificial intelligence (AI) may be used to optimize performance of the renewable energy technologies and maximize the mini-grid's energy efficiency. AI can facilitate accurate predictions of future weather conditions and load demand, activating controls to enhance system performance and minimize overall operational costs.

Data communications functions involve capturing data gathered by sensors, transmitting it to controllers, and then transmitting commands generated by the controllers to the actuators in the automated systems.[30]

The conversion function of a renewable mini-grid system enables energy generated from the renewable sources to be converted and adapted to match the characteristics of the load and storage systems in the mini-grid. These can be classified according to the input and output voltages:

- Converters provide DC-to-DC and AC-to-AC adaptation
- Rectifiers convert DC to AC (e.g. from solar DC power to feed AC load).
- Inverters convert AC-to-DC (e.g. from AC diesel to charge DC batteries/energy storage)

A mini-grid or micro-grid may be designed as AC or DC grids depending on the main load to be served.

Grid-forming inverters are capable of creating an AC grid in autonomous renewable mini-grids.

5.11 Solar-powered rural broadband network – Hopscotch Scotland

Hopscotch is a solar-powered broadband network specially designed for rural connectivity

Case Study - Hopscotch base station network in Scotland

HopScotch is a broadband network installation tested in the remote, sparsely populated highlands and islands of the west coast of Scotland. This trial was performed in a rural region that is located far from the nearest Internet exchange point and is without access to the electricity grid network. To set up a broadband infrastructure that can provide coverage over a vast rural area using a mobile base station powered by diesel generators would require substantial capital investment in areas, where grid power is unavailable or unreliable. In addition to the high and ever-increasing cost of fuel, added expense of fuel transportation and maintenance, diesels are noisy and emit CO_2 gases.

[30] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Innovation_Outlook_Minigrids_2016.pdf

Wireless network

The HopScotch base station test installations are radio systems operating in the 5 GHz Wi-Fi and UHF "white space" bands to illuminated communities using:

- low-power point-to-multipoint (PTMP) wireless access systems (similar to Wi-Fi), connected to
- Point-to-Point (PTP) radio relay backhaul links connecting the base station to the core network or when available, BTS can be directly connected to an IP-backbone;
- BTS is powered by WindFi, off-grid, hybrid renewable energy - solar PV panels, wind turbines and storage batteries.

These radios are designed to minimize consumption powered entirely by renewable and not like conventional cellular base stations with cooling systems that require substantial power.

Prototype "WindFi" base station on the Isle of Bute -2010

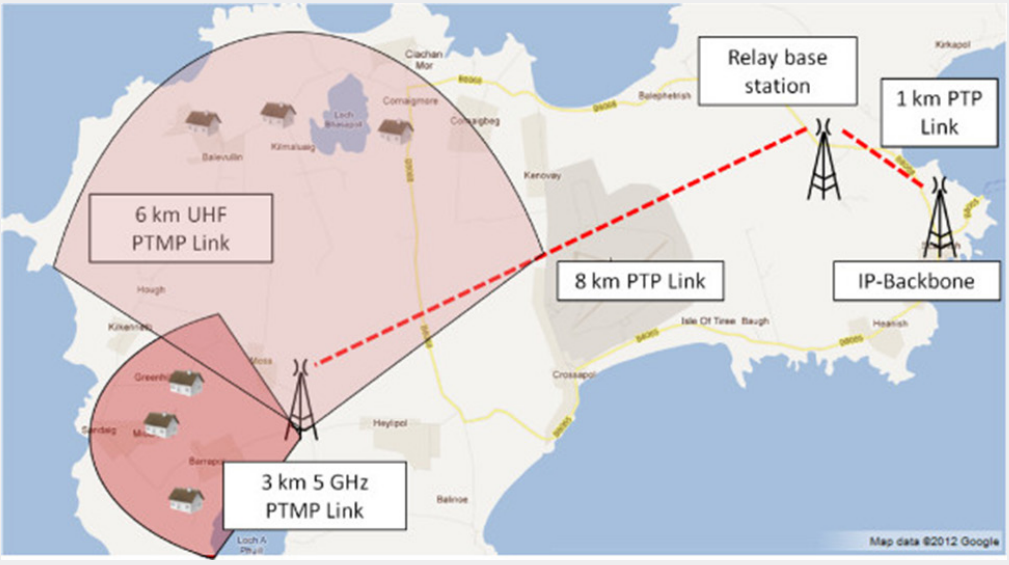
Prototype "WindFi" base station on the Isle of Bute, Scotland. The base contains solar panels and batteries, over which a 10 m mast carries the wind turbine with antennas and radio equipment directly beneath.

Source: https://jwcn-eurasipjournals.springeropen.com/articles/10.1186/1687-1499-2012-112/figures/4

The HopScotch radio system characteristics

- Point-to-Point PTP 5 GHz band C (5.725-5.850 GHz) variant is used to provide backhaul connectivity
  - Maximum EIRP of 4 W - radios based on IEEE 802.11n standard
  - 125 MHz total spectrum - two non-overlapping 40 MHz wide turbo channels
  - two independent spatial streams of 300 Mbit/s on vertical and horizontal polarizations

Example of a HopScotch network connecting a remote community to an IP-backbone



HopScotch: A low-power renewable energy base station network for rural broadband access
Source: https://jwcn-eurasipjournals.springeropen.com/articles/10.1186/1687-1499-2012-112/figures/1

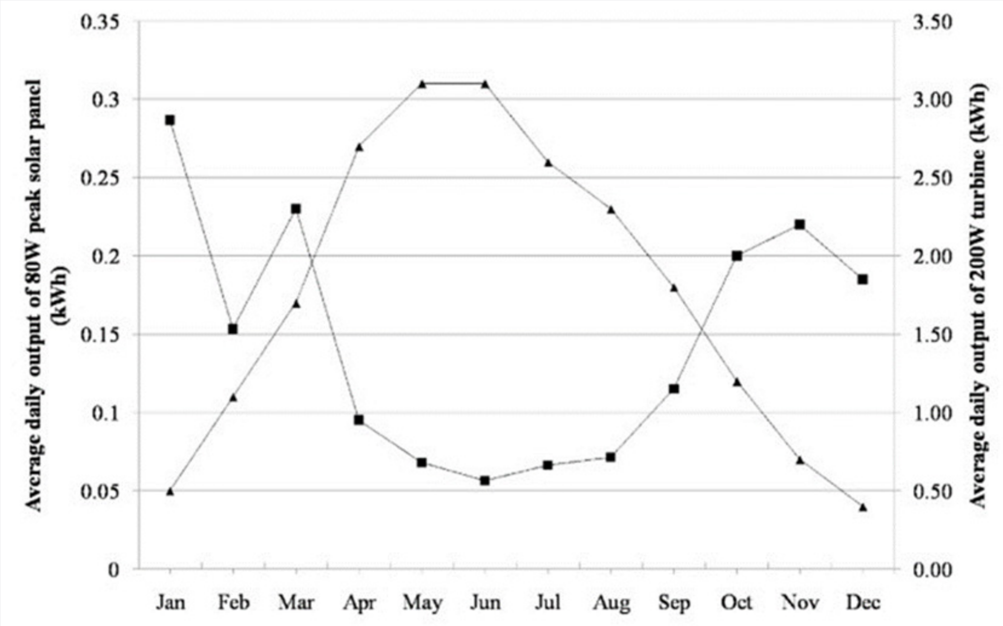
- Point-to-multipoint operating in the 5 GHz spectrum band is used to serve customers in the close vicinity (3 km) of the base station
  - Flexible number of sectors per site (2 to 6 sectors) depending on community size
  - Medium-sized community - 4 sectors
  - Unlicensed band B (5.470-5.725 GHz). Non-overlapping 11 × 20 MHz or 6 × 40 MHz channels
  - 8 to 10 broadband users on 65 Mbit/s (scaled as required)
  - Max EIRP 1 W
- Ultra high frequency system
  - Overlay TV "white space" UHF band, due to its propagation characteristics is used to extend the coverage to 6 km but at the expense of throughput.
  - 400 MHz TV "white space bands.
- Mast is 10 m (mounted with wind turbines, solar PV panels, radio equipment and batteries)

Renewable energy solution

WindFi is an ultra-low power base station, which for the specific site (in figure) use:

- Wind turbines (200 W) and
- Solar PV (80 W) modules with tracking system
- Solar and wind are complimentary renewable sources in Scotland as shown in figure.
- Base station powered 24 hours a day, 365 days a year.
- Batteries backup - continuous operation - 3 days backup
- Battery "depth of discharge" not to exceed 50 per cent.

Daily power generation from wind and solar sources



Average daily power generation from a single 80 W PV module (▲) and a 200 W wind turbine (■) on the Isle of Tiree, Scotland, based on predicted solar irradiation data from the Photovoltaic Geographical Information System and averaged wind speeds measured at Tiree Airport, with the wind turbine used for a "WindFi" base station.
Source: https://jwcn-eurasipjournals.springeropen.com/articles/10.1186/1687-1499-2012-112/figures/5

Renewable system sizing

Total load of radio, access systems and management are calculated. The battery bank is then sized for peak load and at 50 per cent DoD with three days standby. Solar panels are sized to cater for peak loads factoring irradiation data from Photovoltaic Geographical Information and average wind speed data from a nearby airport.

5.12 Hybrid power systems

Hybrid power systems use both renewable energy and fossil-fuelled electricity generation techniques or storage. Mini-hybrid and micro-hybrid, off-grid, distributed power generation systems can provide accessible, cost-effective and reliable electrification for rural installations and communities that are distant from the main electric grid and have little prospect of being connected to it. Hybrid power systems can combine renewable energy system – typically PV or wind generation with battery energy or energy storage systems and, as required, a generator set powered by diesel or another fossil fuel. Other subsystems are provided such as inverters, rectifiers and other control management and conditioning systems.

Renewable-powered small hybrid systems are suitable solutions for delivering basic, reliable electricity services to remote facilities and local institutions such as telecommunication and ICT operation centres, health centres, commercial organizations, small industry, business/office services, government agencies and workshop/vocational training establishments.

Case study: TELE Greenland

TELE Greenland developed a computer-controlled hybrid power system used to power unmanned 1.5 kW radio relay repeater sites in Greenland for five years. It used solar panels with an output power of 4800 watts each, batteries with a capacity of 4500Ah, and a small diesel-generator. It included a power distribution board and supervision equipment. The batteries provided primary power supply for the telecommunication equipment charged from the solar cells. TELE Greenland reports fuel savings of 80 per cent compared to a permanently running diesel-powered generator, and maintenance trips reduced to once per year.

Key drivers for hybrid mini-grids include:

- need for reliable and affordable access to electrification;
- fuel savings, dependency on or elimination of diesel generation;
- reduced CO_2 emissions.

A wide of variety of applications and configurations exist for renewable-hybrid mini-grids for rural and remote sites. When coupled with storage, they can smooth out and manage the variability of renewable power generation to match load demand throughout the day.

Mini-grids are often used for the following;

- Utility installations such as telecommunication tower facilities, water stations etc
- Community services – homes, government agencies, educational institutions, hospitals
- Local businesses and campus establishments etc.

Micro-hybrid schemes that generate under 5 kWp can be used to meet the electrification needs of small rural village communities, remote telecommunication base stations (low-capacity sites) and, in combination with diesel-generators, can very effectively reduce fuel consumption while providing high reliability.

Small distributed PV hybrid systems operating in the range 5 to 30 kWp are suitable for small remote/rural wireless access repeater sites and mobile base stations, and for providing lighting for households and standalone systems for local health centres, training centres, cottage industries and other community services.

Medium-size hybrid systems operating in the range 30 to 100 kWp require more advanced electrification capabilities and are suitable for communities with highly productive activities, for powering larger telecommunication facilities, small local industries.

Hybrid power systems can come in a variety of configurations:

- Solar PV with diesel-generator mini-grid/micro-grid solutions,
  - suitable for networks which have historically relied on diesel-generators and primary source or with unreliable grid, renewable energy can be deployed to reduce fuel use, minimize OPEX and maintenance costs and also reduce greenhouse emissions.
  - where there is inadequate space to build large-scale solar array plant
  - to improve reliability and allow for more modular network design
- Solar PV and wind turbine
- Solar PV, wind and diesel-generator

5.12.1 Hybrid AC mini-grid

Typically, an AC hybrid grid system will feed power from an AC source direct to the grid, while power from a renewable DC source, such as solar PV, will employ inverters to convert its power to feed the AC grid. Power from the AC grid will be rectified to charge the standby batteries or energy storage systems. When the AC source is unavailable, DC power will be drawn from the renewable source or from the batteries by converting their DC power back to AC to feed the load.

The design to match peak demand must consider that for community schemes, peak loads can fluctuate greatly in the course of the day. Daytime peak load demand comes mainly from the operation of offices, business and commercial users, centres, schools and health facilities and other institutions etc. Evening loads are dominated by residential demands: lighting, refrigeration, domestic appliances and entertainment systems.

In hybrid networks, a diesel-generator set, where used, will support peak loads, to increase reliability and ensure that batteries and energy storage systems are optimally charged. Hybrid system must be designed to minimize investment costs and to optimize the CAPEX and OPEX of the system.

Figure 23 provides an illustration of an AC-coupled system operated from solar and wind sources with inverters, incorporating a diesel-generator set that feeds the AC load directly via voltage stabilizing systems. The system design ensures that the batteries are optimally charged to smooth out demand and act as the standby source during periods when the main power sources are unavailable.

5.12.2 Hybrid DC mini-grid system

Telecommunication networks are usually powered by 48 volt DC systems with backup/standby batteries to maintain high reliability and assure around-the-clock availability, whereas IP equipment are designed to operate predominantly from AC as they require high power.

DC mini-grid distribution can provide greater energy efficiency and improved sustainability for powering DC loads, without the inefficiencies involved in the DC-AC-DC conversion required on AC grids (EMerge Alliance, 2015),[31] as conversion can reduce efficiency by 3 per cent or

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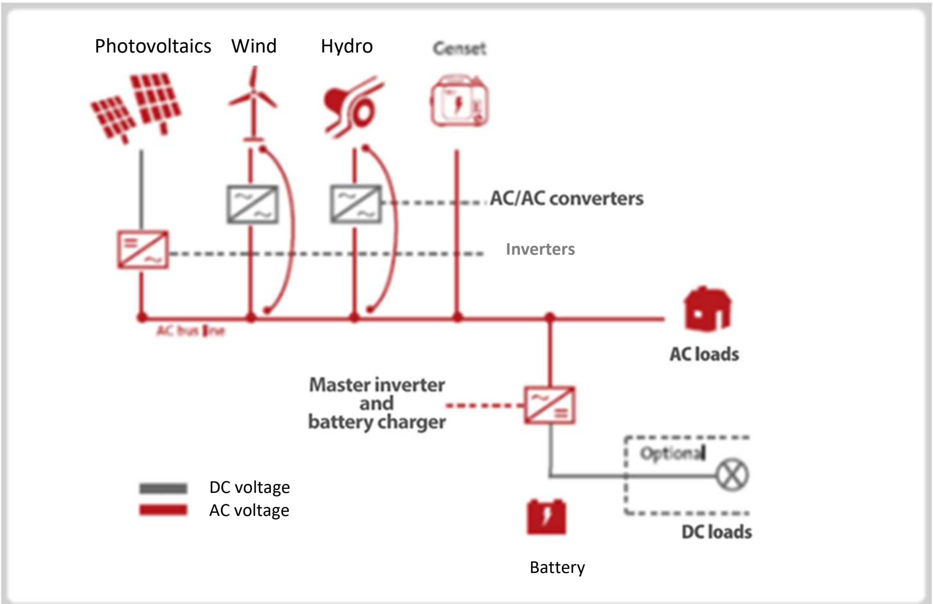
[31] Elsevier Image Alliance A comparison of DC - versus AC - based mini-grids https://reader.elsevier.com/reader/sd/pii/S2352484719300617?token=1CC673EF309F79143500252E66AA3A5642A79806AB4AD265761B8C9871538F1E3D0802384DFD3C1A8CE766B4EAB4B5A6

more (Willems et al., 2013).[32] Efficiency can be significantly improved by utilizing DC-powered appliances, which are more efficient and economical to operate, such as 12-volt LED light bulbs powered directly by PV, which provides savings of up to 30 per cent in electricity consumption without the need for inverters (Graillot, 2013).[33]

A hybrid DC mini-grid using solar PV, a wind turbine and battery backup system to power a remote telecommunication base station with only DC loads is illustrated in Figure 24.

Figure 23: AC-coupled hybrid mini-grid power system



Source: Schematic AC mini-grid system with system components, adapted from ARE (2011) https://www.ruralelec.org/sites/default/files/inensus-toolkit-en-21x21-web-ok.pdf

32 Willems, S., Aerts, W., De Jonge, S., Haeseldonckx, D., van Willigenburg, P., Woudstra, J., Stokman, H., 2013. Lirias: Sustainable Impact and Standardization of a DC Micro Grid. Presented at the Ecodesign International Symposium, KU Leuven, Jeju Island, Republic of Korea

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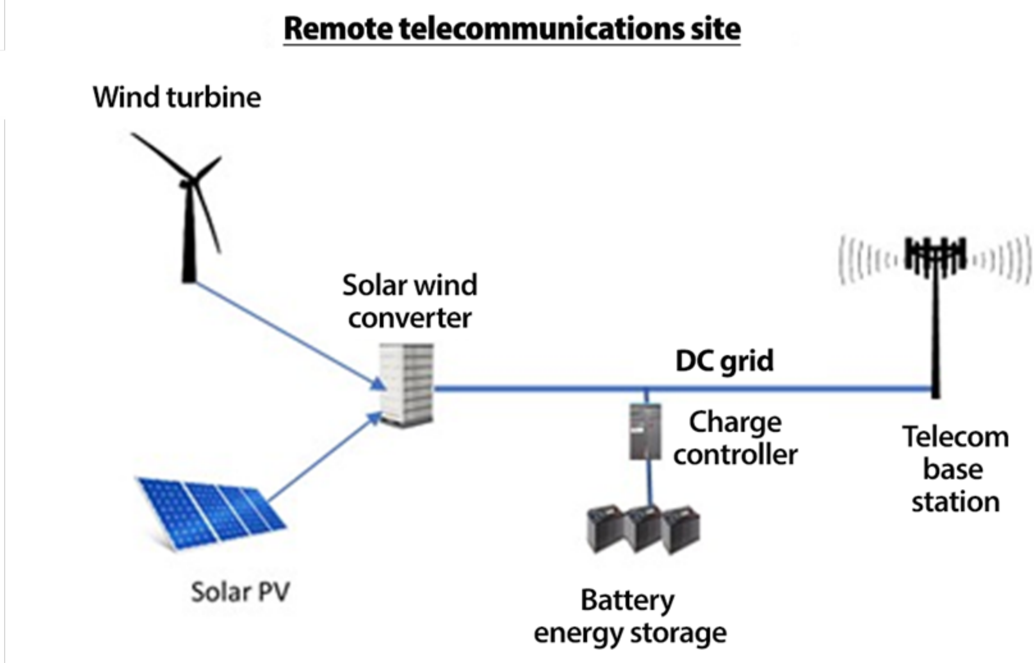
Figure 24: Hybrid DC grid – wind and solar PV



5.13 Hybrid solar and diesel generation

Solar panels have a very long lifetime. Manufacturers advertise a lifetime of 20 to 25 years, with output decreasing to around 80 per cent of the original yield after this time. The reason for this longevity is that solar panels have no moving parts. It is only the slow degrading effects of ultraviolet (UV) that wear the panels down.

Solar PV-diesel-generator mini-grids use batteries or other energy storage systems to smooth out the energy supplied to the load throughout the day and ensure that peak load demands are satisfied while minimizing diesel runtime and fuel use.

The solar PV system must be designed to satisfy peak daytime loads; excess energy can be used to charge the standby batteries. The batteries must be dimensioned to provide standby power in the worst case when all primary energy sources are unavailable. This could be for a few days in the worst case, for example when direct sunlight may be unavailable for a prolonged period.

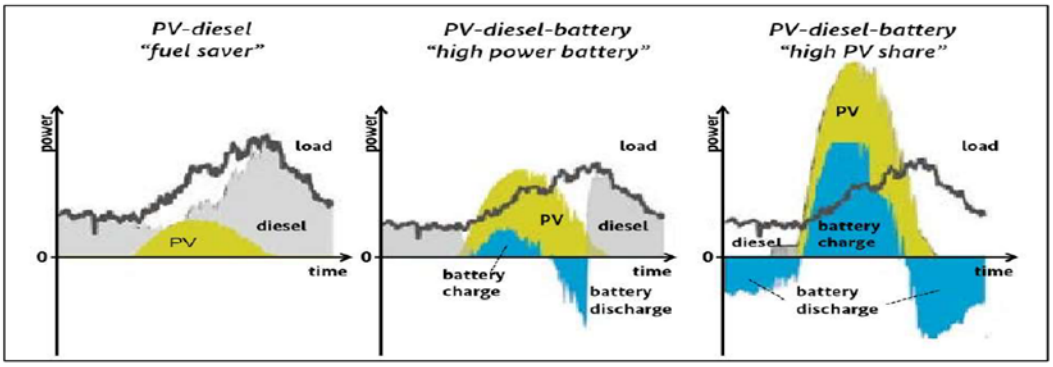
Diesel-generators, on the other hand, have a constant running cost due to the need for fuel, cleaning and filter changes. Though diesel-generators are cheap to begin with, their net cost slowly accrues over time. Diesel-generators are also unreliable and often require expensive overhauls to keep running. For this reason, numerous case studies have found that solar generators are a cheaper option over the long term.[34]

Despite this, diesel-generators remain a popular choice for electricity generation, because the acquisition cost of solar PV is over five times that of a diesel-generator set. Communities with limited access to capital may not have the resources to pay the large up-front costs for solar without finance. However, the lifetime cost of solar PV will be lower due to the cost of fuelling, transportation and regular maintenance of the diesel-generator.

[34] Solar Electric Light Fund; Universities Gadjah Mada; Abubakar Tafawa Balewa University; Arba Minch University; and Indian Institute of Technology

In order to size the system, the load factor of the diesel-generator and cycling of the battery must be determined as these have a significant impact on the lifecycle cost of the system (IEA 2013). Figure 25 illustrates a typical daily load profile and the operation of the diesel-generator and solar PV system.

Figure 25: Illustration of different operation modes of hybrid systems



Source: The German Climate Technology Initiative GIZ Promotion of Solar-Hybrid Mini-Grids, August 2016

5.14 Solar PV diesel-generator

Situation: No grid power at site in Pakistan, previously only diesel-powered supply

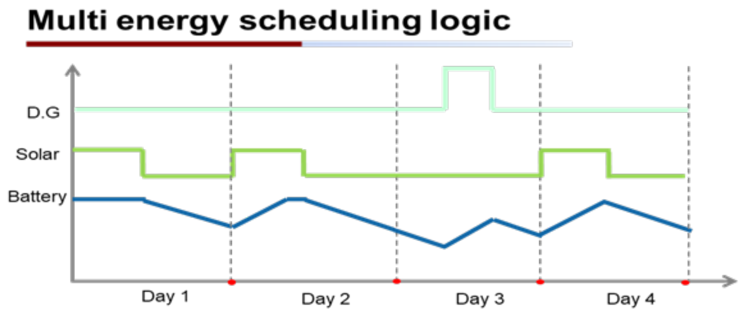
Solution Proposed: Hybrid solar PV, diesel-generator, lithium-ion battery bank

Result:

- The diesel-generator runs for less than two hours a day on average.
- The systems generated 12 per cent more energy than a diesel-only solution.
- Fuel consumption reduction of 80 per cent was achieved.

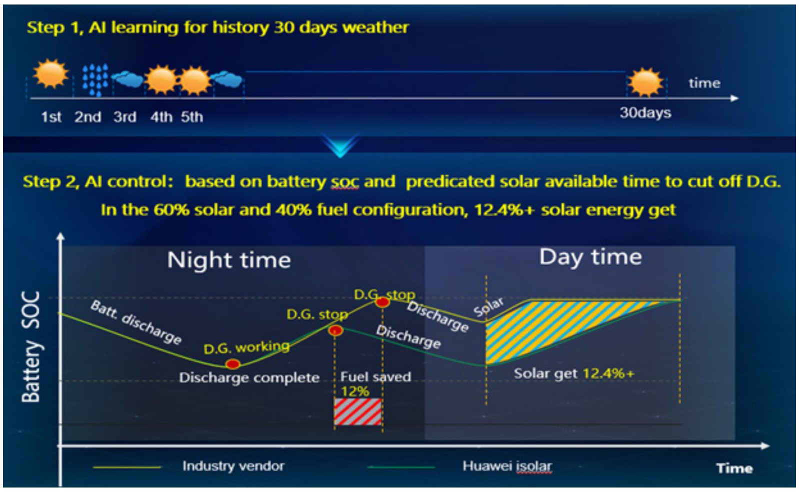
Source: Huawei

The charging and discharge cycles are shown in the chart below.



AI technology is used to control the diesel-generator. As illustrated below, the diesel-generator is turned on when the battery voltage reaches the minimum discharge threshold. In a normal situation without AI, the diesel-generator is turned off only when energy from the solar PV panel reaches 12.4 per cent of peak power.

With AI control, the systems predict the next day's sunrise times, i.e. when solar irradiance will be sufficient to charge the batteries, so as to turn off the diesel-generator at an earlier point. The charged battery level is monitored and the AI technology is used to predict at what battery voltage threshold and time the solar PV source will be available, to recharge the battery sufficiently during the day.



Huawei case study

Huawei's rural solution for hybrid mini-grid renewable energy - Reducing operational costs for Ufone mobile operator in Pakistan

Ufone is part of the Etisalat group of companies and the 4^{th} largest mobile telecommunication operators in Pakistan with 14 per cent market share and 22 million subscriptions. Ufone operates thousands of mobile base stations, with some located in urban areas which are powered from the main electricity grid network and others operating off-grid in remote rural areas. Ufone has installed diesel generators in over 8 000 sites to provide stable and standby power for its base stations in areas with unstable grid power. Because of power outages that last long, diesel generators had to operate for several hours at a time. The average power outages were 6 hours to 10 hours in cities, and between 8 hours and 20 hours in some rural towns and villages.

Competition in the Pakistan mobile market has resulted in operators receiving very low average revenue per user (ARPU) of USD 2.50, Ufone therefore examined network costs and sought ways to reduce operational and capital costs. The high cost of operating and maintenance, particularly fuelling diesel generators, in areas with unreliable grid supply was identified as a major concern and target for cost reduction.

Huawei proposed and implemented four models of hybrid power solutions for Ufone based on various combinations of using Solar, Photovoltaic systems, storage battery banks and diesel generators (provided as standby). Minimizing the operation of diesel generators or removing them completely would reduce environmental pollution.

Model 1. Sites experiencing 6-8 hours outage.

Huawei proposed:

- removing the diesel generator and
- install a fast- charging batteries (3-4 hours to full charge).

This was an adequate solution as the diesel generator and previous lead acid battery bank were no longer required.

Model 2. Sites experiencing 10-16 hours power outages.

Huawei proposed diesel sets and a hybrid solution of

- lithium batteries with a one-hour fast charge capability, higher capacity, longer cycle life (100 Ah, 3 500 cycle lifetime).

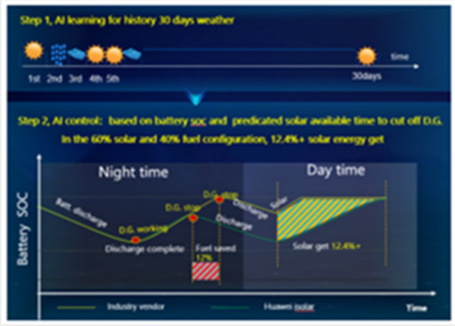
- Fast charge batteries as standby, offering 2 - 3 hours fast charge in standby mode. (100 Ah, 2 000 cycle lifetime.)

Mode 3. Sites experiencing 16-20 hours power outages.

Huawei proposed removing the diesel generators and installing a hybrid solution:

- install solar PV array.
- lithium batteries 2 hours fast charging time.

This solution was appropriate and did not require any power feed from an alternative source.



Model 4. Sites standalone without access to the grid.

Huawei proposed implementing a hybrid solution of solar, generator, batteries, AI management:

- install solar PV array
- lithium batteries 2 hours fast charging time
- diesel generator as standby

This solution resulted in an 80 per cent reduction of diesel generator operation and fuel use as the solar array generated sufficient power to operate the communication equipment and fully charge the lithium batteries. The AI technology was used to predict the optimum period for the generator to operate and control its functioning.

5.15 Storage solutions

Storage provides or absorbs power to balance supply and demand and to counteract fluctuations in customer loads and generation.[35]

Due to the rapidly falling costs of solar and wind power technologies and increasing production volumes, renewable energy systems are becoming the norm for most off-grid applications. Electricity storage is emerging as a critical part of off-grid solutions and directly impacts on decarbonization initiatives in these key segments of energy use that currently rely heavily on diesel fuel.

It is estimated that with improvements in battery technology, total electricity storage capacity could triple by 2030. The costs of battery storage technologies are projected to fall by up to 66 per cent.[36] As the price of electricity storage technologies continues to decline and become more affordable, the share of renewable energy used in mini-grids will continue to increase with an increasing range of technical, economic and social benefits (IRENA, 2016).

5.15.1 Lead-acid batteries

Lead-acid batteries have been the predominant energy storage technology used over decades as a backup solution to diesel-generators, powering on-grid or off-grid telecommunication

[35] SE4All HIO CEMG. Off-grid renewable energy solutions to expand electricity access https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_Off-grid_RE_Access_2019.pdf

[36] https://www.powerelectronics.com/alternative-energy/6-promising-energy-storage-options-tie-grid

facilities in urban and rural areas worldwide. Two main classes of lead-acid batteries are wet cell batteries (flooded unsealed batteries), and valve-regulated lead-acid batteries (VRLA) which use gel or absorbed glass mat (AGM) sealed battery banks. Sealed gel batteries are preferred for applications that require slow discharge, or that operate at higher ambient temperatures, while AGM has better charging rates.

Lead-acid batteries are an inexpensive, widely deployed rechargeable technology. They are suitable for a wide range of applications; however, they have low energy density, very short lifecycles and poor depth of charging. Their optimum operating temperature range is also quite restricted.

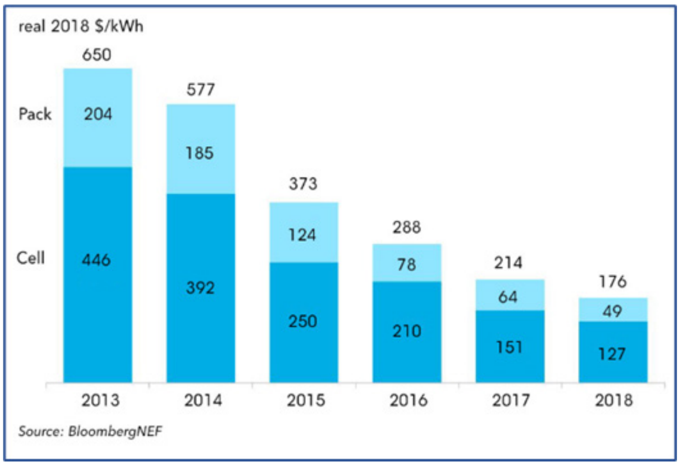
Flooded batteries require thermal management system and require periodic maintenance for water replacement. VRLA batteries, on the other hand, are designed with self-regulating valves that prevent electrolyte loss, and although more expensive than flooded batteries, have much longer lifecycles and can operate without maintenance for 10 years.

If discharged to below 50 per cent depth of discharge, the lifetime of lead-acid batteries will be reduced, while lithium batteries can be discharged to 80 per cent without significant long-term damage.

5.15.2 Lithium batteries

Lithium-ion batteries have seen the most rapid growth and cost declines in recent years, driven largely by the development of electric vehicles. They are predominantly used in mobile and portable devices and consumer electronics due to their superior energy density. The Bloomberg New Energy survey report of 2017 (see Figure 26) indicated that the average price of a lithium-ion battery pack fell by 85 per cent between 2010 and 2018 and will continue to decrease over the next few decades, due to increased volumes in the main, and driven by the transport industry and research and development. IRENA predicts a significant decline in the installed cost of lithium-ion batteries of 54 per cent in 2016 to 64 per cent by 2030 for stationary applications.[37]

Figure 26: Lithium-ion Battery Price Survey: Pack and Cell Split



[37] IRENA. Electricity Storage Costs 2917

Lithium batteries are the most widely deployed battery storage solution, used in over 90 per cent of the grid battery storage market globally.[38] Their ability to store energy economically during the day when solar energy is plentiful, and cheaper, and then to release it at night when residential demand increases, will drive greater generation of solar energy. Likewise, low cost, excess wind power generation at night from wind farms can be stored and released during the day to satisfy peak demand.

Compared to lead-acid batteries, lithium batteries have the following advantages.[39]

- High energy density, low weight (new innovations include replacing graphite with silicon).
- Can tolerate deeper levels of depth of discharge (DoD) without significant deterioration, unlike lead-acid batteries.
- Lower lifecycle costs with significantly longer usable life; approximately six times the number of charge cycles than lead-acid batteries can handle (particularly lithium-ion phosphate batteries).
- Can be charged very rapidly (lithium-iron can be charged fully within 30 minutes) and only lose a fractional charge when left idle for an extended period of time.
- Are maintenance-free and do not need to be stored vertically or in ventilated compartments.
- Improved efficiency.
- Prices have dropped in recent years, lithium batteries are becoming more attractive for off-grid energy installations.

5.15.3 Flow batteries

Flow batteries are different from conventional rechargeable batteries in that their electroactive materials are not all stored within the cell around the electrodes but, instead, are dissolved in electrolyte solutions that are stored in separate tanks for the anode and cathode sides.

Flow batteries have a lower energy density than Li-ion batteries, but their energy and power characteristics can be scaled independently.

5.15.4 Flywheels

When surplus energy is to be stored, flywheels can store it in the form of rotational kinetic energy by accelerating a rotating mass in a frictionless enclosure. When energy is required, the kinetic energy is released back to electrical energy by decelerating the flywheel's rotor speed.

Flywheels are suitable for shorter discharge times (a few seconds to several hours) and are used for power management, such as improving grid stability. They are often used for regulating and improving power quality. Flywheels are used to smooth out energy produced by outputs from wind turbine farms. They are capable of releasing a large amount of power in a very short period of a few seconds.

Although very expensive to install, flywheels have high power potential and can achieve 100 per cent DoD for more than 150 000 cycles without degrading over time. They also have relatively high standby losses due to very high discharge rates of up to 15 per cent per hour, so are suitable for short-term storage.

[38] Environmental and Energy Study Institute Fact Sheet: Energy Storage (2019) https://www.eesi.org/papers/view/energy-storage-2019

[39] Lithium-ion Batteries - https://www.usaid.gov/energy/mini-grids/emerging-tech/storage

5.15.5 Solid-state batteries

Solid-state batteries have benefited from considerable research investment in recent decades. Batteries are being developed that have a solid cathode and anode with a solid electrolyte between them instead of a liquid. They are therefore more durable and are extremely safe to use. Solid-state batteries also have higher energy densities than standard lithium-ion batteries. However, they are very expensive and generally not commercially viable.

5.15.6 Supercapacitors

Supercapacitors are another emerging technology for energy storage systems that can offer higher power density than traditional batteries and higher energy density compared with traditional capacitors. Supercapacitors are becoming an attractive power solution for an increasing number of applications. A supercapacitor is built as a double-layer capacitor with very high capacitance but low voltage limits and stores more energy than electrolytic capacitors. Electrical energy is stored at an electrode-electrolyte interface which consist of two metal plates, coated with a porous, activated carbon material which presents a bigger surface area for storing much more charge. The plates are immersed in an electrolyte.

Superconductors offer the advantages of high-power density and ability to handle high load currents. Their efficiency is good, with long cycle lifetime of hundreds of thousands of times and wide temperature range.

Supercapacitors are ideal for applications requiring many rapid charge/discharge cycles and can be charged in a matter of seconds. They are ideal for short-term power needs, such as in grid stability (voltage and frequency stability). They are also used in consumer electronics, uninterrupted power systems for wind turbines and in devices used in distribution networks etc.

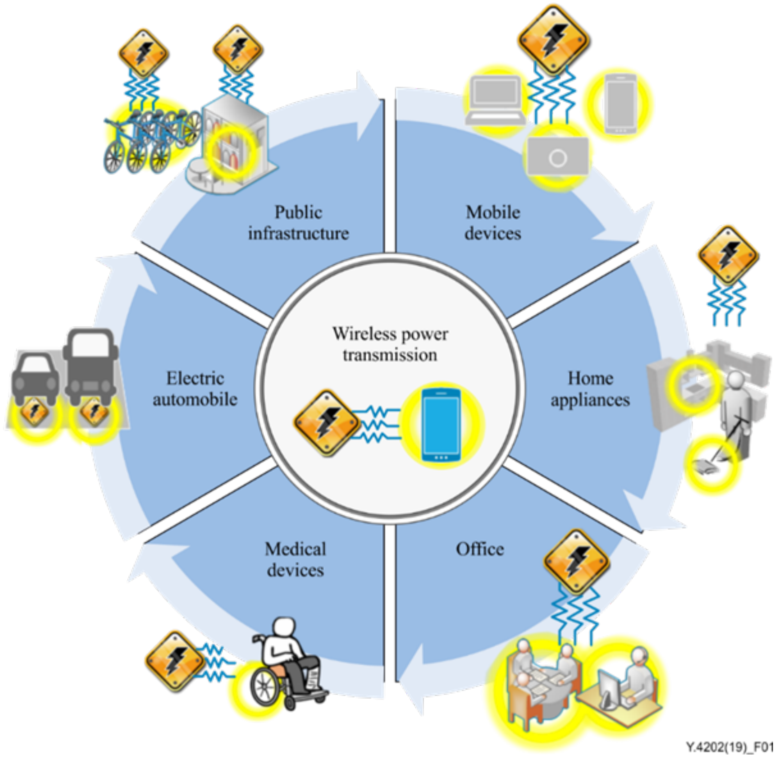
A major disadvantage is their low energy density. They are therefore not suitable for use as a continuous storage power source.

5.16 Wireless power transmission

Wireless power transmission (or transfer) (WPT) technology is considered a game-changing technologies, as it promises to deliver electric power even in the most challenging scenarios. Power transmission by radio waves dates back to the early work of Nikola Tesla in 1899. Tesla carried out his first attempt to transmit power without wires in 1899. He used low-frequency power at 150 kHz, but his attempts failed. Information about WPT using technologies other than radio-frequency beams, as partial answers to Question ITU-R 210-3/1, was published in Report ITU-R SM.2303 in 2014 and several times updated until 2021. Following a demonstration at the Massachusetts Institute of Technology (MIT), several promising WPT technologies are being explored, including magnetic induction, resonance coupling, transmission via radio frequency beam, etc. Details can be found in the above-mentioned ITU-R Report.

Studies of the impact between such WPT systems and the radiocommunication services are being carefully studies within ITU-R and some Recommendations have already been approved (see at: https://www.itu.int/rec/R-REC-SM/en). Further studies regarding the safety aspects such as human exposure to electromagnetic fields are also on-going.

Figure 27: Typical wireless power transmission scenario



5.16.1 Power access using wireless power transmission via radio frequency beam

Wireless charging technologies have been in constant evolution, currently offering support for radiated transmission without regard for distance (beam WPT). Beam WPT technology can offer substantial improvements in some applications as compared to non-beam WPT, which utilizes inductive, resonant and capacitive coupling technologies.

Beam WPT technology can be designed and implemented into many different-sized electronic devices for the home and office, as well as the medical, industrial, retail and automotive industries, and it ensures interoperability across products. These devices include wearables, hearing aids, earbuds, Bluetooth headsets, Internet of Things devices, smartphones, tablets, e-book readers, keyboards, mice, remote controls, rechargeable lights, cylindrical batteries, medical devices and any other device with similar charging requirements that would otherwise need a battery or a connection to a power outlet.

Beam WPT transmitters use narrowband spectrum, typically 400 kHz or less, to transmit RF energy to a client device. The transmitter is inactive until an authorized client device has been identified, authenticated, and determined to be at zero distance from the WPT charger pad. Beam WPT over-the-air technology operates in similar spectrum and relies on antenna arrays and beam focusing techniques to transmit RF energy to precise client device locations. Because some beam WPT power transmissions from wireless charging systems are directed to a client device, they should not be viewed as an isotropic radiator; focus their energy on specific locations and transmit only when an authorized client is present.

Figure 28: Image of point-to-point WPT

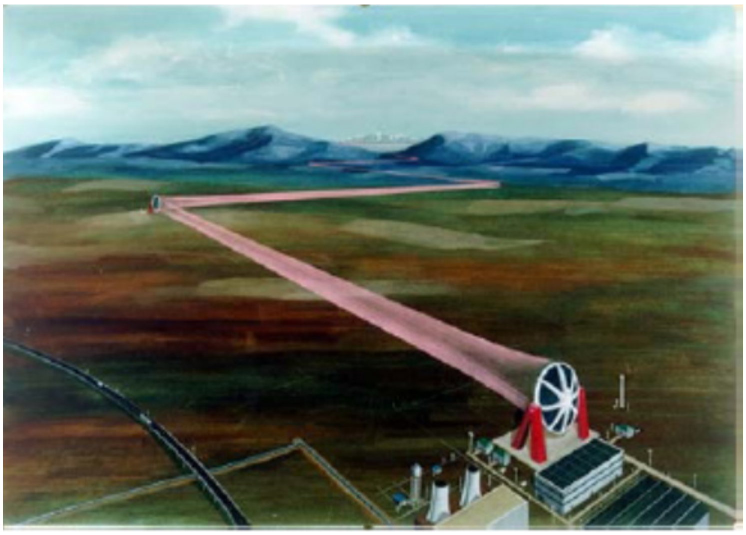


Figure 29: One mile point-to-point power transmission experiment with a 26 m parabolic antenna and a 450 kW, 2.388 GHz klystron as a transmitter and a 3.4 × 7.2 m rectenna array as a receiver

In a WPT system via radio frequency beam, antennas are used to transmit and receive radio waves. The transmitting and receiving antennas are not electromagnetically coupled. So, a number of transmitters and receivers are free from the circuit parameters of transmitters and receivers. The principle of the WPT via radio frequency beam is based on the Friis transmission formula. The radio wave which transmits wireless power does not need modulation, unlike a wireless communication system.

Several companies in the United States have developed beam WPT technology for use cases requiring transmission at a distance. In 2020 a digital shelf labelling system for retailers was demonstrated that requires no wires or batteries. Operating at 2.4 and 5.8 GHz, it has an operating range of about 10 metres and can also power smartphones, compatible smart home devices, automotive sensors and many other devices. Other technologies have been developed that operate at different frequencies. However, existing beam WPT technologies are not currently authorized by the FCC to operate at these larger distances in public settings in the United States. Another company uses the Industrial, Scientific and Medical (ISM)-band (in the millimetre wave range).

Additional information on applications using WPT via radio frequency beam can be found in Report ITU-R SM.2392 updated until 2021.

5.16.2 Power access using wireless power transmission with other technologies

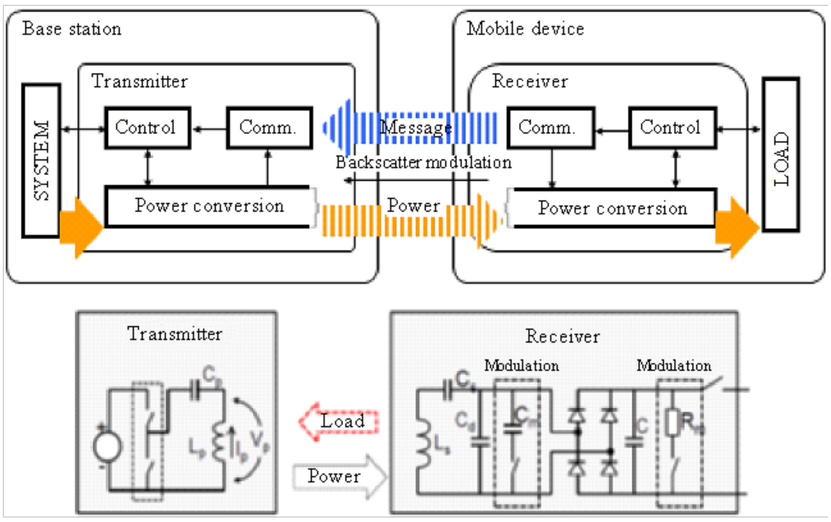
The following technologies are also described in Report ITU-R SM.2303.

Magnetic induction WPT technology

WPT by magnetic inductance is a well-known technology, using the same principle that underlies conventional transformers, where primary and secondary coils are inductively coupled, with a shared magnetically permeable core to improve coupling. Inductive power transmission through the air with primary and secondary coils that are physically separated is a technology that has been known for more than a century. It is also known as tightly coupled WPT. A feature of this technology is that the efficiency of the power transmission drops if the air gap is larger than the coil diameter and if the coils are not aligned within the offset distance. The efficiency of power transmission depends on the coupling factor (k) between the inductors and their quality (Q). This technology can achieve higher efficiency than the magnetic resonance method. This technology has been commercialized for charging smart phones. With a coil array, it also offers flexibility in the receiver coil location of the transmitter.

Portable and mobile devices form by far the largest volume of WPT devices currently being used. An IHS consumer survey indicates that 35 per cent of consumers in the United States use wireless power charging for their mobile devices (primarily smartphones). The Wireless Power Consortium website indicates that about 150 million WPT transmitters for smartphone charging are in use as of mid-2017.

Figure 30: Block diagram of a typical magnetic induction WPT system



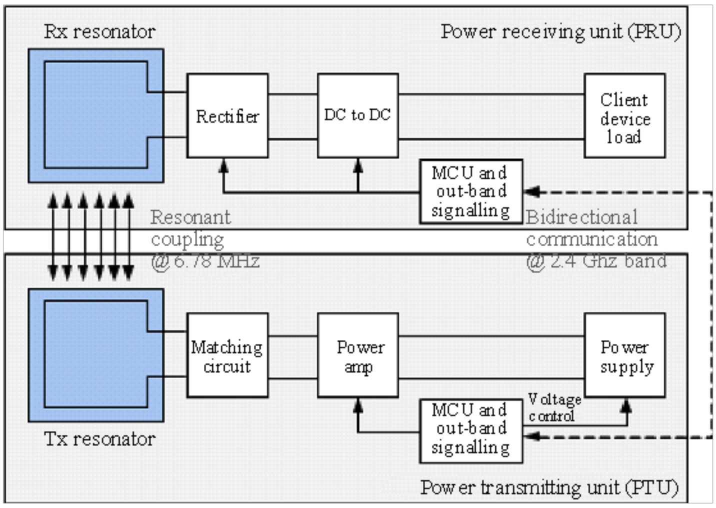
Report SM.2303-3-01

Magnetic resonance WPT technology

WPT by magnetic resonance is also known as loosely coupled WPT. The theoretical basis of this magnetic resonance method was first developed in 2005 at MIT, and validated experimentally in 2007. The method uses a coil and capacitor as a resonator, transmitting electric power through the electromagnetic resonance between transmitter coil and receiver coil (magnetic resonant coupling). By matching the resonance frequency of both coils with a high Q factor, electric power can be transmitted over a long distance where the magnetic coupling between two coils is low. A magnetic resonance WPT system can transmit electric power over a range of up to several metres.

This technology also offers flexibility for the location of the receiver coil of the transmission coil. Practical technical details can be found in Report ITU-R SM.2303.

Figure 31: Block diagram of a typical magnetic resonance WPT system



Report SM.2303-3-0

The WPT base station can perform WPT charging only for identified WPT devices, blocking unidentified devices. This environment can be an office or home, with registered devices, as shown in Figure 32.

Figure 32: Example of fixed WPT devices

If a user wants to install new WPT devices in their home or office, the new devices are required to be registered to the WPT base station. The WPT base station will keep information related to the new devices, such as device identification and type of WPT charging.

6 Financial mechanisms for renewable energy investments

The least developed countries (LDCs), home to 13 per cent of the world's population but accounting for just 2 per cent of the world's gross domestic product (GDP), face severe structural impediments to achieving the SDGs (UN-OHRLLS, 2017). With average access rate to electricity at 44.8 per cent and a global electrification rate of 87.4 per cent in 2016, the LDCs are far from achieving universal access to modern energy by 2030. Expanding access into rural areas has been hindered by high implementation costs and high connection and operational costs, coupled with a lack of investment (UN-OHRLLS, 2017).

Within the LDCs, access to electricity tends to be far greater in urban areas than in rural areas. In 2016, 75 per cent of the urban population had electricity access, compared with only 31 per cent of rural populations, but access is expanding only slightly faster in rural areas from a very low base. Due to the high up-front investment required for mini-grid projects, tariffs are usually higher than grid-based tariffs (unless there is a significant subsidy for the mini-grid), which may be unaffordable for rural businesses and households.

The energy access situation in the LDCs varies from a regional perspective, as well. In 2016, the Asia-Pacific LDCs had achieved an average electrification rate of 73.6 per cent, while the rate in African LDCs was much lower at 30 per cent.[40]

6.1 Financing rural renewable energy infrastructure

The financing of green mini-grids in rural areas of developing nations has, over the years, constituted a major challenge for private developers. The main reason for this has been the high cost of green energy technology and the challenge this imposes on the profitability of such projects. This cost has significantly decreased over the past 10 years, but the very low-income levels in rural regions of the Third World means that clean energy technologies remain largely inaccessible in these parts of the world.

In 2013, Africa's total energy infrastructure needs were estimated at USD 63 billion. Only 12 per cent of these financing needs were addressed that year, with 50 per cent of the financing coming from domestic sources (from the respective governments) and the rest from external sources.[41] African countries generally have low tax-to-GDP levels and, therefore, lack the revenues to adequately finance the development of their local energy infrastructure.

One of the recommended ways of boosting domestic revenues in these countries is by reducing government spending on such things as the payment of subsidies on hydrocarbon fuel. This cost-saving strategy, alongside others, can give governments financial latitude to offer tax and other financial incentives to private developers of green mini-grid solutions. These incentives are helpful, but create a new challenge for investors: the uncertainty around their sustainability,

40 UN Energy access and main challenges in the LDCs https://www.un.org/ldcportal/energy-access-and-main-challenges-in-the-ldcs/

41 Sy, Amadou and Copley, Amy (2017): Closing the Financing Gap for African Energy Infrastructure: Trends, Challenges, and Opportunities. Policy Brief, Africa Growth Initiative, The Brookings Institution, Washington, DC.https://www.brookings.edu/wp-content/uploads/2017/04/global_20170417_africa-energy-infrastructure.pdf#page=10&zoom=auto,-99,92

given that they are based on policies that can change within the lifetime of the project. Even when these incentives are considered, the start-up costs are still very high.

Telecommunication tower – anchor customer

The telecommunication industry offers a great opportunity to private developers. The telecoms industry is experiencing very rapid growth in off-grid rural regions of the Third World. This is possible because network operators generate their own off-grid power, typically using diesel-generators but increasingly turning to renewable energy, to run their mobile base stations. To improve base station security, lower the cost of power, grow revenue streams, and facilitate increased usage of mobile phones in these off-grid communities, telecommunication operators are trialling different approaches to providing electricity beyond the base station into local communities through the Mobile for Development Utilities Programme[42] (Taverner, 2010). Foremost among these approaches is the outsourcing of power to private developers, with the mobile base station providing a stable anchor demand for the power. Anchoring their business around providing power to the mobile base station can allow private developers to profitably power the surrounding communities. While this model of partnership between network operators and private developers of mini-grid solutions does not solve the problem of high start-up costs, the reliable power demand from the mobile base stations provides a solid business case that can attract investment and long-term research funding.

6.2 Universal service funds

Universal service funds are traditionally employed to create incentives for telecommunication companies to expand telecommunication services to remote areas.[43] Financing community power projects in the target communities is not part of that, at present. There is a need for the funds to be diversified to include financing the initial phases of community power projects as a means of facilitating the uptake of telecommunication services in these off-grid communities.

Finance will be a major challenge for the proposed massive expansion and upgrading of electricity systems for the LDCs that are considered necessary to achieve universal access by 2030.

As with other production processes, generating, transmitting and distributing electricity entails fixed and variable costs. The electricity industry faces a substantial front-loading of investments before cost recovery can take place. In particular, the transmission and distribution network is associated with massive fixed costs.

Non-hydro renewable generation technologies, such as wind and solar, also have high fixed costs, although they are much lower than those of large-scale centralized fossil fuel-driven plants or renewable sources.

Commonly assessed risks in the LDC electricity sector are the low ability of consumers to pay; the absence of frameworks to guide private-sector participation; and the perceived regulatory risk from monopoly public utilities, subject to social mandates and political uncertainties.

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[42] Taverner, David (2010): Community Power: Using Mobile to Extend the Grid. Green Power for Mobile. GSMA, London. 80p.

[43] Dorward, Lynne A. (2013): Universal service funds and digital inclusion for all. International Telecommunication Union, Geneva. 142p.

Between 2012 and 2014, the share of middle-income countries in finance mobilized through guarantees, syndicated loans and shares was 72.3 per cent. The LDC share was 8 per cent, and for other low-income countries it was 2 per cent. Developing countries in Africa (29.1 per cent) benefited the most, followed by those in Asia (27.2 per cent) and the Americas (21.1 per cent) (OECD, 2016a).

Pay-as-you-go schemes

Pay-as-you-go (PAYG) providers can take one of two approaches to financing the system through the consumer.

- An indefinite fee for service, in which the consumer never owns the system itself, but rather merely pays to use it. This functions on the basis that the consumer only pays when power is needed and available at an affordable price, typically on a daily, weekly, or monthly basis (resembling a typical financing arrangement).
- The consumer will eventually own the system after paying off the principal system costs and the consumer must make discrete payments.

M-KOPA case

M-KOPA Solar is an often-cited example of a firm with good experience of successful PAYG applications, having connected more than 330 000 homes in Kenya, Tanzania, and Uganda to solar power with over 500 new homes being added every day (The Economist 2016).

6.3 External financing

Presently, the principal sources of financing for community power projects are external, mainly official development financing from such multilateral organizations as the African Development Bank, the World Bank, and OECD-DAC, as well as from private investors. The multilateral organizations are increasingly collaborating to find more innovative ways of offsetting the high risks and costs associated with these projects to encourage participation of private investors. Numerous platforms have thus been created by these organizations to facilitate the development of bankable green energy projects and link investors with these projects. Most of these platforms also influence energy policies in Third World countries, especially as policy is one of the main factors that investors cite as being important in determining their decision whether to invest in certain countries. Some of the financing platforms are outlined below.

6.3.1 Sale of carbon

The Kyoto Protocol, which was signed in 1997[44] and came into force in 2005, has assigned greenhouse emission caps to all signatory countries. The objective is to accelerate the development of clean technologies and to reverse the trend of global warming. The Protocol therefore instituted a mechanism by which to reward efforts towards the development of clean technology.[45] Countries (i.e. projects within these countries) that are slow in reducing their greenhouse emissions to the acceptable levels can buy carbon credits to offset the excess emissions they are generating (measured as metric tonnes of carbon dioxide equivalent). These carbon credits are issued by countries (i.e. projects within these countries) whose emissions are below their assigned emission caps. Carbon trade is highly regulated and involves several steps of verification by third parties.

6.3.2 Clean Development Mechanism (CDM)

CDM is the platform set up under the Kyoto Protocol for carbon crediting of project-based emission reductions in the developing world. These credits, referred to as certified emission reductions (CER), are sold to industrialized countries, who purchase it to meet their emission reduction targets. The trade is supervised and managed by the Adaptation Fund Board (AFB).

The CDM project cycle consists of seven steps, all of which are regulated by separate rules and references. These steps consist of: (1) project design by project participants, (2) national approval of project by designated national authority, (3) validation of project by designated operational entity, (4) registration of project by the CDM Executive Board, (5) monitoring of project-by-project participants, (6) verification of the project by a designated operational entity, and (7) the issuance of the CER by the Executive Board of CDM.

Sources of Funds	Eligible projects	Restrictions	Impact
CDM	– Hydro, wind, solar, geothermal, and biomass energy projects – Energy-efficient household device projects	– Nuclear energy projects – Hydroelectric projects must not exceed 20 MW installed capacity (except under certain conditions) – Applicable in countries that have ratified the Kyoto Protocol – To be discontinued in 2020 and replaced by Paris Agreement provisions	– More than 8 409 projects registered so far. • 1 097 in Latin America • 6 877 in Asia and Pacific • 84 in Europe and Central Asia • 241 in Africa • 110 in the Middle East
Key references (includes policy frameworks and methodologies for modelling expected value of funding)			
– https://cdm.unfccc.int/Projects/diagram.html – http://climateneutralnow.org/Pages/Home.aspx			

44 United Nations (1997): Kyoto Protocol to the United Nations Framework Convention on Climate Change. United Nations, New York. 192p.

45 UNFCCC (2007): The Kyoto Protocol Mechanisms. United Nations Framework Convention on Climate Change. 6p.

6.3.3 Africa Carbon Credit Exchange (ACCE)

ACCE is a carbon exchange that is being set up by the Zambian government to serve as a platform for individuals and firms across Africa to raise capital for green projects. The ACCE is just one of several carbon exchanges that already operate around the world.

Source of funds	Eligible projects	Restrictions	Impact
Africa Carbon Credit Exchange	All Africa-based green projects	Will not be available to projects that are not based in Africa	Not yet operational
Key references			
- http://www.africacce.com/ - https://www.daily-mail.co.zm/carbon-credit-exchange-set/			

6.3.4 Carbon Trading Exchange (CTX)

CTX is a London-based carbon exchange that operates globally. It is owned by Global Environmental Markets (GEM). CTX interfaces with many environmental commodity registries and is electronically linked to financial intermediaries for efficient trading and transparency.

Source of funds	Eligible projects	Restrictions	Impact
Carbon Trading Exchange	Global green projects	None mentioned	The world's first and largest electronic carbon trading exchange
Key references			
- http://ctxglobal.com/ - http://www.gemglobal.com/			

6.3.5 African Renewable Energy Fund (AREF)

AREF is a pan-African private equity fund focused on supporting small- to medium-scale independent power producers in sub-Saharan Africa. The fund, which was launched in 2014, has a committed capital of 200 million USD. It is headquartered in Nairobi, Kenya, and is principally sponsored by the African Development Bank (AfDB). Other major sponsors include Sustainable Energy for Africa (SEFA).

Source of Funds	Eligible projects	Type of assistance	Impact
AREF *Other partners include: SEFA, AfDB, ABREC, EBID, BOAD, FMO, Calvert Foundation, CNUCED, BIDC, Berkeley Energy Africa Limited, GEF, DANIDA, USAID*	– Small/medium independent power projects from solar, wind, biomass, hydro as well as some geothermal and stranded gas technologies	– Equity financing – Engineering support – Management support	– 10 million to 30 million USD in equity capital is committed per project.
		Key references	Restrictions
		– http://www.berkeley-energy.com/index.jsp#home	– Projects must range between 5 and 50 MW output – Does not support projects in South Africa

6.3.6 Power Africa, Beyond the Grid

Power Africa is a US government-led initiative focused on investment and growth of off-grid and small-scale energy solutions across sub-Saharan Africa. The organization has partnered with more than 40 investors and practitioners to leverage more than 1 billion USD in commitments towards achieving innovative solutions. Power Africa is also working with African governments to ensure that the regulatory environments are supportive of off-grid private options. Power Africa has so far generated a list of 13 early-stage Project Preparation Facilities that operate across sub-Saharan Africa's energy sector.

Source of funds	Eligible projects	Type of assistance		Impact
Power Africa – a US government-led partnership *Other partners include: AfDB, ATI, Canada, DBSA, UK Aid, France, EU, IDC, IRENA, Israel, Japan, NEPAD, Norway, SE4All, Sweden, World Bank*	– Hydro, wind, solar, geothermal and biomass energy projects – Energy-efficient household device projects	– Grant funding – Debt financing – Equity – Mezzanine financing – Insurance – Guarantees – Early stage risk capital	– Project preparation – Project development support – Technical assistance – Legal assistance – Technological/scientific research – Market research	– Already committed more than USD 54 billion. – Supports 130 private-sector partners in more than 14 sub-Saharan African countries. – 40 of the private-sector partners are focused on developing mini-grid and distributed power services and infrastructure in rural and peri-urban areas.
Key references				
– https://www.usaid.gov/powerafrica/beyondthegrid – https://www.usaid.gov/powerafrica/toolbox				

6.3.7 Sustainable Energy Fund for Africa (SEFA)

SEFA is an AfDB-hosted USD 95 million multi-donor facility funded by the governments of Denmark, Italy, United Kingdom and the United States. It supports the sustainable energy agenda in Africa. SEFA operates by issuing grants to facilitate the preparation of bankable projects, making equity investments in these projects via AREF, and supporting public-sector institutions in improving the enabling environment for private-sector investments. It is aligned with the Sustainable Energy for All (SE4All) initiative of the United Nations. Together, they run the Green Mini-Grid Help Desk, which provides a complete information service for developers of green mini-grids (GMGs) in Africa.

Source of funds	Eligible projects	Type of assistance	Impact
SEFA *Partners include: AfDB and SE4All*	– Green mini-grid projects in Africa – Project must target capital investment of USD 30 to 200 million	– Cost-sharing grant funding to facilitate pre-investment activities (pre-feasibility to financial closure) – Technical assistance at pre-investment stage – Equity investment via AREF – Help governments create enabling environments for private investments (legal, regulatory and policy regimes)	– One of the major contributors to the AREF initiative.

(continued)

Source of funds	Eligible projects	Type of assistance	Impact
		Key references	
		- https://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/sustainable-energy-fund-for-africa/ - https://www.se4all-africa.org/se4all-in-africa/financing-opportunities/sustainable-energy-fund-for-africa/ - http://greenminigrid.se4all-africa.org/	

6.3.8 OPEC Fund for International Development (OFID)

OFID is the development finance institution established by the Member States of the Organization of the Petroleum Exporting Countries (OPEC) in 1976 as a channel of aid to the developing countries. OFID's Energy for the Poor Initiative, which is funded through a revolving endowment of USD 1 billion pledged by OPEC's Ministerial Council, seeks to pursue viable solutions to make clean energy universally available to the rural poor in developing countries. In 2016, the initiative made a total of USD 412 million in new commitments. More than half of this was approved through the private sector for the construction of power plants that included photovoltaic and hydropower installations in Africa.

Source of funds	Eligible projects	Type of assistance	Impact
OFID *Partners include: SE4All, the energy industry*	- All energy projects in developing countries	- Infrastructure and equipment provision - Research and capacity-building Grants for small-scale renewable energy schemes	- Projects spread across 90 developing countries have been supported so far
		Key references	Restrictions
		- http://www.ofid.org/FOCUS-AREAS/Energy	- Does not support projects in Nigeria and Ivory Coast.

6.3.9 International Renewable Energy Agency (IRENA)

The IRENA Project Facility is a funding facility for renewable energy projects in developing countries. It offers concessional loans allocated over seven funding cycles to support renewable energy projects recommended by IRENA to ADFD (Abu Dhabi Fund for Development) for funding in developing countries. Applications can be submitted by governmental, semi-governmental, private or non-governmental entities but must have the support of and must be prioritized by the government of the country where the project is to be implemented.

Source of funds	Eligible projects	Type of assistance	Impact
IRENA *Partners include: SE4All, the energy industry*	– Project must be implemented in an IRENA member country – Project must deploy renewable energy – Project must have advanced beyond feasibility and pre-implementation stages – Project must have a full feasibility study and economic analysis at the full project proposal stage	– USD 5-15 million debt financing per project	– Projects spread across 90 developing countries have been supported so far
		Key references	Restrictions
		– http://www.ofid.org/FOCUS-AREAS/Energy	– All applications should be supported by a government guarantee letter, issued by the ministry or the authority that deals with the international cooperation and borrowing affairs of the country.

6.3.10 Renewable Energy and Energy Efficiency Partnership (REEEP)

REEEP is a Vienna-based international multilateral partnership accelerator for the deployment of renewable energy and energy efficient systems in developing countries. REEEP invests in reliable, affordable and secure distributed electricity solutions for off-grid small-scale household (standalone solar lighting and power sources) to micro-grid and mini-grid applications in communities with unreliable or no grid connectivity. The REEEP co-hosted Private Financing Advisory Network (PFAN) provides participating companies with business and strategy mentoring, and investor matchmaking to help transition projects from donor to private financing. REEEP follows these projects closely, using a monitoring, evaluation and learning framework that helps them capture, process and react to project experiences as they occur, and generate evidence-based intelligence towards further growing and replicating promising models. This knowledge is a fundamental step in reducing the risk of market engagement for businesses, investors and public sector stakeholders. REEEP also follows a multi-tiered approach to sharing knowledge, beginning with direct collaboration with close partners who can put evidence to good use by developing policy and shaping investment pipelines. The organization hosts an emerging alliance of climate knowledge brokers known as the Climate Knowledge Brokers Group, of which it is a leading member.

Source of funds	Eligible projects	Type of assistance	Impact
REEEP *Other partners include: UNIDO, IRENA, Sida, Austria, Blue Moon Fund, CDKN, Germany, GIZ, Norway, OFID, Switzerland, United Kingdom, CEC, EURIMA, EU, Australia, Canada, Ireland, Italy, New Zealand, Spain, Netherlands, United States, NAIMA, Rockefeller Foundation*	– Technically viable – Commercially viable – Reduces greenhouse gas emissions – Has developmental benefits – Has competent management team – Has potential for growth	– Project development support – Project structuring (including financial structuring) – Funding for feasibility and technical studies – Grant sourcing – Debt sourcing – Equity sourcing – Collaborative knowledge-sharing technology for policy development and shaping of investment pipelines – Efficient and high-performance knowledge management systems – Mezzanine financing – Insurance – Guarantees – Early stage risk capital	– Over 1.2 billion USD for financing of 87 project concluded – Project Power Africa: Beyond the Grid Fund for Zambia – USD 25 million investment to bring clean energy solutions to 1 million Zambians.
		Key references	Restrictions
		– https://www.reeep.org/ – https://www.bgfz.org/ – http://pfan.net/ – http://www.reegle.info/ – https://www.climateknowledgebrokers.net/ – https://www.climatetagger.net/	– REEEP cannot accept unsolicited proposals outside of project calls

6.3.11 Department for International Development (DFID) Impact Fund, United Kingdom

The DFID Impact Programme aims to catalyse the markets for impact investment in sub-Saharan Africa and South Asia to stimulate investment into businesses that benefit poor and low-income people through improving access to affordable goods and services and enabling income-generating opportunities at the base of the pyramid (BoP). The programme has two core components: two investment vehicles managed by CDC and a range of market-building activities. The programme started in 2012 and DFID plans to provide up to GBP 197 million over 16 years to this end. The impact investment covers a wide range of social and environmental issues with different investors and intermediaries. In the short term, the Fund will catalyse increased capital by giving confidence to co-investors via robust due diligence of investees' financial returns and development impact, and by offering limited potential subordination to private investors where necessary to catalyse their participation. In the longer term, the fund aims to catalyse further capital by proving the financial viability of pro-poor business models and demonstrating the positive impact that this type of investment will deliver. As part of DFID's Impact Programme which aims to catalyse the market for impact investment in sub-Saharan Africa and South Asia, DFID has launched a GBP 40 million Impact Acceleration Facility. The Facility, managed by CDC, aims to generate economic opportunity and employment through the creation of both direct and indirect jobs, and by increasing access to basic goods and services, especially in remote areas or fragile states. The high impact investment strategies are focussed on two specific areas. (1) Helping businesses to do high development impact interventions related to their core business that they wouldn't otherwise have done, such as entering a new, very difficult geography or developing a product offering at a significantly lower price to allow access to goods and services for poorer consumers, particularly women and girls. (2) Helping businesses in challenging geographies to establish green or brownfield companies adjacent to their mainstream investments to provide essential goods and services vital to their operations, such as housing, health care and transport.

Source of funds	Eligible projects	Type of assistance	Impact
DFID Impact Fund *Other partners include: CDC Group, etc.*	- Projects focused on poverty alleviation in low-income communities - Project must have demonstrable social impact and be financially viability	- Robust due diligence - USD 5 to 15 million equity financing - Project diversification	- The fund supports seven energy companies in Africa. - It aims to provide finance to more than 100 enterprises in sub-Saharan Africa and South Asia.
		Key references	Restrictions
		- http://www.theimpactprogramme.org.uk/investments-dfid-impact-fund/	- Does not finance projects that can be supported through micro-financing. - The fund has 11 more years to complete its mission.

6.3.12 Sustainable Energy for Economic Development (SEED)

SEED is an initiative of the Rocky Mountain Institute in the United States, and works with governments, utilities, development partners, and private sector energy developers in sub-Saharan Africa to drive affordable, efficient, whole-systems energy programmes that incorporate emerging distributed, renewable technologies and rapidly provide energy access to those without electricity.

Source of funds	Eligible projects	Type of assistance	Impact
Sustainable Energy for Economic Development (SEED) *Other partners include Virgin Unite, The Rockefeller Foundation*	– Hydro, wind, solar, geothermal and biomass energy projects – Energy efficient household devices projects	– Technical, policy and financial advice – Participation in implementation of projects	– Partnered with Rwanda to build capacity and strategy for more efficient energy management leading to USD 20 million short-term and USD 1 billion long-term savings on energy and increase on-grid and off-grid electricity access in rural areas from 22% to 70% . – Currently working in Sierra Leone and Uganda.
		Key references	
		– https://www.rmi.org/our-work/global-energy-transitions/seed/	

6.3.13 Renewable Energy Performance Platform (REPP)

REPP supports small to medium-sized renewable energy projects below 25 MW throughout sub-Saharan Africa. The initiative was developed by the United Nations Environment Programme (UNEP) and the European Investment Bank (EIB) to deliver the UN SE4All objectives in sub-Saharan Africa by supporting renewable energy projects. A wide range of renewable energy technologies are eligible for support, including wind, solar PV, geothermal, waste to energy (landfill gas and thermal waste to energy), run-of-river hydropower, biomass and biogas. REPP has initial funding of GBP 48 million from the Department for Business, Energy and Industrial Strategy of the United Kingdom through the International Climate Fund. REPP supports both grid-connected and off-grid projects. It also considers projects being developed by private developers, if REPP eligibility criteria are met.

Source of funds	Eligible projects	Type of assistance	Impact
REPP *Partners include: Department of Energy & Climate Change, UNEP and European Investment Bank*	– Renewable energy projects. – Projects must be in the 1 to 25 MW capacity range. – Projects must be in at least one of the following countries: Benin, Burkina Faso, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Liberia, Madagascar, Malawi, Mali, Mozambique, Nigeria, Rwanda, Senegal, Sierra Leone, Tanzania, Togo and Zimbabwe. – Project developers must follow the REPP environmental and social policy and procedures.	– Technical assistance – Facilitates access to risk mitigation instruments and long-term lending provided by REPP partners equity financing – Provides results-based financial support to financially sound projects. Results-based financial support can take the form of feed-in tariff top-ups or other appropriate instruments	– The fund supports seven energy companies in Africa. – Aims to provide finance to more than 100 enterprises in sub-Saharan Africa and South Asia.
		Key references	Restrictions
		– https://www.repp-africa.org/africa.org/	– No more than five projects can be sponsored from any one of the eligible countries – Projects that receive REPP funding are not expected to receive further revenues from carbon credits through the CDM or any other formal carbon market mechanism.

6.3.14 Summary of the categories of the funding options

The table below summarizes the different funding options discussed above.

	Funding platforms	Category
1.	Universal service funds (USF)*	Government, international agency
2.	Carbon credit trading	
a)	CDM	International agency
b)	Africa Carbon Credit Exchange (ACCE)	Government
c)	Carbon Trading Exchange (CTX)	Private
3.	African Renewable Energy Fund (AREF)	Private, international agency
4.	Power Africa, Beyond the Grid	Government, international agency
5.	SEFA	International agency
6.	OFID	International agency
7.	IRENA	International agency
8.	REEEP	Government, international agency
9.	DFID Impact Fund	Government
10.	SEED	Private
11.	REPP	Government, international agency

* Currently finances only telecommunication operators without provision for financing community power projects.

6.3.15 Broadband infrastructure financing to minimize risks for private investors

In rural area with low population densities, providers are deterred from investing in telecommunication projects since building broadband infrastructure is expensive, takes a long time to pay back and the returns from a small customer base are perceived to be unattractive. Funding agencies can set up financial facilities that provide incentives to the private sector to invest in the development of open-access, broadband digital networks in underserved rural communities.

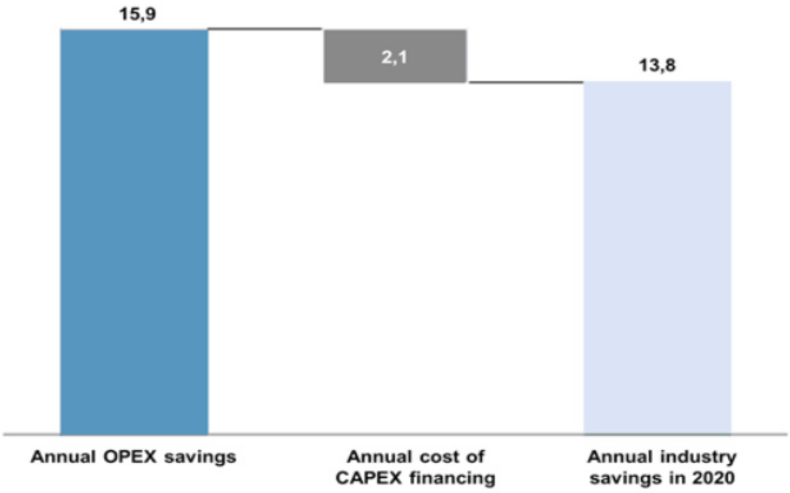
Open-access broadband infrastructure projects of this sort could incorporate the development of off-grid renewable electricity micro-grid networks, or partner with local energy producers to power telecommunication sites as well as isolated rural communities in the vicinity.

A typical example is the Connecting Europe Facility (CEF) Fund, a partnership between EIB and the European Commission's Connecting Europe Facility that grants incentives to investors to encourage the funding of broadband networks for extending high-speed digital Internet services in sparsely populated, underserved rural and remote areas in Europe.

6.3.16 Telecommunication and energy working together for sustainable development

Many base stations in areas with poor grid availability and off-grid installations are still powered by diesel-generators. However, innovative renewable technologies and hybrid methods of energy provision are increasingly being deployed. According to research conducted by GSMA (2014), these systems can lead to significant annual cost savings for telecommunication operators (see Figure 33).

Figure 33: Annual industry cost savings due to transition to green energy solutions (USD billions)



Source: GSMA, 2014

7 Policy mechanisms and recommendations

7.1 Introduction

Renewable energy policies must increasingly be integrated into the overall national energy sector planning and strategic framework that encompasses the entire renewable energy development and implementation cycle. Policy-makers should define long-term strategies and targets and adapt policies and regulations that also promote a decarbonized energy environment. Polices should be aligned and coordinated across the energy and environmental sectors.

IRENA recommends that this should include "identifying best practice and trends in policy design and evaluating support mechanisms and their adaptation to changing market conditions".53

The expansion of broadband services into rural areas necessitates the development and significant expansion of electricity access in rural areas. Governments will have to create an enabling environment which requires the participation of the private sector. To facilitate this, a robust policy and regulatory environment will be needed to reduce investment risks, improve viability and increase the overall attractiveness of the off-grid energy sector in particular.

Traditional energy policies

Globally, the digital economy of developing countries is growing at the impressive rate of 15 to 25 per cent per year.[46] Nevertheless, the one billion people who still live off the grid cannot enjoy the benefits of this digital expansion because they do not have electricity to access the Internet. Therefore, efforts to expand digital services to these off-grid communities must go hand in hand with the expansion of the electricity infrastructure. Since large incumbent electricity operators are often reluctant to expand their services to low-income and sparsely populated remote areas, policy support mechanisms are necessary to promote the intervention of small, innovative power operators. Encouragingly, as of 2016, developing countries had enacted policies to promote investments in renewable energy projects aimed at expanding electricity access to off-grid communities[47]. Some of these policies are:

Renewable portfolio standards (RPS): This is a regulation that places an obligation on power companies to produce a specified fraction of their electricity from renewable energy sources. Energy producers earn certificates for every unit of electricity they produce from renewable sources. This certificate is sold along with the electricity to supply companies, who then pass it to the regulatory body to demonstrate their compliance with the regulations.

Financial incentives: Several countries are providing public funds through grants, loans or tax incentives to encourage investments in renewable energy. India, for example, offers a 30 per cent capital subsidy for solar PV rooftop systems.

[46] Bock, W., Vasishth, N., Wilms, M. and Mohan, M. (2015): The Infrastructure Needs of the Digital Economy. The Boston Consulting Group. https://www.bcg.com/ publications/2015/infrastructure-needs-of-the-digital-economy.aspx.

[47] Hsu, H., Rosengarten, C., Weinfurter, A., Xie, Y., Musolino, E and Murdock, H.E. (2017): Renewable Energy and Energy Efficiency in Developing Countries: Contributions to Reducing Global Emissions. The 1 Gigaton Coalition. 90p.

Feed-in tariffs (FIT) – for grid-connected systems: This is the most common regulatory policy support to renewable energy companies. It is designed to offer long-term contracts to renewable energy producers based on the cost of electricity generation of each technology. The power companies are awarded higher per-kWh prices that reflect the cost of producing the electricity. Several countries have, in recent years, revised the policy to support smaller-scale projects.

<u>New business models and the role of policy</u>

Enabling energy policies considerations

The biggest challenge to off-grid renewable energy solutions is the lack of funding. The reasons for this lack of funding are the long break-even periods and the low returns of these projects. Therefore, policies need to address this problem. Efforts are already being made to increase public funding through grants, loans and tax incentives for investors. More needs to be done to encourage private investment.

General policies: Policies should create an enabling environment for investments in energy efficiency and renewable energy supply, storage, digital applications.

- There must be close cooperation between the public and private sectors for the energy transformation.
- Creating a level playing field for renewables (e.g. fossil fuel subsidy reforms, carbon pricing policies)
- Define standards that ensure the reliability of technology and networks (e.g. quality and technical standards, certificates)
- Create guarantee mechanisms supported by multilaterals on behalf of governments with limited funding and debt capacity so as to reduce the risks for the private sector and attract larger investments.

Financial policies: Policy instruments are needed for banks to issue reliable long-term loans to these projects. Through a suitable policy and regulatory framework, policy-makers can mitigate the economic risks of projects by defining appropriate tariff structures that reflect the project's cost structure, including a well-designed process for obtaining and holding permits, licences and concessions. Low-income groups may also be exempted from import duties on electrical appliances and VAT on energy-related services.

a) Energy efficiency policies: Energy efficiency measures are very effective in reducing per capita energy consumption and expanding electricity access. This leads to lower electricity costs and less energy waste. Effective energy efficiency practices can dramatically improve the economics of renewable energy projects.
b) Energy tariffs: Tariffs should also reflect the costs and unique characteristics of renewable source generation and regulations should allow for variations in tariffs that depend on time of use.

7.2 Digital policies

a) The traditional approach to digital network deployment is based on each operator building its own distinct infrastructure. In regions that are predominantly rural and remote, the traditional approach is not efficient and mobile operators have been actively and successfully finding ways to share infrastructure investment so as to expand network coverage while preserving healthy competition in service provision. Infrastructure sharing models can improve the economics of network expansion into rural and remote areas. Operators can reduce their capital and investment costs by as much as 50 to 70 per cent.[48]

b) Mobile operators are also divesting their communication towers to tower operators as a cost-saving strategy.

7.3 Digital policy considerations

a) Deploying publicly-owned backbone networks to penetrate rural areas and reach remote locations.
b) Aggregation of rural areas can be realized by deploying multipoint fixed wireless access or new-generation 4G and 5G mobile technologies.
c) Reducing transit costs by subsidizing rural broadband network providers.
d) Introducing innovative ways of allocating radio spectrum to reduce the cost of implementing wireless networks, by simplifying and reducing the high costs of acquiring rural spectrum licences allowing spectrum sharing or assignment on a cooperative basis, while following the rights and obligations of the ITU Radio Regulations.
e) Creating the right regulatory environment to promote digital innovations, such as smarter energy systems, use of AI, the Internet of Things.
f) New models for standalone solutions (e.g. PAYG, post-paid service and battery charging) and mini-grids (e.g. a public-private partnership approach).

The report "Renewable Energy Policies in a Time of Transition", (IRENA, IEA REN21)[49] identifies key barriers and highlights policy options to boost renewable energy deployment, focusing on direct support, integration and enabling environment.

Table 7 proposes a classification for tracking key sector policy mechanisms linked to developmental objectives.

48 GSMA (2016): Unlocking Rural Coverage: Enablers for commercially sustainable mobile network expansion. Connected Society. https://www.gsma.com/mobilefor development/wpcontent/uploads/2016/ 07/ Unlocking-Rural-Coverage-enablers-for-commercially-sustainable-mobile-network-expansion_English.pdf
49 IRENA, IEA REN21 https://www.irena.org/publications/2018/Apr/Renewable-energy-policies-in-a-time-of -transition

Table 7: Classification of policies

Policies to achieve the energy transition		Deployment (installation and generation) of renewables in the general context	Deployment (installation and generation) of renewables in the access context (including energy services)	Maximization of socio-economic development from renewable energy deployment
Direct policies	Push	– Binding targets for use of renewable energy – Electricity quotas and obligations – Building codes – Mandates (*e.g.* solar water heaters, renewables in district heating) – Blending mandates	– Rural electrification targets, strategies, programmes – Clean cooking strategies, programmes – Biogas digester programmes	Deployment policies designed to maximize benefits and ensure a sustainable transition (*e.g.* communities, gender) including requirements, preferential treatment and financial incentives provided to installations and projects that help deliver socio-economic objectives
	Pull	– Regulatory and pricing policies (*e.g.* feed-in tariffs and premiums, auctions) – Tradable certificates – Instruments for self-consumption (*e.g.* net billing and net metering) – Measures to support voluntary programmes	– Regulatory and pricing policies (*e.g.* legal provisions, price/tariff regulation)	
	Fiscal and financial	– Tax incentives (*e.g.* investment and production tax credits, accelerated depreciation, tax reductions) – Subsidies – Grants	– Tax incentives (*e.g.* reduction) – Subsidies – Grants – Concessional financing – Support for financial intermediaries	

Table 7: Classification of policies (continued)

<table>
<tr><th>Policies to achieve the energy transition</th><th>Deployment (installation and generation) of renewables in the general context</th><th>Deployment (installation and generation) of renewables in the access context (including energy services)</th><th>Maximization of socio-economic development from renewable energy deployment</th></tr>
<tr><td rowspan="3">Integrating policies</td><td>- Measures to enhance system flexibility (e.g. promotion of flexible resources such as storage, dispatchable supply, load shaping)</td><td colspan="2">- Policies for integration of off-grid systems with main grid
- Policies for mini-grids and smart distributed energy systems
- Coupling renewable energy policies with efficient appliances and energy services</td></tr>
<tr><td colspan="3">- Policies to ensure the presence of needed infrastructure (e.g. transmission and distribution networks, electric vehicle charging stations, district heating infrastructure, road access)
- Policies for sector coupling
- RD&D support for technology development (e.g. storage)</td></tr>
<tr><td colspan="3">- Better alignment of energy efficiency and renewable energy policies
- Incorporation of decarbonization objectives into national energy plans
- Adaptation measures of socio-economic structure to the energy transition</td></tr>
<tr><td rowspan="3">Enabling policies</td><td>- Policies to level the playing field (e.g. fossil fuel subsidy reforms, carbon pricing policies)
- Measures to adapt design of energy markets (e.g. flexible short-term trading, long-term price signals)
- Policies to ensure the reliability of technology (e.g. quality and technical standards, certificates)</td><td colspan="2">- Industrial policy (e.g. leveraging local capacity)
- Trade policies (e.g. trade agreements, export promotion)
- Environmental and climate policies (e.g. environmental regulations)</td></tr>
<tr><td colspan="3">National renewable energy policy (e.g. objectives, targets)
- Policies to facilitate access to affordable financing for all stakeholders
- Education policies (e.g. inclusion of renewable energy in curricula, coordination of education and training with assessments of actual and needed skills)
- Labour policies (e.g. labour-market policies, training and retraining programmes)</td></tr>
<tr><td colspan="3">- Land-use policies
- RD&D and innovation policies (e.g. grants and funds, partnerships, facilitation of entrepreneurship, industry cluster formation)
- Urban policies (e.g. local mandates on fuel use)
- Public health policies</td></tr>
</table>

Table 7: Classification of policies (continued)

Policies to achieve the energy transition	Deployment (installation and generation) of renewables in the general context	Deployment (installation and generation) of renewables in the access context (including energy services)	Maximization of socio-economic development from renewable energy deployment
Enabling and integrating policies	– Supportive governance and institutional architecture (*e.g.* stream-lined permitting procedures, dedicated institutions for renewables) – Awareness programmes on the importance and urgency of the energy transition geared towards awareness and behavioural change – Social protection policies to address disruptions – Measures for integrated resource management (*e.g.* the nexus of energy, food and water)		

Source IRENA April 2018 https://www.irena.org/publications/2018/Apr/Renewable-energy-policies-in-a-time-of-transition

7.4 Mini-grid operational policy recommendations

Mini-grid operator models describe the organizational structure of mini-grid implementation and operation, and specifically determine who owns the power generation and distribution assets, and who operates and maintains the system.

Four main mini-grid operator models can be considered:

- utility
- private sector
- community
- hybrid.

Successful implementation of each model depends on their unique context:

a) the natural environment (e.g. geography, energy resources and climate/weather conditions),
b) the local socio-economic context,
c) the policy and regulatory environment.

Appropriate regulatory measures must permit the private sector to produce (generate) and sell (distribute) power either to public power distributors or directly to end users via mini-grids.

7.5 Specific off-grid policies

Most of the additional power needed to achieve universal access will involve micro-grid and mini-grid off-grid networks that are owned privately; or a utility operator; or they will be community-owned power grids in rural areas of developing countries. These off-grid solutions are unlikely to be incorporated into the main grid and most likely will continue to operate autonomously. There may be a case for the larger community schemes to be absorbed into the national grid, funded or managed by the incumbent electrical power company that is responsible for energy generation and supply. Most of the countries subsidize the electricity supplied by the grid. Therefore off-grid power source cannot compete with the distributed grid electricity price.

Policy considerations:

Given the key role of decentralized, decarbonized power sources to bridge the electricity gap in remote areas, the policy and funding mechanisms of off-grid solutions and private-sector actors are crucial.

Off-grid operators will have to mitigate against the potential risk of the future arrival of the national grid, which may introduce major uncertainty for the long-term viability of mini-grids. Policies relating to the arrival of the main grid must govern how and when the main grid will arrive and mitigate the risks faced by off-grid and mini-grid operators.

Private mini-grid developers, operators and investors should be allowed to recover costs for sustainable operation and given reasonable time to do so and at appropriate margins.[50]

Access to electricity empowers people and local communities to increase their income and productivity, enhances their access to health care, water and education, and improves their overall socio-economic well-being. Access to universal energy service and broadband-enabled digital services is essential to achieving the SDGs for 2030.

[50] https://www.academia.edu/38089928/Renewable_Energy_Policies_in_a_Time_of_Transition?auto=download

8 Conclusion

Connectivity is energy-intensive and will not develop without access to power, in particular affordable, reliable and scalable sources of power. Not surprisingly, deficiencies in connectivity and electrical power are often found in the same locations.

Power production and distribution are being disrupted thanks to technology innovation around clean energy, the following trends being observed: decarbonization, digitalization and decentralization.

Renewable sources of energy combined with storage and energy-efficiency software are the key to support reliable and affordable connectivity access in remote areas.

Furthermore, access to essential services such as electricity and connectivity can and must be addressed in combined or shared infrastructures, to minimize investments and operational costs while accelerating progress towards achieving multiple SDGs.

Connecting the next billion requires innovation not only in technology but also in business models and financing. Like any other aspects of the fourth industrial revolution, social and economic development can only be achieved in scalable, replicable models inspired by the platform revolution that applies to every segment of the economy and society.

It is in the sharing economy, both between actors of the private sector but also in public-private partnerships, that access to electricity and connectivity can be addressed in an efficient manner. Funding support from development and international organizations can attract private-sector investment in capital-intensive infrastructure investments. But these infrastructures are the key to bridging the digital gap and electricity access, opening up multiple opportunities for productive leverages of social economic development, including access to digital services.

9 Annexes and case studies

9.1 Energy service companies

A distributed power market will be important to fast-track the deployment of clean power solutions in Africa, supplying reliable, affordable and clean power services to the telecommunication tower operator sector.

A growing market

In Africa, the number of new cellular subscriptions increased at an average annual rate of more than 12 per cent between 2010 and 2015, and the size of the African mobile network is expected to grow from 240 000 towers in 2014 to 325 000 towers by 2020. Mobile network operators (MNOs) are at the core of Africa's fast-growing mobile economy, including e-commerce and m-commerce, mobile money, mobile banking and other value-added services such as e-health, e-government and e-agriculture.

However, as MNOs move towards sparsely populated rural areas, the average revenue per user (ARPU) decreases and energy costs increase, due to the absence of grid power and high fuel costs. Energy costs can amount to 60 per cent of an MNO's infrastructure operating expenditure (OPEX), and acts as a disincentive for the deployment at scale of mobile coverage in rural areas. With the recent price drop of solar PV and energy storage technologies, solar and hybrid power solutions have become increasingly competitive and can provide MNOs and TowerCos with a more reliable and cost-efficient power supply.

But in a fast-growing and intensely competitive environment, MNOs focus on servicing customers and investing in active infrastructure (i.e. radio equipment) rather than investing time and resources in clean energy solutions. In a constantly evolving tower energy landscape requiring specific technical expertise, MNOs are not ideally positioned to drive energy efficiency. Additionally, as ARPU falls, MNOs place a priority on network expansion and technology upgrade of active equipment. With a limited pool of capital, they tend to favour investment in active radio equipment over investment in energy solutions. The cost-saving potential of green and renewable energy solutions is left unexploited, especially as their expectation of payback is a maximum of four years. Energy services companies (ESCOs) are better placed to invest in long-term assets and amortize them over time in order to reap the full benefits of reduced costs.

Figure 34: ESCO power solutions in Africa

Sustainability

Listed MNOs and TowerCos are committed to cut their CO_2 emissions from operations. By cutting fuel consumption by 66 per cent on average through investment in efficient power systems, MNOs are reducing their CO_2 emissions significantly.

Benefits for MNOs and TowerCos from the ESCO solutions include:

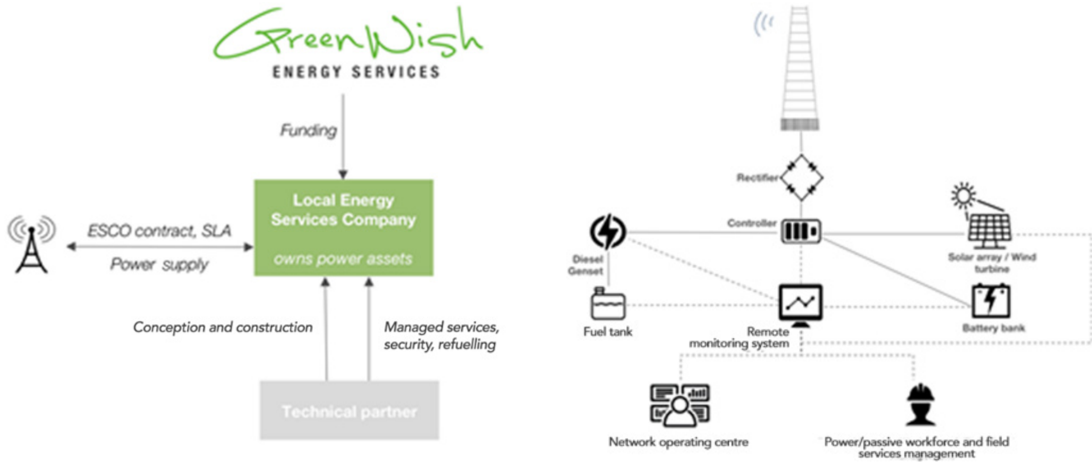
- CAPEX preservation
  Contracting energy generation investment and operation and maintenance (O&M) to the ESCO allows MNOs and TowerCos to limit the impact on capital expenditures cash-out up front and reduce the mobilization of capital reserves for non-core business assets.
- Cost reduction
  The ESCO model allows MNOs and TowerCos to benefit from a significant total OPEX reduction (between 20 and 35 per cent depending on the country) thanks mainly to energy expenses reduction but also O&M cost reduction without having to disburse any investment cash-flow, as the ESCO is investing for them.
- Reliability
  Energy is crucial for MNOs and TowerCos in order to ensure the reliability of its network and the level of services provided to their clients. The ESCO model enables them to benefit from a reliable source of power that needs little maintenance on sites, as well as contracted performance guarantees.

9.2 Typical financial, contractual and operating solutions

A local ESCO will be in charge of designing, procuring, operating and maintaining energy efficient equipment to power telecommunication towers. Each local ESCO will contract with one or more clients through a ten-year (or more) master services agreement, charging them:

- a fixed infrastructure fee covering initial and replacement CAPEX, financing costs and ESCO management costs;
- an energy fee covering fuel and grid costs, with a guaranteed volume of fuel savings (risk passed through to technical partner);
- an O&M fee covering operation and maintenance services (risk passed through to technical partner).

Figure 35: Example of contractual and technical solutions for telecommunication companies



Risk allocation

The ESCO model enables the MNO/TowerCo to isolate the energy assets related to its towers into a dedicated special purpose vehicle. As in a standard asset-based/project finance structure, construction, performance and operational risk will be passed on to the EPC and O&M partners to the project.

Replicability and scalability

Thanks to the local presence and activities of operation and maintenance (O&M) partners already working with MNO players in sub-Saharan Africa, the ESCO model is easily replicable and scalable in other countries. Master service agreements between the ESCO and operators should be highly standardized between projects. As such, the local ESCO will be bundled together with future projects at ESCO portfolio level, enabling lenders to either support projects at a portfolio level or at a project level, always relying on asset securities, but eventually with a diversified risk profile in the portfolio approach.

Strong environmental impact of the investment

The ESCO business is based on replacing highly fuel-intensive energy generation systems by hybrid power generation systems. As an example, the investment makes it possible to install renewable energy equipment generation or efficient batteries, reducing fuel consumption by

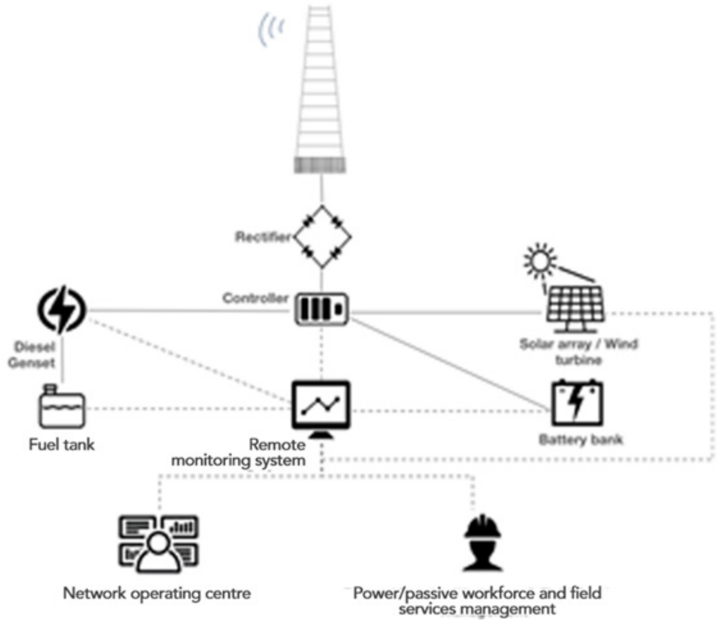
66 per cent on average, which corresponds to about 5 500 tonnes equivalent CO_2 emissions saved per year in the sole case of the Orange DRC project.

A reliable technical solution

Each local ESCO will replace inefficient diesel power generation systems owned by MNOs or TowerCos by energy-efficient solar hybrid systems that will supply electrical power that is:

- cheaper, thanks to reduced reliance on diesel-generators;
- cleaner, as fuel consumption is reduced by 50-100 per cent;
- more reliable, thanks to guaranteed uptime with availability up to 99.9 per cent.

Figure 36: Example of a reliable technical solution



9.3 Smart Green Communities

9.3.1 The Smart Communities

Smart Communities is a global physical and digital shared distribution platform targeting underserved areas with the ultimate goal to foster social and economic development.

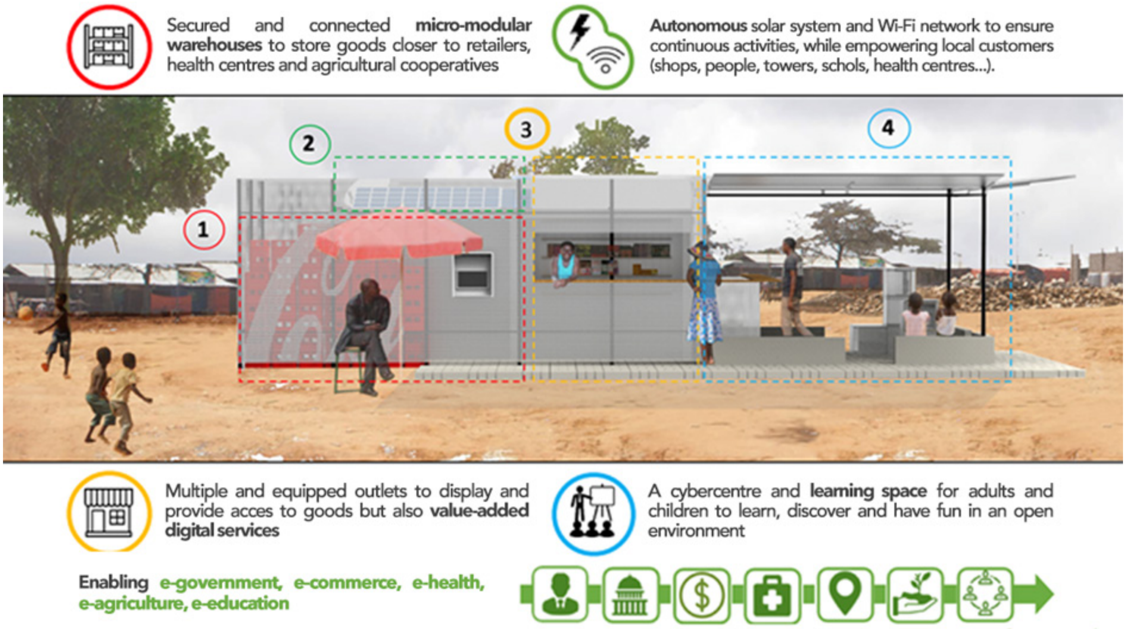
Smart Communities addresses 15 out of the 17 SDGs defined by the United Nations, in line with the French Presidency's initiative, introduced at the One Planet Summit in Nairobi in March 2019, involving the French development agency AFD and Bpifrance, among other institutions.

Through a B-to-G/B-to-B-to-C model, the solar powered and connected hubs serve as autonomous micro-warehouses and corners, efficient and smart distribution points to make commercial, government and NGO products and services available to the last mile. By accessing the shared infrastructure network, they can expand their activities and businesses at low cost, while contributing to their social and environmental strategies.

Smart Communities also unlocks opportunities in a sustainable manner for the local people, serving as a one-stop-shop for all these various services and a gateway to the global market.

In a scalable and profitable model, the ambition is to provide access to universal services at a minimal marginal cost: electricity, water, connectivity, education, health, e-government services, banking as well as farmers, women, youth empowerment.

Figure 37: Example of a smart green village



Source: GreenWish.

9.3.2 Business model

Route to market

Through the Smart Communities network, government and private-sector partners access new markets at a competitive cost for distribution or delivery, but also gain access to advertising spaces and provide access to data that can be invaluable as a public policy input and for improving the understanding of consumers. The B-to-B partners enjoy the inclusive business model of Smart Communities, addressing 15 out of the 17 SDGs defined by the United Nations through access to water, electricity, connectivity, education, health, agriculture, job creation, women and youth empowerment, e-government services and banking, and so on.

Local Smart Communities are operated by a mix of in-house employees and subfranchisees as shop tenants.

Infrastructure management and the digital platform are provided by GreenWish through subcontractors.

The franchise structure aims to accelerate the exponential growth of the Smart Communities platform, giving local and international brands access to consumers and users, advertising, digital platform and shared logistics, power and connectivity in multiple countries.

The model is incentive-based and exponential: the faster it becomes profitable, the more extra services and impacts can be offered. It can only succeed through shared and collaborative approach between brands and governments.

Income model

The Smart Communities income model is based on:

- long-term tenant or user fixed fees from B-to-B partners
- transactional fee sharing on physical and digital transactions on-site
- advertising
- data collection and monetization, co-owned with local governments
- CSR grants from private partners and NGOs to support non-profit social activities

Contractual structure

The most viable and sustainable model involves the financing of infrastructure by the local government, through development finance institutions (DFIs) funding or export credits.

As the mission of the Smart Communities is to foster social and economic development in underserved territories by bringing new and innovative products and services, both private and public-oriented, it makes sense to set up the activity as a concession model where the government owns the infrastructures while Smart Communities builds and operates them and manages the activities.

9.3.3 Key services

- Electricity

Smart Communities are solar/battery powered and totally off-grid.

Power sizing is adapted to the size of the Smart Communities and services (cold storage, connectivity etc.), which are modular and adaptable to the location: peri-urban or rural.

Shop tenants can also sell power charging on-site to individual customers.

- Water

Smart Communities are equipped with low-cost water purification systems to serve 200-3 000 people per day.

- Storage and cold storage

Each Smart Communities is equipped with storage and cold storage, including frozen storage where relevant.

Storage space is available for fast-moving consumer goods (food, drink, personal care), pharmaceutical products, telecommunication appliances and products, solar home systems, potentially fertilizers and other locally relevant products. These storage points will also serve as local distribution points.

A digital platform supports traceability of products from import to B-to-C sales with stock monitoring.

- Retail

Smart Communities has a corner shop for direct sales.

- Wi-Fi connectivity hotspot

Each Smart Community has access to Wi-Fi with various forms of access.

If no Internet connection is available in the village, whether via 3G or an Internet service provider (ISP), then different options are available.

In a completely off-grid environment, Internet can be sourced thanks to the nearest BTS or a satellite connection (VSAT), or using TV white space.

Smart Communities will be the lab for multiple access routes to connectivity at competitive price in remote areas.

- Digital services

The dedicated digital platform, available in each Smart Community serves as a marketplace for services and hosts e-services from strategic partners including: e-gov, e-health, e-education, e-banking, e-agriculture, e-commerce.

Some specific e-services may be developed in-house.

- Data collection

The platform will collect physical and digital data customized for clients and partners.

Each Smart Community serves a catchment of 15-20 thousand people in a 5 km area, and is strategically placed for traffic.

This footprint and the multiple services and products offered in the Smart Communities will create a major opportunity to collect targeted data for all partners.

The data is co-owned by GreenWish and local government, and is made available to other partners on a fee basis, subject to the purpose of the use.

9.3.4 Corporate social responsibility (CSR)

Smart Communities measures its CSR impact through SDGs.

Deploying an infrastructure to improve energy access and reduce the digital divide in connectivity-deprived communities, Smart Communities addresses 15 SDGs out of 17.

Figure 38: Smart green communities and SDGs

- Participating in **education** and capacity building with general and sector-specific training.
- Unlocking the **distribution of various added value goods**, including solar products and specialized agricultural inputs.
- Disseminating key services and products through women entrepreneurs and to **women.**
- Fighting against poverty allowing people to have access to **information** and know the real market price of the commodities. Also offer them a new sales channel through e-commerce.
- Making **e-agriculture**, **e-health** and **e-education** a reality in areas that need it the most.
- Providing connectivity helping make manufacturing smarter and less carbon-intensive.
- **Coordinating** the action of key private actors, public bodies, multilateral agencies and non-governmental organization in less connected areas.

9.4 Useful links:

Hydropower technologies and hydroelectric power plants:

- https://www.youtube.com/watch?app=desktop&v=d8kQe9VdG4I
- https://www.youtube.com/watch?app=desktop&v=B5qIB-asIeo
- https://www.youtube.com/watch?app=desktop&v=W1PR9fhsf9c
- https://www.youtube.com/watch?app=desktop&v=UW_SgFUfYds
- https://www.youtube.com/watch?app=desktop&v=_qaUufeq_7IIIIII

A power conversion specialist

- https://www.enetek-power.com/industries

Wireless power transmission

- **WiPE (Wireless Power Transmission for Sustainable Electronics)**
  - http://www.cost-ic1301.org/

- **WiPoT (Wireless power transfer consortium for practical applications)**
  - http://www.wipot.jp/english/
- **BWF (Broadband wireless forum)**
  - http://bwf-yrp.net/english/
  - https://www.iea.org/data-and-statistics/charts/renewable-capacity-growth-between-2019-and-2024-by-technology

Acronyms

ESCO	Energy services company
SDGs	Sustainable Development Goals MNO: mobile network operator
O&M	operation and maintenance
IRENA	International Renewable Energy Agency
ADFD	Abu Dhabi Fund for Development
DFIs	development finance institutions
CPE	customer premises equipment

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