2021/02
COMMONWEALTH
SUSTAINABLE ENERGY
TRANSITION SERIES

SUSTAINABLE ENERGY TRANSITION SERIES

Technology and Innovation in Sustainable Energy Transition

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The Commonwealth

Commonwealth Sustainable Energy Transition Series 2021/02

ISSN 2413-3175

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Please cite this paper as: Precht, P (2021), 'Technology and Innovation in Sustainable Energy Transition', *Commonwealth Sustainable Energy Transition Series* 2021/02, Commonwealth Secretariat, London.

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The author gratefully acknowledges the peer reviewer of this paper for their comments and suggestions, as well as Paul Mathew Cheruvathur, who provided valuable research assistance.

The Commonwealth Sustainable Energy Transition (CSET) Agenda encourages and promotes collaboration amongst Commonwealth member countries in the transition to sustainable energy systems and action towards achievement of the SDGs. It builds on the recognition at CHOGM 2018 of the critical importance of sustainable energy to economic development and the imperative to transition to cleaner forms of energy in view of commitments by member countries under the Paris Agreement. It is anchored on the following three key pillars drawn from the agreed outcomes of the inaugural CSET Forum in June 2019 and leverages existing programmes of the Commonwealth Secretariat:

- *Inclusive Transitions:* advocating equitable and inclusive measures for energy transitions that recognise and address impacts on economies, communities and industries.
- *Technology:* propagating advances in technology solutions and innovations as well as research and development for sustainable energy systems.
- *Enabling Frameworks:* supporting the development of enabling frameworks, including policy, laws, regulations, standards and governance institutions for accelerating energy transitions.

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Abstract

Achieving universal access to affordable, reliable energy and increasing the share of renewable energy in the energy mix requires fundamental, rapid and large-scale shifts towards new technologies. Technologies to expand energy access and transition to low-carbon energy resources are available and need to be accessed. This paper reviews enabling low-carbon technologies for sustainable energy transition in the Commonwealth. It describes the range of resources and technologies that can facilitate a sustainable energy transition and explores case studies that describe the expansion of energy access.

JEL Classifications: O13, O14, O32, Q42, Q48

Keywords: renewable energy, innovation, technology, Commonwealth, low-carbon

Contents

Abbreviations and Acronyms

CAAGR	compound average annual growth rates
CCS	carbon capture storage
CSEF	Commonwealth Sustainable Energy Forum
CSP	concentrated solar power
GDP	gross domestic product
GHG	greenhouse gas
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LDC	least developed country
LCOE	levelised cost of energy
LLDC	landlocked developing country
LPG	liquefied petroleum gas
MTOE	million tonnes of oil equivalent
NDCs	nationally determined contributions
PV	photovoltaic
SDGs	Sustainable Development Goals
SDG7	Sustainable Development Goal 7
SIDS	small island developing states
SHS	solar home system
TPES	total primary energy supply
VRE	variable renewable energy

Summary

> *The energy world is marked by a series of deep disparities. The gap between the promise of energy for all and the fact that almost one billion people still do not have access to electricity. The gap between the latest scientific evidence highlighting the need for evermore rapid cuts in global greenhouse gas emissions and the data showing that energy-related emissions hit another historic high in 2018. The gap between expectations of fast, renewables-driven energy transitions and the reality of today's energy systems in which reliance on fossil fuels remains stubbornly high.*
>
> International Energy Agency, World Energy Outlook 2019

The aim of the UN's Sustainable Development Goal 7 (SDG7) is to achieve universal access to affordable, reliable and modern energy and to substantially increase the share of renewable energy in the energy mix. Progress toward achieving SDG7 is generally measured using:

- the portion of population with access to modern energy sources, typically by measuring access to electricity and clean cooking fuels and technologies – this target primarily applies to developing countries, where energy access is below 100 per cent; and
- the portion of energy consumed that is generated from renewable energy resources – this target is broadly applicable to all countries.

Many Commonwealth countries fall substantially short of meeting these goals, despite having been endowed with an abundance of renewable energy resources[1] that could be deployed economically and commercially to foster and accelerate achievement of SDG7. The costs of some renewable energy technologies are falling dramatically, presenting the opportunity for rapid growth in the adoption of the technologies, especially in those Commonwealth countries which are least developed countries (LDCs), landlocked developing countries (LLDCs) and small island developing states (SIDS).

This paper will review enabling low-carbon technologies for sustainable energy transition in the Commonwealth. After describing the range of potential technologies to be adopted, it will briefly review two case studies of the implementation of clean cooking technologies and decentralised solar photovoltaic technologies. In both cases, existing technologies are found to be economically competitive, but consumer adoption of the technologies is slow. Better consumer education and stronger government policies and incentives are needed to accelerate the uptake of these technologies and therefore the achievement of the aim of SDG7.

Key Recommendations

Citizens of many countries, especially LDCs, do not have universal access to modern energy sources, and many countries rely inordinately on non-renewable energy resources and technologies. These recommendations are offered to address directly some of the most urgent and biggest challenges to be overcome in getting on the technology paths that lead towards attaining universal access to modern energy and successfully transitioning to sustainable energy systems:

- Scaling up deployment of decentralised energy generation from renewable energy technologies to accelerate achievement of SDG7, in particular broader access to modern energy.
- Ensuring appropriate prices are in place for energy resources that encourage use of clean energy and provide the right signals to investors in energy resources and energy technologies.
- Assisting fossil fuel dependent countries, companies, communities and workers to adapt to changes that will inevitably arise from the energy transition and the decarbonisation of the energy system, and to embrace and benefit from new energy technologies.
- Implementing policies and incentive structures that encourage and prompt immediate actions to accelerate the transition to low-carbon economies.

1. Introduction

The focus of this paper is on the transition of energy systems in Commonwealth countries to energy resources and technologies that will facilitate and enable achievement of SDG7.

Access to modern energy is critically important to the well-being of all citizens. For energy to be sustainable, it must be based on low-carbon technology solutions that curb greenhouse gas emissions to ensure the sustainability of life on the planet. Human dependence on energy has increased considerably, but energy poverty remains an international development challenge. Since energy is a prerequisite for so many aspects of modern life, lack of access reflects social and economic inequities.

1.1 Countries of focus

Commonwealth countries, and especially those that are least developed countries (LDCs), landlocked developing countries (LLDCs) and/or small island developing states (SIDS) would benefit by learning from each other's implementation of energy transition technologies and the progress made in advanced economies of other member countries. Of the 54 Commonwealth member countries, 36 are LDC, LLDC and/or SIDS, as classified by the UN or its agencies. They are located in Africa, Asia, the Pacific and the Caribbean and Americas.

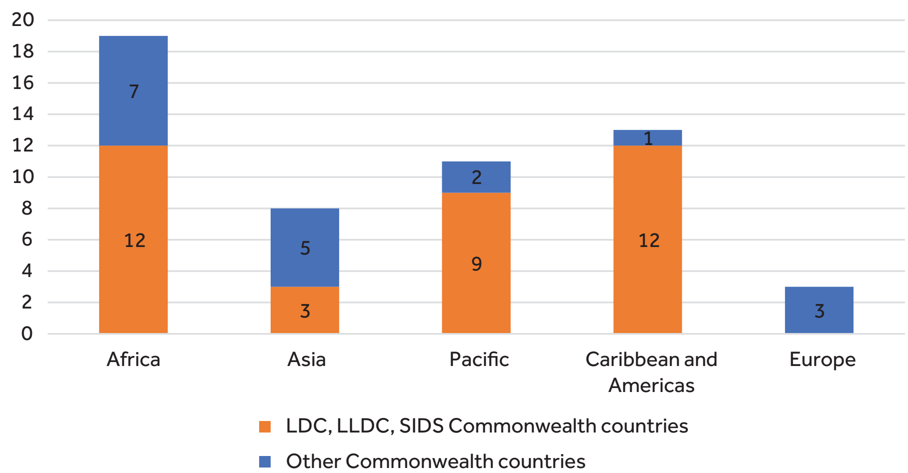
1.2 SDG7 progress

The Commonwealth Secretariat 2019 report on energy transition in Commonwealth countries (Polack, 2019), recognised that the energy transitions necessary to successfully implement the Paris Agreement and to achieve the goals of SDG7 are intrinsically linked. While the transition pathways may differ across nations, the move to decarbonise all economies is the common goal of a sustainable energy transition. Changing the energy landscape towards a net-zero carbon or low-carbon energy system presents opportunities and risks for Commonwealth countries.

As in the rest of the global economy, progress in the transition to a low-carbon economy has been slow and uneven across the Commonwealth. The transition provides an opportunity for member countries to learn from achievements and experiences within the Commonwealth and other countries and be inspired with new possibilities and perspectives to accelerate implementation of their nationally determined contributions (NDCs) under the Paris Agreement and their strategies for achievement of SDG7.

The 2019 study by the Commonwealth Secretariat (ibid.), found that Commonwealth countries were modestly progressing in terms of increasing access to modern energy and access to clean cooking. However, large gaps generally remain in transitioning to renewable energy and in implementing their NDCs. Critically important to the achievement of these NDCs is adopting energy technologies to transition to low-carbon economies and securing the significant investments required for their implementation.

Figure 1. Number of Commonwealth countries by region and economic characteristics

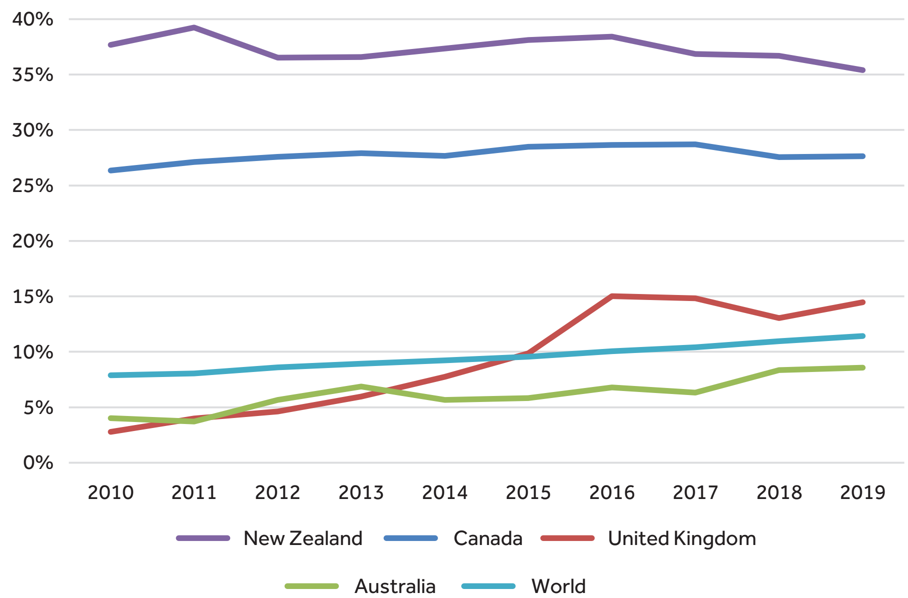


Box 1. Specific goals of SDG7

- 7.1 Ensure universal access to affordable, reliable and modern energy services.
- 7.2 Increase substantially the share of renewable energy in the global energy mix.
- 7.3 Double the global rate of improvement in energy efficiency.
- 7.A Enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.
- 7.B Expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support.

In its 2020 report on tracking SDG7 progress, the International Renewable Energy Agency (IRENA) reported '*the latest data on progress toward SDG 7, before the onset of the pandemic, demonstrated that stepped-up efforts toward all targets were urgently required if SDG 7 was to be met within the coming decade. Even greater efforts will be needed to meet the SDG 7 targets in a post covid-19 world*' (International Energy Agency [IEA], IRENA, UN Statistics Division [UNSD], World Bank, World Health Organization [WHO], 2020). Currently, no Commonwealth country is on track to meet all 17 SDGs. The developed Commonwealth countries are closest to achieving SDG7, with New Zealand ranked 11 globally, followed by the United Kingdom at 13, Canada at 20, Malta at 28 and Australia at 38 (Sachs et al., 2019). LDC, LLDC and SIDS Commonwealth countries were generally not on track, showing little to no improvement towards achieving SDG7 (ibid). The achievement ranking appears to be based more on energy access than on transition to renewables. There remains a long way to go in transitioning to renewable energy resources for all these countries. Even the Commonwealth countries found to be closest to achieving SDG7 all had modest shares of renewable energy as a share of total energy, and except for the United Kingdom, these shares were stagnant or increasing modestly, as seen in Figure 2.

Figure 2. Share of renewables in total primary energy consumption, 2010–19



Source: BP Statistical Review of World Energy 2020 (selection of Commonwealth countries closest to achieving SDG7).

2. Review and findings

2.1 Low-carbon technologies

Achieving SDG7 requires decarbonisation of energy systems and significant expansion of renewable energy systems in many countries. Much of that will necessitate deployment of renewable resources in electricity generation and implementing technologies critical for renewables growth and cleaner energy. This section will review low-carbon technologies that the energy transition will rely on, including renewable resources. It will review low-carbon energy resources, technologies, application, deployment progress (opportunities and challenges), and potential.

Renewable energy resources

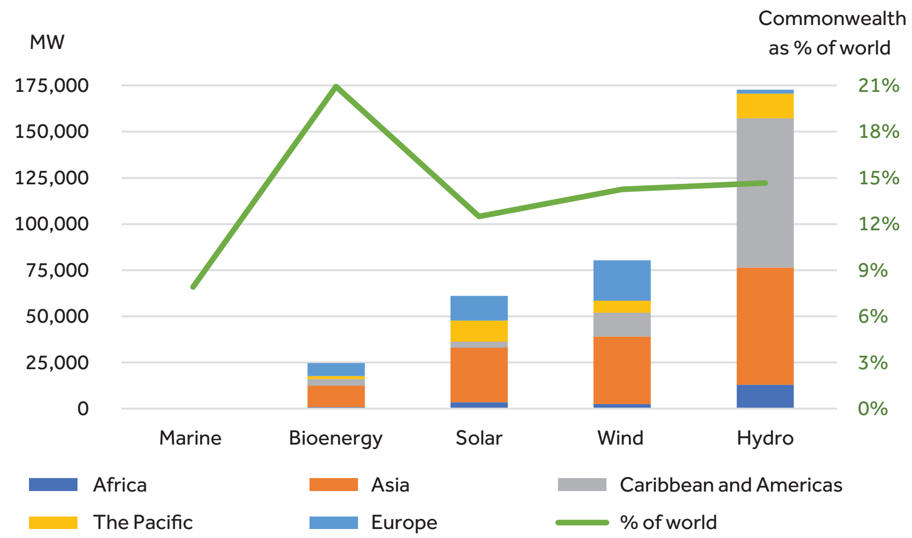
Renewable energy is defined by the IPCC as 'any form of energy from solar, geophysical, or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. Renewable energy is obtained from the continuing or repetitive flows of energy occurring in the natural environment and includes low carbon technologies such as solar energy, hydropower, wind, tide and waves and ocean thermal energy, as well as renewable fuels such as biomass' (IPCC, 2012: 166).

The challenge of transitioning to renewable energy sources is increased by concurrently having to meet rising energy consumption, resulting from growing global populations and expanding economies. Renewable resources are important in terms of the sustainability of the energy they provide and their environmental sustainability (i.e., meeting both the UN's SDGs and the Paris Agreement's goal to limit carbon emissions). A key factor in sustainable energy transition is developing and expanding electricity generation capacity using renewable resources. The nature of many renewable resources supports uses such as off-grid deployment, such that they can serve to foster greater access to modern energy services, another important aspect of SDG7.

While renewables have a major role to play in the electrification processes of many Commonwealth countries – including small-scale and off-grid users – challenges remain. Figure 3 shows that Commonwealth countries represent a small portion of current total renewable energy capacities globally, with the possible exception of bioenergy, relative to the 33 per cent of total global population these countries represent. This indicates that Commonwealth countries are generally lagging in the energy transition and have a bigger gap to close than most of the rest of the world.

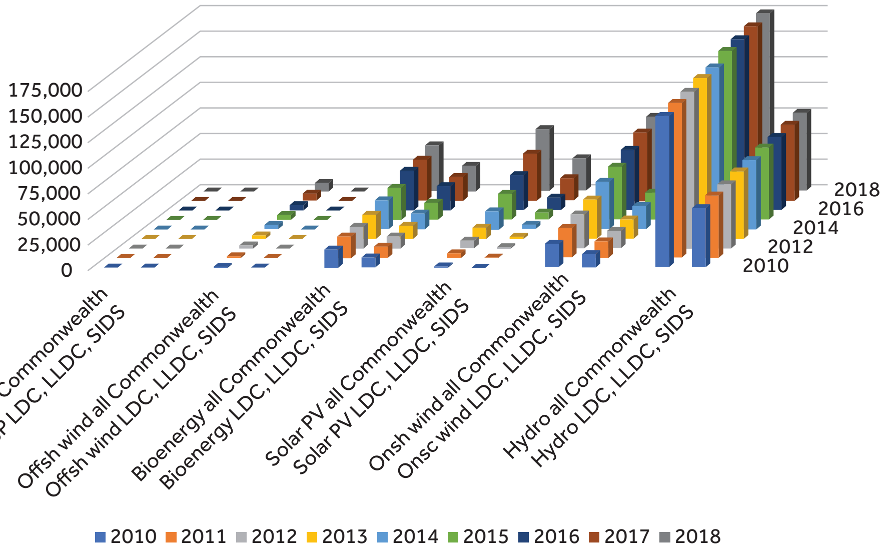
Figures 4 and 5 show that renewable energy capacity has generally been growing faster in Commonwealth countries in recent years than it has globally. The exception is hydropower,

Figure 3. Renewable energy electricity capacity (MW) in Commonwealth countries by type and region, 2018



Source: IRENA 2020a.

Figure 4. Renewable energy electricity capacity (MW) by technology and country characteristics, 2010–18.



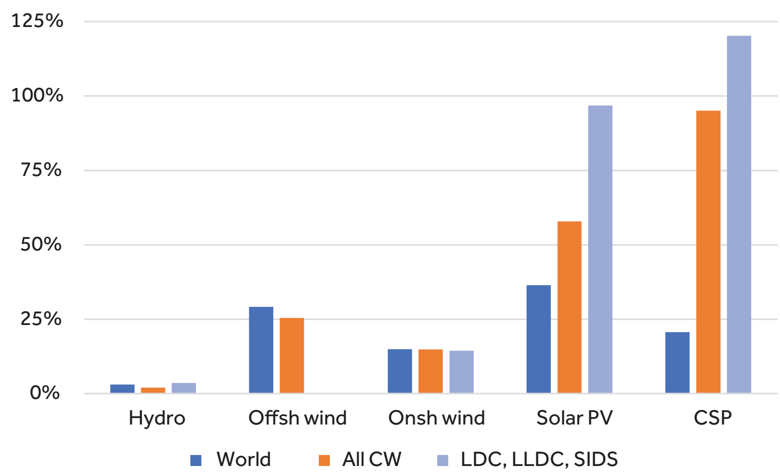
Note: PV = photovoltaic CSP = concentrated solar power.
Source: IRENA 2020a.

which is the largest renewable energy source developed to date – but is growing very slowly generally. The figures show that renewable energy capacity is growing even faster in LDC, LLDC and SIDS Commonwealth countries than in all Commonwealth countries, indicating that they are starting to close the gap shown in Figure 3. There is no offshore wind development to date in LDC, LLDC and SIDS Commonwealth countries; thus, offshore wind remains a renewable energy resource yet to be tapped by these countries. This may be an area where the Commonwealth Secretariat could facilitate technology transfer and development.

Figure 5 shows that compound average annual growth rates (CAAGR) from 2010 to 2018 of renewable energy capacities are growing faster in LDC, LLDC and SIDS Commonwealth countries than in all Commonwealth countries and faster than in all countries of the world.

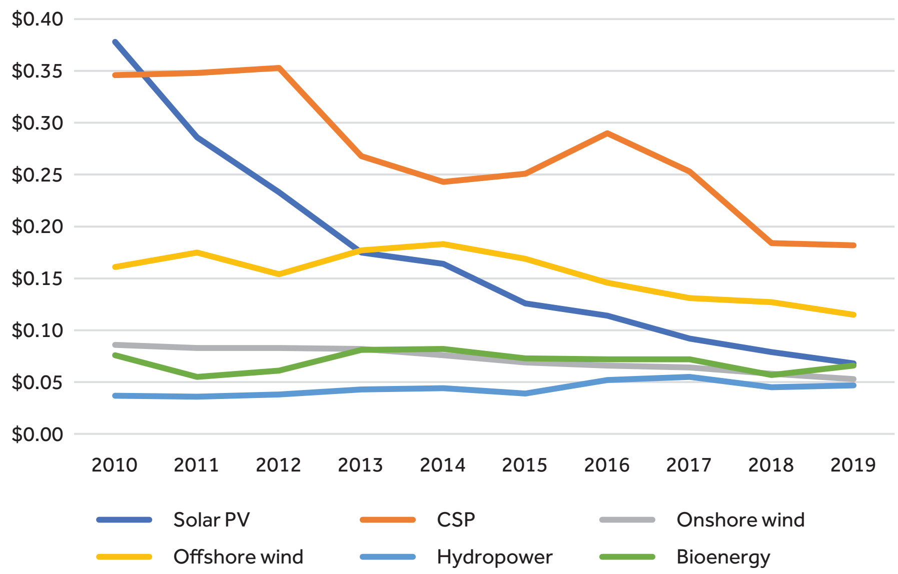
Declining costs are an important driver of growth in renewable energy resource development. Figure 6 shows how renewable energy costs (the mean levelised cost of energy [LCOE], as provided by IRENA) have declined in recent years, especially for solar PV and CSP. Hydropower remains the least expensive, although onshore wind now has almost the

Figure 5. Renewable energy capacity (MW) CAAGRs 2010–18



Source: IRENA 2020a.

Figure 6. Renewable energy prices 2010-19 (LCOE, $US/GWh)



Source: IRENA 2020b.

same cost per GWh as hydropower. The price of bioenergy has been essentially flat and that of hydropower, a very mature renewable energy source, has actually increased slightly.

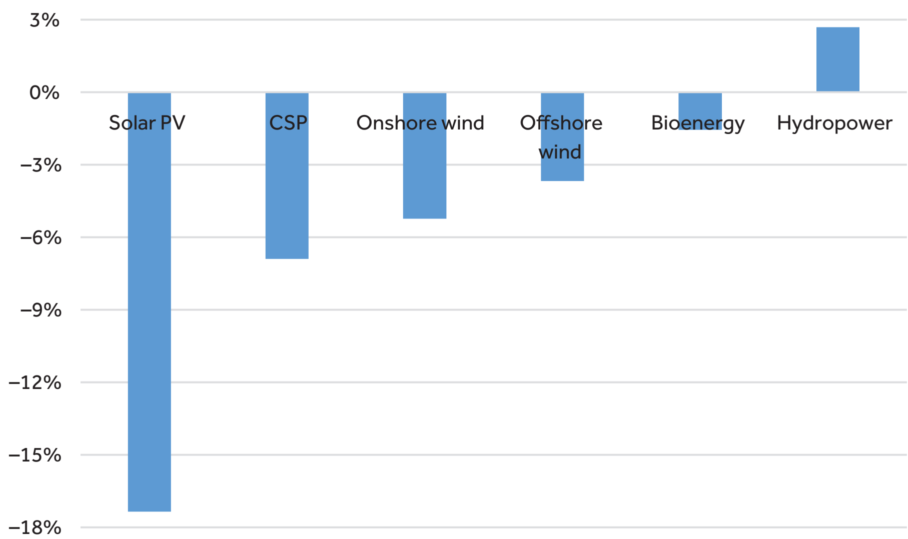
The decline in the cost of solar PV makes it very competitive with onshore wind, bioenergy and hydropower. The IEA's 2020 World Energy Outlook notes that 'with sharp cost reductions over the past decade, solar PV is consistently cheaper than new coal- or gas-fired power plants in most countries, and solar projects now offer some of the lowest cost electricity ever seen' (IEA, 2020g).

The major renewable resources discussed below will be critically important to a sustainable energy transition, each having unique technologies associated with their deployment and expansion.

Hydropower

Hydropower has been the primary renewable energy resource developed to date in most countries, including Commonwealth countries. The technology for converting the energy of water into electricity is mature and relatively simple. Hydropower exploits the energy of

Figure 6. Renewable energy price (LCOE, $US/GWh) CAAGRs 2010–19



Source: IRENA 2020b.

flowing or falling water, which pushes against blades in a turbine causing them to turn to spin a generator to produce electricity. There may be little scope for enhancements to the technology, but the economics of hydropower are more dependent on the geographical characteristics of the site than the technology.

Hydropower has attractions, as it can produce a significant and steady supply of electricity using a domestic renewable source and a well-established technology. It can provide reliable baseload power to cities and industrial areas at relatively low cost and is often the cheapest large-scale option for electricity. As a 'dispatchable' source of electricity, which can be available on demand at the request of power grid operators in response to market needs, hydropower can be a valuable complement to the intermittent nature of variable renewable energy (VRE) sources such as wind and solar.

Hydro dams can serve multiple purposes, including providing urgently needed water access in some areas for water supply, sanitation and irrigation. Large and small hydropower projects are distinguished by whether they have major or minor electricity generation capacity and have major or minor impacts on water flows. Generally, large projects have the biggest environmental impacts, affecting water and sediment flows while inundating large land areas to create reservoirs, and sometimes resulting in spillover effects on water flows in downstream countries. Smaller hydropower plants with little or no water accumulation are called 'run-of-river'. Small-scale hydropower (<10MW) and mini-hydro power (<1MW) can provide power for rural electrification and irrigation in some areas.

Whether hydro is a renewable energy resource is often contested, based on its impacts on water flows and watershed management. Large-scale hydro developments may not be entirely environmentally or socially benign, as their permanent inundation of large areas may force relocation of populations and their livelihoods, and may negatively impact water flows to downstream communities and sometimes to downstream countries.

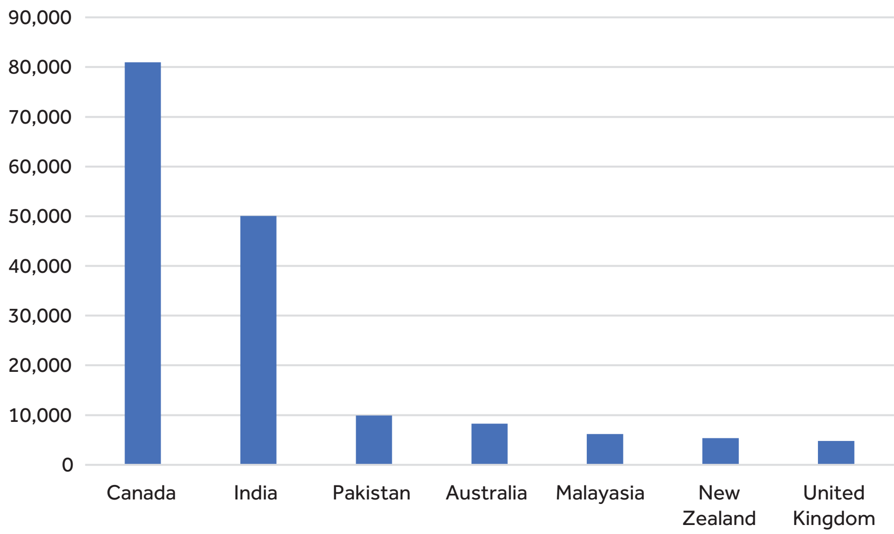
The reliability of hydropower in many areas is expected to be increasingly variable and unreliable as a result of changing rainfall patterns and temperatures due to climate change, leading to changes in river flows, evaporation and transpiration patterns, so altering the potential for hydropower.

Canada has the largest hydropower capacity in the Commonwealth (almost half of the total), followed by India, Pakistan, Australia, Malaysia, New Zealand and the United Kingdom.

Solar

The harvestable potential of solar energy varies with the amount of solar energy available at any location, subject to daily and seasonal variations, and its irradiance intensity, which depends upon geographical and weather variations. Equatorial countries receive more radiation than those at higher latitudes, making these countries

Figure 7. Commonwealth countries with largest hydropower capacity (MW), 2018



Source: IRENA Renewable Capacity Statistics, https://www.irena.org/Statistics/Download-Data especially attractive for solar energy development. LDC, LLDC and SIDS Commonwealth countries are located between latitudes of about 38°N (the northern tip of Pakistan) and 35°S (the southern tip of South Africa), spanning the equator and both tropics, so the potential for solar energy in these countries is generally high. Solar technologies can be widely used to supply power and heat within these countries, to even the most remote communities.

Options for solar power generation include:

- small-scale PV systems suitable for off-grid power generation; and
- utility-size PV (conventional or concentrated photovoltaic) and CSP (concentrated solar power).

Solar photovoltaics (PV) convert the sun's radiation, in the form of light, into usable electricity. PVs consist of an arrangement of components, including solar panels to absorb and convert sunlight into electricity and a solar inverter to convert the output from direct to alternating current, as well as associated hardware. The most common material for solar panel construction is silicon, which has semiconducting properties. Several solar cells are required for a solar panel, and several panels for a solar array. Solar PV includes solar home systems (SHS), off-grid solar arrays and pico PV systems (independent 'plug and play' appliances such as solar lanterns, mobile phone chargers, radios or small TVs). Solar PV has no lower applicability threshold – the feasibility of a PV project depends on the technology used and the specific design.

Small-scale PV systems are expected to see rapid growth, particularly in developing countries, because they are often the best option for electricity compared to more expensive or less convenient alternatives. Standalone systems, such as small-scale solar PV, are key to making electricity accessible in rural areas where grid connection is generally too expensive (see case study on decentralised electricity, described below). India has the largest solar PV capacity of Commonwealth countries, followed by the United Kingdom, Australia, Canada and South Africa.[2] Many other Commonwealth countries have very small solar PV capacities.

Silicon-based PV panels appear to have limited potential for further cost reductions. Third generation PV technology currently points to a perovskite solar cell (PSC) made of a hybrid organic/inorganic lead or tin halide material as the light harvesting active layer. PSC cells are expected to be less expensive to manufacture than silicon cells and have a higher conversion efficiency, but are currently limited by a shorter lifespan compared to other solar cells (Energy Education, 2018).

CSP systems (also called CST, for thermal) use mirrors to concentrate the sun's rays and create heat. In most CSP systems, the heat created from the sun's energy is transferred to a heat transfer fluid, which is used to create steam and then generate electricity in the same way as in a conventional thermal power plant. A CSP plant requires direct sun rays and a clear sky, so deserts provide ideal natural conditions for CSP. South Africa and India have over 99 per cent of Commonwealth country CSP capacity to date (Figure 8).

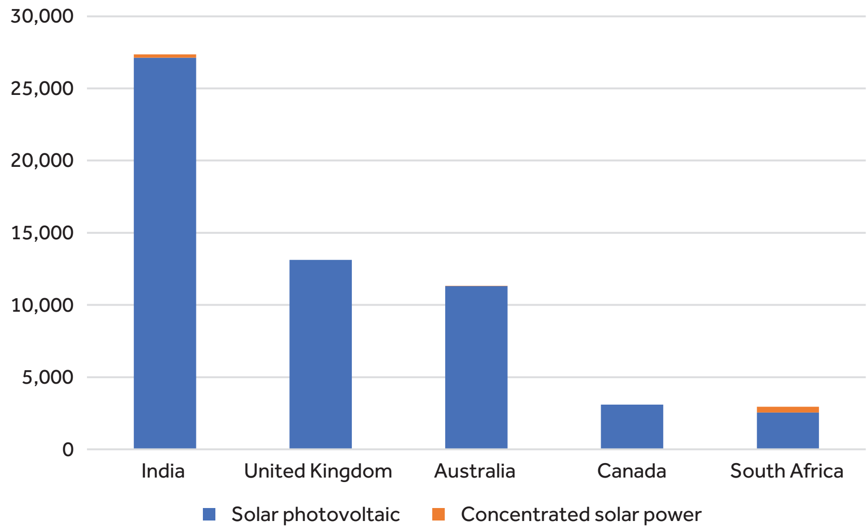
In addition to power generation, solar energy can produce heat for domestic uses or non-intensive industrial activities (e.g., textiles) or cooling (e.g., remote hospitals and clinics). Agricultural solar uses include irrigation, food processing and storage. Either CSP or PV technologies can provide desalination and wastewater treatment to communities where freshwater is scarce. A solar-powered water desalination and purification plant has recently been constructed in Mombasa, Kenya.

Although economies of scale and experience play important roles in achieving lower module costs, recent cost reductions are based on module manufacturing process optimisation and efficiency gains from increased adoption of newer cell architecture types. Cost reductions have also been achieved in the solar PV module manufacturing value chain (for example, reduced materials losses from diamond wire sawing, higher factory throughputs and automation leading to reduced labour costs) (IRENA, 2020b: Chapter 3). The solar cell manufacturing industry is dominated by China, but Malaysia has a significant manufacturing capacity, and is the largest manufacturer of PV cells/modules in the Commonwealth (Jäger-Waldau, 2019: Figure 1).

Wind

Wind energy is widely available but diffused. Although quality varies according to location, there is sufficient potential to support high levels of wind energy generation in most countries.

Figure 8. Commonwealth countries with largest solar power capacity (MW), 2018



Source: IRENA Renewable Capacity Statistics, https://www.irena.org/Statistics/Download-Data

Wind potential is mainly determined by wind speed, which is in turn highly dependent on pressure gradients and the shape of the landscape. The presence of deserts, coastlines and natural channels all favour high wind speeds. Wind turbine technology has made significant advances, with larger and more reliable turbines, higher hub heights and larger rotor diameters combining to increase capacity factors. A combination of economies of scale, increased competition and increasing maturity within the sector have led to continuing cost reductions. Wind energy capacity in African low-income Commonwealth countries grew at a CAAGR of 82.6 per cent from 2010 to 2018, much higher than the 14.5 per cent CAAGR for all Commonwealth LDC, LLDC and SIDS countries. South Africa, Pakistan, Kenya and Namibia have all seen exceptionally high growth rates in wind energy capacity in the past decade, although starting from very small bases. So far, there are no offshore wind energy installations in Commonwealth LDC, LLDC or SIDS countries, although the United Kingdom has developed significant offshore wind capacity. Globally, wind electricity generation (TWh) growth averaged 19.1 per cent annually from 2005 to 2019, although wind still represents only 5.3 per cent of 2019 global electricity generation (BP Statistical Review of World Energy, 2020).

India has the largest onshore wind capacity in the Commonwealth (almost half of the total), followed by the United Kingdom, Canada, Australia, South Africa and Pakistan, comprising over 97 per cent of total wind capacity among Commonwealth countries.

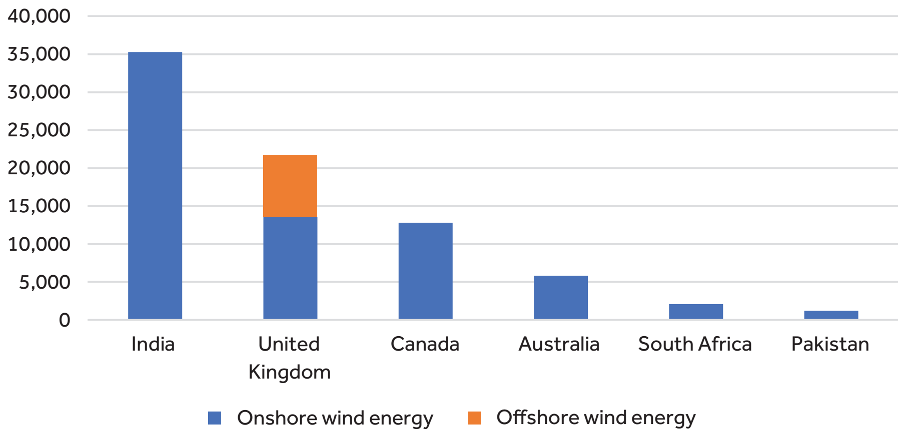
Geothermal

Geothermal heat relies on steam or hot water that is naturally stored underground and converted to electricity through steam turbines when brought to the surface. While geothermal resources are potentially widely available, they are more easily accessible near volcanoes, geologic rifts and hot springs. The bulk of Africa's geothermal resource potential, for example, is in the East Africa Rift System. There is large potential in some African Commonwealth countries, including Kenya, Tanzania, Uganda, Rwanda and Malawi, where total potential could be as much as 15GW, of which less than 1 per cent is tapped at present.

Like oil and gas exploration, geothermal exploration is an expensive and risky process in that the specific potential of a site for geothermal energy is not known until drilling has taken place. Unlike with oil and gas, electricity generation from geothermal resources needs to happen on site, because steam cannot be stored or transported and therefore must either serve local or regional off-grid users or require potentially costly transmission of electricity to connect to the grid.

Like hydropower, geothermally generated power is dispatchable, making it a good complement to variable renewable energy (VRE). It is typically used to provide base load power

Figure 9. Commonwealth countries with largest wind power capacity (MW), 2018



Source: IRENA Renewable Capacity Statistics, https://www.irena.org/Statistics/Download-Data

because of its low variable costs. New Zealand has the largest geothermal energy capacity in the Commonwealth (1,005MW), followed by Kenya (676MW) (Think Geoenergy, 2019). Kenya has plans to increase geothermal production to 5,000MW by 2030 (Ministry of State for Planning, National Development and Vision 2030 [Kenya], 2013).

Biomass

Bioenergy continues to be an important energy source in many countries, and especially important to the poorest people in rural areas in developing countries. Almost three-quarters of bioenergy use in Commonwealth countries is traditional use of solid biomass as fuel for cooking, with some use of solid biomass for modern power generation and heat. Biomass energy is dependent upon the availability of a supply that is predictable, low cost and sustainably sourced. Feedstocks may include agricultural crops and residues, food processing residues, forest products and forestry residues, aquatic plants, animal manures, and wastes such as municipal solid waste and wastewater.

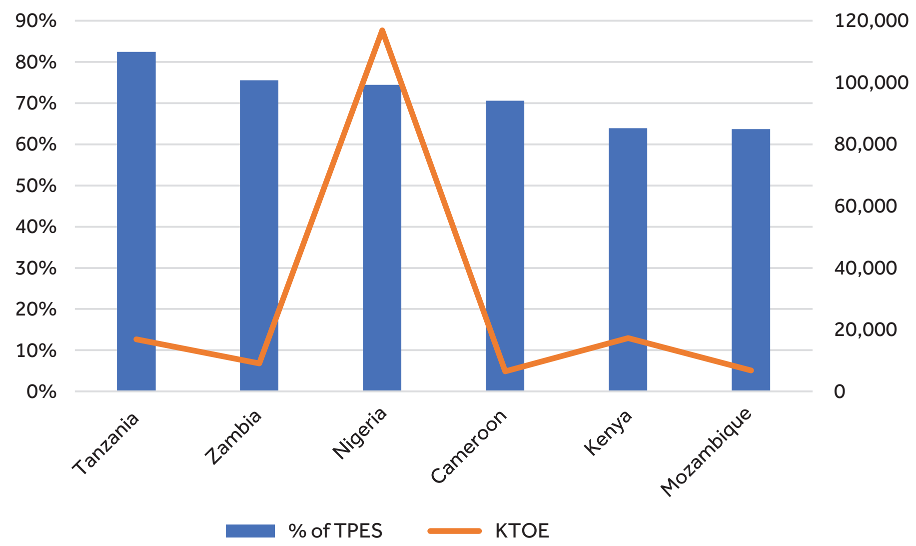
Inefficient use of solid biomass in households is common and linked to several factors, including poverty and the geographical remoteness of population. The primary policy rationales for transitioning to efficient, clean and environmentally sustainable biomass use are to increase the efficiency of combustion on the user side, to build sustainable value chains on the production side, and to reduce outdoor and indoor exposure to harmful air pollution from household solid fuel combustion. The transition requires efficient cookstoves and high-efficiency fuels, as well as sustainable forest management practices.

Whether biomass can be considered renewable is predicated upon its sustainability. This depends on whether the biomass sources are being regenerated, which for wood products requires good forest management practices. Much of the forest-derived biomass used in traditional cooking may not be sustainable, where it leads to desertification, but with proper resource management, use of biomass fuels like wood and biogas could be made more sustainable.

India is by far the largest user of solid biomass fuels in the Commonwealth, reflecting the size of India's population and economy. Biofuels represent 21.2 per cent of India's total primary energy supply (TPES).[3] They may represent much higher portions of TPES in other member countries, but smaller consumption because of the much smaller populations and economies of a country – as shown in Figure 10.

A more sustainable form of biomass can come from wastes and residues of various sorts, especially from wastes that would otherwise be disposed of. Bagasse, a by-product of sugarcane processing, is a common source of sustainable biomass energy. Australia is the largest user of bagasse in the Commonwealth, followed by Pakistan and South Africa. Municipal waste is another potential sustainable source, largely underutilised in many low-income countries to date. The United Kingdom is by far the largest Commonwealth user of municipal waste as an energy source, followed by India and Singapore.[4] Canada uses more than 99 per cent

Figure 10. Biofuels and waste energy in selected countries, 2017



Source: IEA Data and Statistics, https://www.iea.org/data-and-statistics/data-tables
Note: Energy Balances are not available for all countries in this data base, so this depiction does not include all Commonwealth countries; KTOE = thousand tonnes of oil equivalent.

of the liquid biofuels among Commonwealth countries, as an additive to gasoline.

Modern biomass energy may compete with food production, urban and infrastructure areas, biodiversity conservation and forestry land use. It is important to distinguish first-generation biofuels (i.e., crops grown for biofuel purposes) from second-generation biofuels (i.e., bioenergy feedstock derived from crop residues or non-crop plants). First-generation biofuels may raise significant land and food security concerns, whereas second-generation biofuels, with suitable sustainability safeguards, pose few concerns.

Biogas

Biogas is a modern use of bioenergy that provides clean energy from feedstocks, such as animal manure, agricultural residues, wastewater sludge and municipal waste. Biogas is ideally suited to households and communities where agricultural residues, animal manure and food wastes are available as a feedstock. Because biogas relies on residues and waste for feedstock, it is an environmentally sustainable renewable energy source. In addition to providing clean energy, anaerobic digestion produces a valuable fertiliser as a by-product that can enhance agricultural production.

The main process for biogas production uses a biodigester, an airtight system where anaerobic digestion produces biogas, a mixture of methane and CO_2. Biodigesters can be either decentralised (household scale) or centralised (urban scale). A decentralised biodigester is built to provide enough biogas to fulfil a single family's energy needs for cooking and water heating.

A recent IEA report notes 'the feedstocks available for sustainable production of biogas and biomethane are huge, but only a fraction of this potential is used today' (IEA, 2020d). The IEA states that biogas has the potential to provide 50 million tonnes of oil equivalent (MTOE) annually of locally produced low-carbon energy in Africa, largely via household-scale biodigesters – enough to satisfy the entire demand for clean cooking in Africa. Every country of the world has significant potential to produce biogas, and large-scale biogas production could provide a green substitute for gas imports and consumption for clean cooking in many countries.

Biomethane is a near-pure source of methane produced either by 'upgrading' biogas to remove CO_2 and other contaminants or through the gasification of solid biomass followed by methanation. Methanation uses a catalyst to promote a reaction between the hydrogen and carbon monoxide or CO_2 to produce methane, followed by removal of any remaining CO_2 or water at the end of this process.

Hydrogen

Hydrogen is the most abundant element in the universe, but most hydrogen exists in molecular forms as water or organic compounds. Energy from any source, ideally renewable energy, can be used for electrolysis to split water for green hydrogen production (Sanborn Scott, 2007). Hydrogen is cleaning burning and ideal for fuel cells. Fuel cells are made up of three adjacent segments: the anode, the electrolyte and the cathode. Chemical reactions occur at the interfaces of the three different segments, resulting in consumption of hydrogen, with water as its exhaust, and an electric current being created which can power electrical devices.

Hydrogen is a potentially attractive sustainable energy fuel for air and ocean transport. Energy storage for off-grid and back-up power could also be provided by hydrogen fuel cells. Hydrogen is not a widely used energy source at present, and 99 per cent of current hydrogen production is by steam reforming of methane – which results in significant CO_2 emissions (Wood Mackenzie, 2019). Hydrogen can be an important fuel of the future, however. If it is to contribute to a sustainable energy transition strategy to meet SDG7, its production would use renewable energy, or be produced as 'blue hydrogen' from methane using carbon capture storage technology (CCS) (FuelCellsWorks, 2020). The IEA and Wood Mackenzie (IEA, 2019c; Deign, 2020) have both reported recent increases of green hydrogen[5] projects, using electrolysers that produce clean-burning and storable hydrogen fuel from electricity and water, in the United Kingdom, Australia and Canada.

Marine energy

Marine energy, another form of hydropower, captures the tidal and wave energy of the ocean to drive turbines and produce electricity. The oceans have a tremendous amount of energy and are close to most concentrated populations. Marine energy projects currently generate an estimated 500MW of power – less than 1 per cent of all renewables. The potential is great, but no marine energy has been developed in low-income Commonwealth countries to date. The United Kingdom and Canada are Commonwealth leaders in wave and tidal power generation development and research. The only accredited wave and tidal test centre for marine energy in the world is based in Orkney, Scotland.[6] Canada's Fundy Ocean Research Center for Energy is also a leading research centre for in-stream tidal energy and home to five innovative demonstration projects, as well as working with the United Kingdom to advance tidal energy research.[7]

2.2 Technologies to complement the transition to renewable resources

Carbon capture and storage

Carbon capture and storage (CCS) prevents CO_2 from being released into the atmosphere (IEA, 2016). It involves capturing CO_2 from large single point emitters (for example, power plants and large industrial plants), compressing it for transportation and then injecting it into an underground geological formation at a carefully selected site for permanent storage. CCS can reduce CO_2 emissions from these plants by 80 to 90 per cent.

CCS is not an energy technology; it is an energy transition technology and is green in the sense it allows continued combustion of carbon fuels without adding to greenhouse gas (GHG) accumulations in the atmosphere. The IEA includes CCS as a necessary component of a strategy to reach the Paris Agreement goal. Its development and growth are dependent on the presence of a commercial incentive to engage in CCS. In the absence of a subsidy or a sufficiently high carbon price to make CCS viable, a commercially viable market for CCS cannot exist. CCS is potentially valuable in places without good renewable energy potential or where it would be too costly to retire and replace existing plants combusting carbon fuels (IEA, 2020e). The IEA believes that CCS (or CCUS for underground storage) must play an important role in achieving net-zero emissions. Wood Mackenzie, a leader in energy policy and technology analyses, points out that current installed CCS capacity is capable of capturing just 1 per cent of annual global emissions, and current policy frameworks and technologies are not adequate to allow CCS to contribute significantly to meeting the goals of SDG7 and the Paris Agreement (Wood Mackenzie, 2020a).

Commonwealth countries with CCS projects include Australia, Canada, India, Malaysia and the United Kingdom, with Canada having developed by far the largest capacity to date.

Natural gas is also touted as a critical resource in the context of conversion of methane for export as blue hydrogen in natural gas resource-rich countries.

Another way carbon can be captured and sequestered is by planting trees. This is not capturing emissions from any single emitter, but can be used as a natural offset mechanism by a variety of emitters. Ensuring that the sequestration is occurring and maintained requires an effective forest management system analogous to that needed to ensure the sustainability of biomass. Like CCS, planting trees to create carbon sinks may require a subsidy or carbon price to make it viable. A sustainably managed forest can allow regular harvesting and replanting of trees, potentially allowing this form of carbon sequestration to be viable on its own.

Article 6 of the Paris Agreement provides for establishment of a mechanism with the dual purposes of reducing GHG emissions and supporting sustainable development, although its structure and processes have not been determined yet. The Green Climate Fund set up by the United Nations Framework Convention on Climate Change (UNFCCC) in 2010, which is still substantially underfunded, could be used to support projects under Article 6 in developing countries that reduce emissions from deforestation and forest degradation (REDD) and enhance forest carbon stocks.

Natural gas transition

Natural gas has the lowest carbon content of any of the hydrocarbons and is therefore the most environmentally benign hydrocarbon fuel. While its use as a fuel results in CO_2 emissions, natural gas is often viewed as an acceptable bridge fuel to the extent its use can lower CO_2 emissions by replacing other hydrocarbon fuels which have higher carbon emissions. Natural gas can reduce emissions by as much as 66 per cent when replacing coal (Hausfather, 2016).

The other advantage of a relatively low emission fuel like natural gas is that it provides dispatchable electricity generation that can be dispatched on request to the power grid in response to market needs. This contrasts with electricity from VREs such as solar and wind, which only provide electricity when the sun shines and the winds blow. While electricity from VREs has marginal costs near zero, they cannot always be relied upon when needed, so back-up generation must be available from a dispatchable source. Natural gas is a potential source of back-up generation capacity, but it must compete with other more environmentally benign and sustainable alternatives, such as demand-side management (e.g., peak shaving, time-of-use pricing, etc.), smart grids, hydro pumped storage, small battery systems, and regional interconnections.

There are many Commonwealth countries with gas resources and gas production, and gas will continue to be an important energy source.[8] Under SDG7 and the Paris Agreement, the future role of natural gas may be primarily to serve short-term demand needs and balance electricity supply when more economical energy from solar and wind is not available. Gas will be valued for its flexibility compared to VREs, not as a bulk fuel. Gas will also continue to be an important feedstock for non-energy uses such as petrochemicals and synthetic materials. While CCS can absorb most of the carbon emissions from many gas consumption sites, most gas developments also have elusive fugitive methane emissions which arise prior to combustion and can be more environmentally damaging than the carbon emissions from combustion of natural gas. By their nature, these emissions are often difficult to measure and track. Canada has recently introduced requirements for natural gas producers, processors and transporters to identify sources and measure and report methane emissions (Konschnik and Reuland, 2020).

Battery storage

Natural gas can effectively provide back-up electricity generation for electricity consumers connected to the grid. But to the extent that expansion of energy access in developing countries is by off-grid technology users, they will need to rely on energy storage when VREs are not providing energy. IRENA emphasises the importance of battery storage technologies in the world's transition to sustainable energy systems. Battery systems can support a wide range of services needed for the transition, including reserve capacity on the grid, storing power in electric vehicles, upgrading mini-grids and supporting decentralised solar power. IEA expects increasing deployment of VREs will double the global need for power system flexibility, including from batteries. IRENA expects batteries could support higher utilisation of VREs by storing surplus energy and releasing it when the sun is not shining, the wind not blowing strongly enough, or simply when needed to ensure grid stability and reliability.[9]

Like renewable energy technologies, battery technologies have also been advancing and costs have declined rapidly, largely due to the rapid increase of battery manufacturing for electric vehicles resulting in spillover economic benefits to the power sector. Recently published analysis by BloombergNEF (New Energy Finance) finds that battery storage costs have fallen even faster than wind and solar costs in recent years; for short durations, batteries are now a cheaper energy source for peak shaving than gas turbines, the traditional technology for that purpose (Colthorpe, 2020). BloombergNEF expects the storage duration capacity of batteries to continue to increase. This will allow batteries to complement wind and solar for off-grid users and eventually replace gas as a back-up energy source for the grid.

Energy efficiency potential

If future energy needs are to be met in a sustainable way, many suggest that improvements in energy efficiency will be a vital component. Energy efficiency is an energy resource that all countries abundantly possess. 'Energy efficiency' refers to using less energy input to deliver the same service or using the same amount of energy input to deliver more service. Globally, energy efficiency will contribute to declining energy intensity as less energy is used per unit of gross domestic product (GDP). The IEA notes the decoupling of economic growth (GDP) and energy use (in terms of total primary energy supply), with TPES growing at approximately half the rate of GDP in recent decades (IEA, 2019b). The IEA is concerned by the slowing rate in energy intensity improvement in 2018, which it attributed to a relaxation of energy efficiency policies. Strong and comprehensive energy efficiency policies are necessary to achieving key energy policy goals and yield multiple benefits in the form of lower energy costs, reductions in climate impacts and air pollution, improved energy security, and increased energy access.

Traditional areas for achieving energy efficiency include improvements in buildings and appliances, more efficient vehicles, electricity generation rehabilitation, loss reduction by improving transmission and distribution systems, and improvements in the efficiency of heating and cooling systems. The IEA has reported that sales of energy efficient LED lights are on track to meet 90 per cent of light sales by 2030, one of the few fuels and technologies that is on track (IEA, 2020c). Some economists have observed that the actual economics of energy efficiency projects is often less attractive than predicted by the engineering models and have tempered their expectations for the potential contribution of energy efficiency to the sustainable energy transition (Jaccard, 2020: chapter 10; Banerjee and Duflo, 2019: chapter 6).

In a global energy system largely reliant on fossil fuels, the higher energy prices since 1973 are considered the most important contributor to lowering the energy intensities of developed economies. Higher prices reduce consumption and provide incentives for investments in relatively lower-cost energy sources and in developing new, more cost-effective and energy efficient technologies. Policy tools other than carbon prices that could contribute to further energy efficiency and lower energy intensities are subsidies, regulations and public education. Replacing traditional use of biomass in cooking with clean cooking appliances and fuels will perhaps provide the greatest improvement in energy efficiency in many countries, as well as improving the environment and quality of life and enhancing economic development. Increased use of charcoal can be made cleaner and more sustainable by increasing efficiencies along the entire value chain – manufacturing, transportation and distribution, as well as the efficiency of the stoves themselves using charcoal as fuel.

2.3 Barriers to overcome

The potential low-carbon transition energy technologies for application in Commonwealth countries has been outlined in the previous section. This section will briefly discuss some challenges and barriers to transitioning to these low-carbon energy technologies, and will also seek to identify some strategies and initiatives to address and overcome these barriers.

> *Strong, effective, stable, and coherent policy support through predictable and stable government legislation, policy framework, and targets is imperative in accelerating sustainable energy transitions.*
>
> Laurence Delina

Common barriers to achieving energy access, especially in developing countries, are:

- Technical challenges: availability of the required equipment, standardisation of the equipment, weak after-sales maintenance, poor operational performance, logistical challenges and inconsistent fuel supply.

- Financial challenges: high upfront costs, difficulty in attracting financing, difficulty in collecting revenues and ensuring profitability, market saturation, and bankruptcies.
- Institutional challenges: constrained institutional capacity, the need for long-term plans to include the full range of low-carbon technologies needed for SDG7, commitment of governments to fossil fuels with subsidies and other policy support, commitment of governments to grid electrification instead of distributed systems, grid access needed for renewable energy sources, fragmentation in energy decision-making, and aid dependency.
- Social challenges: low consumer awareness, unrealistic expectations, lack of familiarity with the equipment, and opposition and community disagreements.

Nationally determined energy transition targets are needed to set a coherent direction for navigating the future. This will include NDC targets made under the Paris Agreement and serving to attain SDG7 targets. These targets must be supported by policy frameworks and strategies to meet them.

Economic and financial barriers

A major challenge for renewable energies in low-income countries is economic – that is, the costs of technology adoption for the energy transition to take place. Governments that are struggling to fund schools, hospitals and roads will have difficulty being able to fund energy transition investments as well. Citizens living a subsistence lifestyle or living below the poverty line may be unable to pay for electricity or electric appliances, however attractive they may appear.

An important way to reduce the economic barriers is to get the price signals right, a prerequisite for market efficiency and also helpful to consumers, investors and governments. Getting price signals right for energy includes pricing the carbon emission externalities of fossil fuels and eliminating subsidised prices for fossil fuels. Relative costs of fuels are also particularly important, because of the following issues:

- Failure to include environmental costs associated with carbon emissions in market prices is a distortion of market prices.
- Fossil fuels are subsidised in many countries, including some Commonwealth countries (IEA, 2020b); these subsidies, in effect, act as a negative price on carbon, encouraging its use. Removing subsidies and incorporating externalities into fossil fuel prices would dramatically change relative prices.
- A recent IMF working paper found that fossil fuel subsidies are inefficient in supporting the poor, with 93 per cent of subsidies going to the top income groups (Coady et al., 2015).

Imposing carbon prices and removing subsidies on fossil fuels can provide a source of funds to support renewable energy transition initiatives that do not require the government to reallocate funds from the many other programmes that also urgently need to be addressed in developing countries.

An encouraging development with respect to renewable energy resources is that their costs are declining, in some cases exponentially (as seen earlier in Figure 6). As renewable energy volumes increase with market development, the resulting economies of scale will reduce their prices. This leads to further growing demand and further cost reductions for the technology, resulting in a feedback loop that accelerates the growth of renewables.

Rapidly increasing investments in renewables resulting from public commitments and maturing technologies are making renewable energy sources very competitive against more traditional energy sources. The competition is not just with traditional energy sources as different renewables are starting to compete against each other.

2.4 Time constraints

> *There is no doubt that the energy sector will only reach net-zero emissions if there is a significant and concerted global push to accelerate innovation. It is also clear that there is a disconnect between the climate goals that governments and companies have set for themselves and the efforts underway to develop better and cheaper technologies to realise those goals.*
>
> Dr Fatih Birol

With only ten years left until the target date of 2030 to meet the SDGs, urgent actions are required to get the world on track to meet these goals. Given that sustainable energy transition is costly, individual citizens, firms and countries may have strong incentives to delay actions; this incentive applies to advanced countries as well as developing countries.[10] Global commitments and collaboration are difficult, because the interests of nations differ – e.g., rich versus poor countries and hydrocarbon exporters versus hydrocarbon importers.

Getting price signals right and adopting strong policies to regulate or constrain carbon emissions will be important steps to getting the transition on track. Energy transitions and deep decarbonisation are collective action problems, as the global climate is a global public good and must be recognised as such. Individual actions by citizens and states are helpful, but cannot solve the problem because of the incentive for some individuals or states to 'free-ride' on the emission reductions of others without taking proportionate action on their own. With voluntary commitments made by individual countries in support of the Paris Agreement to reduce emissions not enforceable, the need to garner political will for collective action in honouring of such commitments across countries is critical. This is where an organisation like the Commonwealth can potentially play a helpful role as catalyst.

Nobel laureate in economics William Nordhaus has suggested the creation of 'climate clubs' among jurisdictions, with significant trading relations as a means of applying carbon tariffs among themselves and applying pressure on countries that lag in implementing climate change policies (Nordhaus, 2015:1339–1370; Nordhaus, 2020; Nordhaus, 2018). Commonwealth countries already have strong trading relations, so the Commonwealth could potentially provide an attractive venue for encouraging climate action among its members by seeking to create a climate club. This would involve agreement by participating countries to adopt harmonised emission reduction strategies (e.g., an agreed uniform price on carbon) and appropriate incentives, including tariffs to be applied to carbon emissions of countries underperforming according to agreed standards. The benefit of belonging to the club would be the low tariffs and open borders on trade between members. Beyond being a catalyst among its members, the climate club could invite non-Commonwealth countries to join the club in order to increase their trade with Commonwealth countries and broaden the scope of the initiative to encourage energy transition and climate change amelioration in more countries. Establishing a climate club could provide Commonwealth countries with an opportunity to 'leap-frog' other nations in decarbonising their economies.

3. Case studies of energy transition technologies

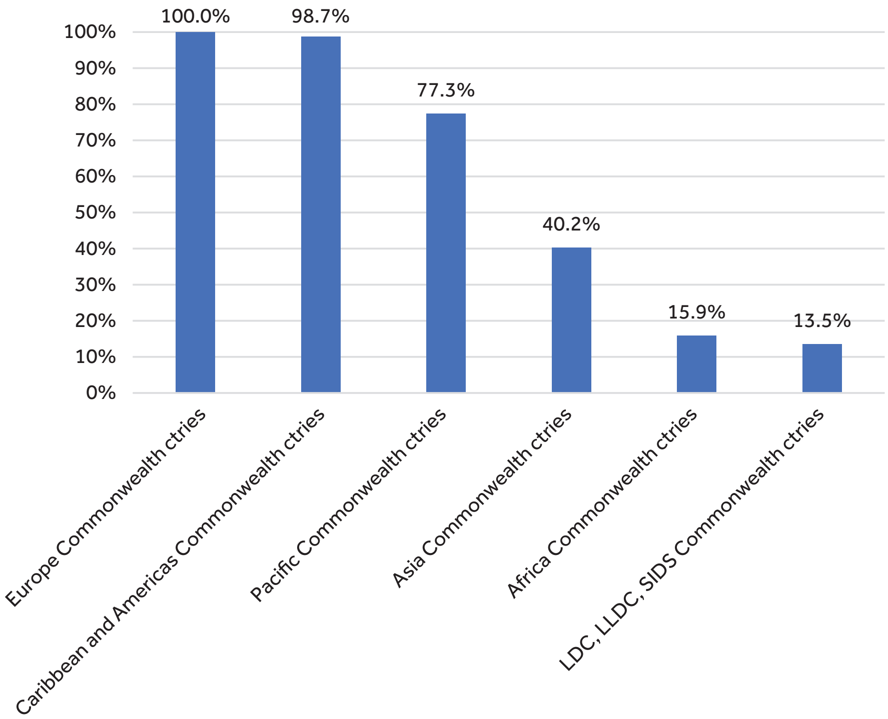
To demonstrate the challenges and benefits of energy transition technologies, two case studies were selected and are described below. Adopting clean cooking technology offers many benefits, including providing a healthier and more sustainable environment. Adopting decentralised solar energy technology may be the most cost-effective way of expanding access to sustainable energy in many Commonwealth LDCs. Case studies of adopting these technologies in specific African countries will be described and discussed below, including the benefits from and challenges to widescale adoption of these technologies in those countries.

3.1 Case study: Clean cooking technology

Overview

Access to clean cooking remains acutely low in many Commonwealth countries, and is especially low in African Commonwealth countries (as seen in Figure 11). The entire population of European Commonwealth countries has access to clean cooking technologies, followed closely by the countries of the Caribbean and Americas, with 98.7 per cent of their populations having access to clean cooking technologies. If Mauritius (93.3 per

Figure 11. Access to clean fuels and technologies for cooking, 2019 (percentage [%] of population)



Source: Based on Sachs et al. 2019.

cent), Seychelles (90.4 per cent) and South Africa ((84.8 per cent) are excluded, only 7.7 per cent of the population other African Commonwealth countries have access to clean fuels and technologies for cooking. The residential sector in the Commonwealth member countries in Africa accounts for around 65 per cent of total final consumption of energy (in contrast to 20 per cent in advanced economies), making it the largest end-use sector (IEA, 2019a). Low access to clean cooking in these countries is exacerbated by low access to electricity, requiring citizens of these countries to use some form of direct combustion of fuel for cooking, which traditionally has been burning wood.

While some Commonwealth countries in Africa may have natural gas resources, natural gas may not be a viable option for cooking for poor households and in remote and rural areas. Distribution of natural gas requires expensive distribution systems, which are not viable for small users.[11] While liquid petroleum gases (LPGs) may be used as cooking fuel, potential challenges often exist in terms of accessibility and affordability.

The technologies, appliances and fuels needed for clean cooking are available and ready for deployment. As part of a broad range of economic and social benefits, clean cooking will result in substantial improvements in energy efficiency.[12]

Biomass-use externalities

The traditional use of solid biomass as fuel has damaging effects on health and well-being. These include:

- serious health effects, including premature death, from the resulting air pollution from indoor cooking;
- the significant opportunity cost of time-consuming firewood collecting, especially creating a major barrier to economic advancement of women; and
- costly forest degradation and deforestation (about 90 per cent of wood harvested in Africa is used for energy).

The sustainability of biomass is enhanced by more efficient use, but remains dependent on the management and sustainability of the sources from which the biomass is obtained. Nigeria has lost 60 per cent of its forest cover since 1990, while Tanzania has lost almost 20 per cent of its forest areas (IEA, 2019a: 198). Efficiency improvements across the various bioenergy value chains could play a significant role in protecting forests, biodiversity and carbon sinks. Pricing wood resources (e.g., from taxation of wood harvesting, licensing fees and certifications) and investing in reforestation activities to ensure sustainable forests are keys to improving the sustainability of biomass.

Improved cookstoves and appliances

Improved cookstoves range from locally designed stoves made of clay, mud or dried grasses to more advanced stoves designed and manufactured in factories. The main benefits of improved cookstoves are fuel efficiency, reduced cooking time and less indoor air pollution. Depending on the design, other benefits may include income savings on the purchase of firewood and kerosene, time savings from firewood collection, poverty alleviation, health improvement, decreased deforestation, and reduced GHGs. Improved cookstove technologies range from simple stoves with minimal combustion efficiencies, intermediate stoves with improved combustion chambers, and advanced biomass stoves with forced ventilation (Amuzu-Sefordzi et al., 2018: 140–154).

Improved biomass fuels

The use of clean cookstoves generally involves the use of an improved fuel, especially compared to cooking on the traditional three-stone fire. Biomass fuels can include products and by-products from the agriculture, forestry and waste sectors (e.g., wood, charcoal, sugarcane, palm oil and animal waste). Modern uses of biomass can include:

- cooking and heating in more advanced, efficient and less polluting stoves;
- use as a fuel in combined heat and power plants; and
- transformation into processed solid biomass (pellets, briquettes), liquid biofuels or biogas.

Case study

The following case study was conducted by the Stockholm Environment Institute in two African Commonwealth countries, Kenya and Zambia (Jürisoo and Lambe, 2016; SEI, 2016; Jürisoo et al., 2018). The authors report that 70 per cent of the population in Kenya and 84 per cent of the population in Zambia use traditional biomass for cooking.

Clean cooking case studies take many different approaches and focus on many different aspects of clean cooking. This case study is predicated on these observations:

- modern, efficient cookstoves are available in most African countries, but the adoption and consistent use of these stoves is not at a level to maximise the opportunity to benefit from this technology; and
- after acquiring a clean cookstove, many households do not use them consistently and often abandon them.

The economic, health and environmental benefits from advanced cookstoves can only occur with proper and consistent use. This study focuses on motivations of households to initially acquire modern, efficient cook stoves, adopt them for their cooking needs, and maintain their commitment to using them for the long term. The study used a technique called ‘user journey’ to sequentially map the households’ interaction with the cookstove, from first hearing about the stove, to purchase, to learning to use it, to making it part of their daily routine.

Compared to traditional biomass stoves, advanced cookstoves function differently, use different fuels, and impart different tastes and textures to food. These point to behavioural changes needed to adopt new cooking practices and recipes, which requires time and effort. Studies on clean cooking adoption necessitate consideration of human behaviour and decision-making determinants, which this study identifies as:

- *Opportunity*: Can the household acquire and use advanced stoves? This includes stove and fuel prices, household income and socioeconomic characteristics, and government incentives.
- *Ability*: Does the household know how to use the advanced stove? This includes household knowledge, skills and social support, mastering of cooking, and technical operating knowledge.
- *Motivation*: Does the household want to use the advanced stove? This includes internal factors such as attitudes and beliefs, values, emotions and priorities; and external factors such as social networks and physical access to service.

Study participants comprised 18 stove buyers in each region, identified through sellers of stoves: a microfinance institution that helps women acquire 'life enhancing products' in Kiambu County, Kenya (immediately bordering Nairobi to the north) and two social enterprises in Lusaka, Zambia. All the Kenyan participants and half the Zambian participants had the Philips forced-draft advanced biomass cookstove, which cost $US115 in Kenya, paid for in monthly instalments. As well as pellets, the stove can be fuelled with wood or charcoal. These stoves reduce emissions of health-damaging pollutants by 60–90 per cent compared to traditional wood stoves, and when used properly, can save up to 80 per cent in fuel compared with traditional three-stone fires. To encourage the use of pellets, each new customer received a free bag. The stove has an electric fan to minimise fumes while cooking, which needs to be charged weekly to accommodate daily cooking.

The remaining Zambian participants cooked on two different types of natural draft gasifier stoves that burn pelletised fuels: the Peko Pe stove, designed in Norway and assembled in Zambia, and the Vitalite stove, designed and manufactured in Zambia. These stoves were less technologically advanced than the Phillips stove and therefore less expensive.

Findings regarding household decision-making to purchase a clean cookstove:

- Ability: finding out about the new stove and gathering information to inform the purchase. More than 95 per cent of households learned about the stove at targeted demonstrations.
- Opportunity: paying for the stove. In both locations, the cookstove wholesalers acted as financial enablers to make the cookstove affordable by offering paying in instalments.
- Motivation:
    - Saving. Most respondents reported the number one motivator for their purchase was the prospect of using less fuel and the resulting savings. To the women, savings primarily meant less money spent on fuels that previously supplemented collected fuelwood. It also meant the (collected and purchased) fuel lasted longer.
    - Convenience. The second most common purchase motivator related to convenience. That is, the stove would make life easier in terms of flexibility in fuel use, reduced smoke during cooking or freeing up time for other activities.
    - Aesthetics. The third most common motivator related to the modernity and aesthetic appeal of the stove, associated with personal goals and aspirations for social mobility.
    - Social effects. Some signed up for the stove immediately following the initial demonstration and marketing pitch because others did.

Findings regarding use of the new stove and establishing new routines:

- Ability and opportunity to use the new stove: learning to use it.
    - While most interviewees believed they had all the information they wanted when buying their stove, many reported being hindered by lack of information when they started to use it.
    - Positive comments related to the increased speed of cooking, the ability to cook indoors without filling the house with smoke, the ease of lighting and cleaning the stove, the nice appearance in the home, and greater physical comfort than using traditional stoves.
    - Negative experiences involved disappointment with technical aspects of the stove, such as not being able to refuel while cooking without causing smoke, non-suitability for cooking some types of dishes, blackening pots during cooking, cooling down too quickly, difficulty in lighting it, not accommodating large pots, the need for active monitoring throughout the cooking, not realising the stove had to be charged weekly, needing to add pellets correctly, and not remembering how to clean and maintain the stove.
- Motivation: establishing a new routine by staying motivated.
    - Not all used the stove for all cooking tasks; often households 'stacked' the new stove alongside the charcoal Jiko, a three-stone fire, and/or an LPG or kerosene stove.
    - Households that cited saving money as their main purchase motivator invested the necessary time to learn how to use the stove and used their stove regularly;

they also seemed to experience the biggest 'life change' and beginning of new habits.
  - Households that used their new stove primarily as a convenient alternative, only cooked on it sporadically.
  - Many appreciated having a stove that could use different types of fuels, allowing them to adjust to circumstances such as higher charcoal prices during rainy seasons or when their disposable income varied.
  - Users whose purchase motivation related to the aesthetic and aspirational appeal were the least frequent users.

Some important lessons from these case studies are:

- The opportunity, ability and motivation to acquire the stove and learn to use it correctly and consistently involves a series of choices – the purchase, regular use and establishment of new routines.
- It is important to support learning how to use the stove, which includes pre-purchase trials, high-quality user manuals, provision of long-term support, and trusting relationships with sales personnel and suppliers. During the learning stage, 'low-threshold' factors such as ease of use, are more important than potential long-term benefits such as savings. Making the user's first encounters with the stove go smoothly is critical.
- Access to finance is crucial, sparing prospective customers from having to save money for a long time before being able to access the stove.
- The aesthetic appeal of the stoves as modern appliances was a frequent motivating factor, showing that tapping into people's collective aspirations and understanding what constitutes a life improvement can be a powerful motivator for change.
- Having a microfinance institution focused on providing loans to women as a 'known' sales agent and trustworthy partner promoting the stove in Kenya was a positive factor in purchase decisions.
- Users would like more information about the products being promoted, particularly in terms of how these products compare with cooking methods they are currently using.
- Cookstove suppliers should allow prospective customers to try out the stoves during the demonstration sessions and when orders are placed, and should try to avoid long delays in delivery.
- Convenience is significant. Cookstove suppliers should provide an easily comprehensible manual with clear instructions and supporting pictures, accessible to both literate and illiterate users. The design needs to be easy to use, convenient and practical in daily operation, and easy to maintain in terms of functionality and appearance. Pellet fuel should be made available in small quantities to make it more affordable to households with low cash reserves.
- Because the factors that motivate the stove purchase may not motivate people as they begin to use it, the cooking experience needs to reinforce that purchasing the stove was a good choice. When mishaps occur, a system must be in place to motivate users to keep using the stove; after-sales support is important.
- Governments can strengthen the enabling environment for advanced cookstove uptake by providing incentives that make advanced biomass stoves and fuels, such as biomass pellets, easily available to clients, thereby lowering the barriers to initial purchase and the formation of new cooking habits.

Lessons for Commonwealth countries:

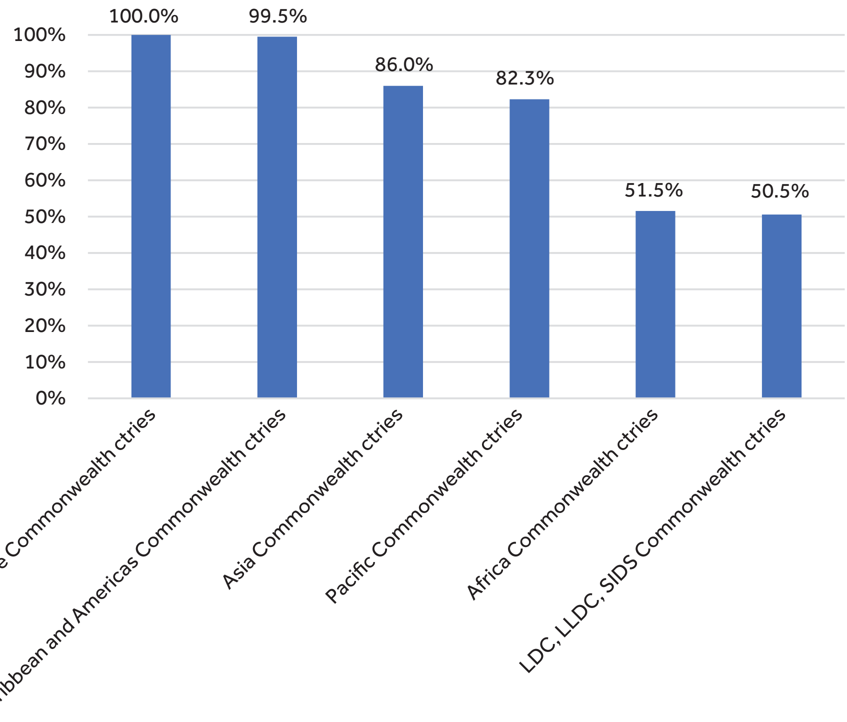
The case study is predicated on the reality that advanced stoves and more efficient fuels are available, so the challenges to increase access to clean cooking are behavioural, not technological. The benefits of clean cooking technologies, referenced and described above, are well known to governments and especially the more educated citizenry. Increased access to clean cooking clearly implies an important leadership role for governments in providing consumer education and consumer incentives.

3.2 Case study: Decentralised solar electricity

Overview

Electricity has been described as the 'lifeblood of modern economies', with most economic activities dependent on access to a reliable supply of electricity. Many citizens of developing countries in the Commonwealth do not have access to electricity (Figure 12).

Figure 12. Access to electricity, 2019 (percentage [%] of population)



Source: Based on Sachs et al. 2019.

Some things in common between Figures 11 and 12: 100 per cent of European Commonwealth country populations have access to electricity, followed closely by Caribbean and Americas countries. African Commonwealth countries have least access, with 51.5 per cent of their populations having access to electricity.[13] If Mauritius, Seychelles and South Africa are excluded, only 47.7 per cent of African Commonwealth country populations have access to electricity.

The geography, demography and level of infrastructure in Commonwealth African countries with the least access to electricity indicate the opportunity for decentralised solutions to achieve universal access, where grid expansion or extension is not a viable option. Grid extension can be cost effective when serving an area with a high density of demand. More isolated and rural areas may be more cost effectively served by decentralised systems. Off-grid solar is a proved and ready solution to providing universal energy access, although the following case study corroborates that it is not being deployed to its full potential yet.

Case study

The case study (Holmberg Hansen, 2018) explores the off-grid solar PV market in Kenya, using a combination of interviews, observations and document analysis. Only 56 per cent of Kenyans had access to electricity in 2019, so significant progress in expanding access is needed to meet the SDG7 goal of 100 per cent by 2030. This case study seeks to understand the major determinants that influence decentralised solar PV systems use in rural Kenya. The decentralised off-grid systems studied were both standalone and mini-grid systems.

Standalone systems – are used in smaller settings such as households, businesses, clinics, schools, etc. Solar PV technology at the household level includes solar lanterns and Solar Home Systems (SHSs), supplying electricity to one household or building.

- SHSs are standalone solar PV systems that offer electricity for lighting and basic appliances to households. Most SHSs include a small solar panel that can be placed on the roof of the building. The panel is connected to a battery placed inside the home. They usually provide low- to medium-level power for DC appliances such as lights, phone chargers, radios and small TVs for three to five hours a day.
- Lanterns are a portable LED-lamp with batteries that are charged through solar panels.

Solar lanterns were initially promoted by non-governmental organisations (NGOs) and businesses as part of small charging stations they operated. Phone charging and radios are now also starting to come on the lanterns, with the most advanced ones having a light, a radio and phone charging. Often lanterns are more useful than a SHS due to their portability. Because of the lanterns' low energy consumption, households relying on them are often not considered electrified.

Mini-grids – serve the energy needs at the village level. The study observed that mini-grids served between 20 and 400 customers and are most effective when customers are within a 1km radius. Private mini-grids in Kenya are mainly based on solar, while the public ones are often a hybrid – for example, solar–diesel. Public mini-grids tend to be bigger and serve more households than private ones. Private mini-grids were found to be more reliable than public mini-grids.

The field research in this case study used a qualitative approach to understand consumer motivations and decision-making respecting adoption of solar PV technologies. The specific techniques were observations and interviews with households using off-grid solar PV systems. The research involved 26 households in 10 different locations in some of the poorest areas of Kenya, and was supported by analysis of relevant and related reports and previous research. The in-home interviews allowed direct observations of how the solar PV system was used.

The key observations and recommendations of this case study included the following:

- The nomadic lifestyles of some communities make portable rechargeable lanterns most suitable.
- Some communities with solar–diesel hybrid mini-grids found the solar component often did not operate, indicating a need for more technical support by suppliers. Because the mini-grid was unreliable, households often had an SHS or lanterns as back-up. Unreliability and the need for back-ups are obviously economically inefficient and deterred households from connecting to the mini-grid.
- Most households selected their system because of its availability and because their friends or neighbours had it. The market, therefore, functions as 'first come, first served' for suppliers. Information on alternatives and the pros and cons of different systems was not available. More suppliers are needed to make the market more competitive and better functioning, with this requiring market growth. In the meantime, better ways of disseminating objective and understandable information are required, possibly by governments or NGOs.
- No households identified price as the main reason for system selection, but higher cost was a major reason for not connecting to mini-grids.
- Mini-grid users tended to have more electrical devices in their homes than SHS and lanterns users; therefore, a mini-grid connection was the only way to obtain enough electricity for their needs.
- Differences in consumer needs, preferences and living situations between households, villages, regions and communities indicate that finding the most suitable technology requires more flexibility in types and costs of systems.
- The solar PV systems available in rural Kenya fulfil most current basic electricity needs, such as light and phone charging. But none are considered optimal in terms of sustainability, self-dependency, flexibility and potential expansion to accommodate future consumption changes.
- The mini-grid is potentially a long-term sustainable solution, but has difficulty attracting customers because of high up-front costs, poor reliability and being less green – because they often consume diesel fuel rather than solar energy.
- SHSs and lanterns are currently more popular among low-income households in rural Kenya, but they can be problematic due to lack of service and spare parts and the short lifespan of the batteries. Expandable systems with standardised spare parts and batteries that could provide greater reliability, portability and flexibility are desirable.

Off-grid solar is a suitable technology for rural Kenya, based on social, geographical and economic considerations, and off-grid decentralised solar is the preferred and most appropriate option to electrify less densely populated areas in rural Kenya. Solar PV use is growing in Kenya, but not as rapidly as it could because of lack of consumer knowledge, lack of adequate consumer choice, lack of optimal systems and lack of quality in service and equipment. Communication and cooperation between the government and private sector players is needed to remedy these deficiencies.

Lessons for Commonwealth countries:

The important lesson for Commonwealth countries with low energy access is that relying on decentralised off-grid access alternatives may be more attractive and more effective than trying to expand the grid to the entire country. The traditional concept of electricity being generated in large power plants and provided to consumers via long-distance transmission and distribution systems is being challenged and disrupted. This is occurring because consumers can now directly access alternative electricity sources, such as solar PVs.

Increasingly, the most attractive means for gaining access to electricity not connected to a grid will likely be solar PV systems and batteries. These can be built at different scales to match a range of needs, from lighting and mobile phone charging to fans, televisions and refrigerators. Energy access will be provided locally and more economically in decentralised systems located on rooftops and in some cases below ground (e.g., microscale geothermal heating and cooling systems).

These systems may be communal, by relying on a mini-grid, generally with capacity of 10kW or less, which serves as a network connecting renewable energy-generating homes, neighbourhoods and buildings in a geographically contiguous area. Mini-grids require a stable flow of power and increasingly rely on renewable-based power, with battery systems for back-up. These off-grid distributed generation systems provide an ideal technical solution to extend energy access, especially in areas not currently connected to the grid.

Mini-grid sizes can increase as demand expands within the service area, and they may eventually be connected to the main grid. The advantages of being connected to the main grid are that the grid can provide electricity when the mini-grid's local supply is insufficient and can also allow excess local energy to be fed into the grid and sold, thereby providing revenues or cost-offsets for small generators.

Decentralised electricity generation can both complement and substitute for the electricity grid. While there are advantages to small generators being connected to the main grid, expansion of a main grid may not be the most cost-effective basis for making electricity accessible in most countries. Most consumers will see in their electricity bills that the costs of transmission and distribution exceed the cost of the electricity (University of Texas at Austin, 2018).[14] This suggests that distributed generation based on off-grid SHSs and mini-grids may be more cost effective than the main grid, and this has important implications for national energy plans and strategies. It indicates that countries that want to make energy more accessible will likely be better served by relying on distributed generation to provide electricity as a substitute for the grid, rather than seeking to extend the grid to connect the entire country.

4. Conclusions and lessons

Sustainable energy transition requires transforming today's predominantly carbon-based energy system[15] to an energy system based on renewable or low-carbon energy sources. This energy transition results in the decarbonisation of our energy systems and economies. While ensuring universal access to energy is an important and laudable goal, the other key driver of this transition is the urgent need to respond to the impending risks of climate change, which is an underlying driver of SDG7 and the primary driver of the Paris Agreement. An energy transition of this magnitude and speed has the potential to be both a major economic disruptor and a major economic opportunity. The disruption potential may be seen as a threat in Commonwealth countries that are major producers and exporters of fossil fuels.[16]

Ramez Naam, a renewable technology expert, has described the transition to renewable energy resources and technologies as typically going through three phases (Naam, 2019):

- *Phase 1*: policy dependent – until roughly 2015, transitioning was reliant on government subsidies and mandates.
- *Phase 2*: competitive for new power – the gradual scaling up and improvements in technologies leading to cost reductions, and making solar and wind electricity economically competitive.
- *Phase 3*: disruptive to existing fossil electricity – building new solar or wind power (or new energy storage systems) becomes cheaper than continuing to operate existing coal- or gas-fuelled power plants.

Similar phases may be seen regarding energy access, where there is clearly a phase which is policy dependent. It may take longer for energy access to reach Phase 3, and this would not likely be a disruptive phase.

Economist Mark Jaccard, a strong climate change policy advocate, warns against complacently accepting the frequent claim that 'renewables have won' (Jaccard, 2020: chapter 11). Jaccard warns of four factors that challenge the transition to renewables:

1. *Energy quality*: compared to liquid fossil fuels, renewables have low-power density. The land area required to produce equivalent renewable energy may be greater by orders of magnitude.
2. *Capacity utilisation*: the actual output of renewable energies compared to full-capacity output is low, requiring costly investments in excess capacity.
3. *Intermittency of many renewables*: they are 'non-dispatchable', meaning they cannot be relied upon to produce at full capacity when needed and when most valuable. Therefore, back-up electricity sources are needed.
4. *Pricing dynamic effects*: as energy increasingly transitions to renewable sources, the prices of fossil fuels can be expected to fall, making them more competitive. This of course can be offset by appropriate carbon pricing.

Further innovations and game-changing breakthroughs in renewable technologies may be desirable and necessary to fully overcome these challenges. But Jaccard also notes they can be overcome in the meantime by strong policies based on a combination of carbon pricing and regulating carbon emissions. These policies will expedite the adoption of commercially available renewable technologies and will stimulate more research and development (R&D) to take advantage of increased market opportunities. While Naam's Phase 3 may be imminent, Commonwealth countries would be well advised to aggressively adopt policies that support and incentivise the energy transition in their countries.

A recent report from Goldman Sachs entitled *Carbonomics* provides insights regarding the progress and costs of energy transition technologies (Goldman Sachs Group, 2020). Goldman Sachs estimates that investment in renewable power in 2021 will exceed upstream oil and gas investment for the first time ever. It notes the critical importance of carbon pricing for energy conservation and energy transition projects to be viable, the need for more technological innovations and greater investment in carbon capture and storage technologies to achieve net zero carbon emissions. It also notes that green infrastructure is more capital and jobs intensive than traditional energy, which is good news for governments that wish to promote activities that will stimulate their economies. In additional to carbon pricing and technological innovations, the investments necessary for energy transition will require a stable, attractive regulatory regime and a low cost of capital, which are issues being addressed by the other CSET pillars, the *Enabling Frameworks* and *Inclusive Transitions*.

IRENA has recently proposed an energy transition strategy as a key component of post-COVID stimulus and recovery policies.[17] This would be an effective economic stimulant and the resulting shift in the global energy mix would help achieve SDG7 and the Paris Agreement targets.

4.1 Impact of COVID-19 on the energy transition

The COVID-19 pandemic has impacted global economic activities at unprecedented magnitude and swiftness, including drastic reductions in energy demand and energy investment. As the pandemic subsides, governments will be seeking ways to stimulate economic recovery. If economic recovery strategies include measures to accelerate the energy transition, the recovery could be an opportune turning point in achieving the energy transitions required by SDG7 and the Paris Agreement.

Wood Mackenzie offers several suggestions for measures that would stimulate the economy and accelerate the energy transition (Wood Mackenzie, 2020b):

- that renewable energy sources, electric vehicles, energy storage and grid enhancements be supported by grants and tax incentives;
- the strengthening of carbon pricing, especially in leading economies;
- trade and travel policies that reflect the costs of carbon emissions; and
- regulatory frameworks and incentive structures to accelerate energy efficiency.

Some of Wood Mackenzie's suggested measures would be facilitated by adopting William Nordhaus' 'climate club' proposal referenced above.

IEA has also recently published a report on *Sustainable Recovery,* with suggested measures for how the recovery could contribute to a sustainable energy transition (IEA, 2020f). The goals of the IEA's sustainable recovery plan are to boost economic growth, create jobs and build more resilient and cleaner energy systems. Suggested policies and targeted investments, in addition to creating jobs and stimulating economic activity, would:

- accelerate deployment of renewable electricity sources like wind and solar, upgrade hydropower facilities, and enhance and digitise electricity grids;
- increase the growth of cleaner transportation, such as more efficient vehicles, electric vehicles and high-speed rail;
- improve the energy efficiency of buildings and appliances;
- enhance the efficiency of equipment used in industries, such as manufacturing, food and textiles;
- make the production and use of fuels more sustainable; and
- boost innovation in important energy transition technologies, such as batteries, CCS and small modular nuclear reactors.

IEA believes that adopting policies to achieve these targets would result in emissions having peaked in 2019 and put the world on a path towards meeting global emission reduction targets.

5. Recommendations

Urgent actions are needed by Commonwealth countries to alleviate energy poverty, forestall climate change risks and meet the imminent targets of SDG7. The following recommendations are for immediate actions that Commonwealth countries can take to address some of the biggest and most urgent needs in tackling energy access and accelerating sustainable energy transition.

5.1 Scale up deployment of decentralised energy generation from renewable energy technologies

> *A billion people still live without electricity. Hundreds of millions more live with unreliable or expensive power, which poses a key barrier to economic development in emerging economies.*
>
> The World Bank

Lack of access to electricity has impacts on a wide range of development indicators, including health, education, food security, gender equality, economic livelihoods and poverty reduction. Recent technological advances and cost reductions for solar and wind energy offer the opportunity to make energy affordable and accessible through decentralised electricity (also called distributed generation). Encouraging adoption of these technologies appears to provide the best path to making energy accessible for residents of many Commonwealth countries. Encouraging greater use of decentralised solar and wind technologies requires creating enabling environments, with supportive policies and institutions, strategic plans, regulations and incentives.

5.2 Get the right energy pricing in place

> *Climate change is a result of the greatest market failure the world has seen.*
>
> Nicholas Stern

Technology will determine our energy future, and prices associated with using energy technologies will be major determinants of which technologies are developed and the pace of that development. Commonwealth countries can introduce policies to get the pricing right for energy commodities, by implementing a carbon pricing policy to account for the negative externalities of carbon emissions and ending any price distortions arising from subsidies to hydrocarbon fuels. We have seen that renewable energy costs have fallen dramatically in recent decades. A carbon price and elimination of fossil fuel pries subsidies will serve to reinforce this trend and facilitate the adoption of these technologies.

These policies are critically important to supporting and facilitating the sustainable energy transition. These policies are market based, actually correcting a serious market failure, and are consistently shown to be the most cost-effective approach for successfully achieving sustainable energy transition. The financial resources available from carbon price revenues and the savings from elimination of subsidies that thwart the transition can be used to support the development of new technologies and hasten the necessary transitions to these technologies.

5.3 Adapt to disruption in the energy sector

> *The stone age did not end for lack of stone, and the oil age will end long before the world runs out of oil.*
>
> Sheik Ahmed Zaki Yamani

The sustainable energy transition will reduce growth of fossil fuel consumption, and inevitably result in declines in the use of these fuels. Structural changes in the economy always create disruptions in some sectors and opportunities in others. The higher carbon fuels – coal and oil – will experience the earliest and largest effects. Many countries and investors will be left with stranded resources of coal, oil and gas, and many workers who have depended on these resources and industries will be left without livelihoods. This will have serious negative effects on the fossil fuel industry, and on the countries that have been the fortuitous recipients of large direct revenue flows from these resources in recent decades. It will also mean some countries with newly discovered oil and gas resources will not realise the full revenue windfalls they may have been anticipating.

The countries, companies and workers that will suffer most will be those that resist change and fail to adapt with the energy transition. There will also be indirect effects on many consumers of fossil fuels, who will need to make transitions, perhaps especially those in the power sector and heavy industries. Many will need assistance to adapt and restructure their economies, refocus their companies and find new livelihoods. Use of energy will not decline, so the transition to sustainable energy resources will also create economic opportunities to be capitalised on. There will be an important role for organisations like the Commonwealth Secretariat to assist in assuring a smooth transition.

5.4 Implement policies and incentives that reward immediate action

> *We are the first generation to feel the impacts of climate change, and the last generation to be able to do something about it.*
>
> Barack Obama

The clock is ticking on the deadlines for meeting the SDG7 and Paris Agreement targets. Urgent actions are required by governments to encourage countries to adopt appropriate energy technologies that meet the agreed-upon goals and avert the threat of climate change to present and future generations. To ensure the required actions on energy access and energy transition are effective, policies must be global, not simply national or local.

An immediate action that Commonwealth governments can take to foster this is to create a ‘climate club’ and/or ‘coalition of champion countries’ that will provide an incentive-based structure for countries to pursue their climate change and Sustainable Development Goals with greater urgency and discipline. The Commonwealth Blue Charter (CBC) action groups could serve as a catalyst for forming coalitions by member countries around a common initiative, such as a climate club. Initiatives such as these could provide the right incentives for adoption of technologies to achieve SDG7 and a sustainable energy transition. The Commonwealth provides a uniquely valuable forum for establishing a climate club and/or coalition of champion countries.

Notes

1 Including biomass, wind, sunshine, wave, geothermal, hydro and ocean thermal energy.
2 The CSP capacity, predominantly in South Africa and India, represents about 1 per cent of total solar capacity.
3 Primary energy is raw energy that has not undergone conversion processes. Total primary energy supply is the total raw energy a country has at its disposal, and includes energy production plus energy imports, minus energy exports. Total final energy supply is the energy available to end-use consumers, and does not include energy losses in converting raw fuels to usable fuels (for example, electricity, gasoline) and transporting these fuels.
4 IRENA Renewable Capacity Statistics: https://www.irena.org/Statistics/Download-Data.
5 'Gray hydrogen' is produced from fossil fuels like oil and coal, which emit CO_2 into the air as they combust. 'Blue hydrogen' is produced in the same way, but carbon capture technologies are used to prevent CO_2 being released into the atmosphere. 'Green hydrogen' is produced using electrolysis powered by renewable energy to produce a clean and sustainable fuel. See: https://www.forbes.com/sites/mitsubishiheavyindustries/2020/03/03/the-three-colors-of-hydrogen-explained-video/#5b76709d5149.
6 Marine Energy: EMEC: European Marine Energy Centre.
7 Force website: https://fundyforce.ca/.
8 The Stated Policies Scenario of the IEA's, 2020 *World Energy Outlook* sees global natural gas demand in 2040 rising by 30 per cent, concentrated in South and East Asia. Its Sustainable Development Scenario sees global natural gas demand peaking in the mid-2020s, before falling at roughly 0.8 per cent annually, declining back to 2019 demand levels by 2030. Advanced economies drive the decline between 2025 and 2030, while regions with rapidly growing electricity demand and large coal fleets continue to rely on gas for fuel, switching before their demand peaks in the late 2030s.
9. Electricity storage and renewables: Costs and markets to 2030 (irena.org).
10 Ironically, in looking at the results reported by Climate Action Tracker on progress of individual countries to achieve the Paris Agreement targets (https://climateactiontracker.org/countries/#), only 2 of 32 countries assessed are Paris Agreement compatible, and both are developing countries – Morocco and The Gambia. The Gambia is a Commonwealth member.
11 The author of this paper is from Alberta, Canada, which has among the highest saturations of natural gas distribution in the world. That extensive distribution is made viable by the need for fuel for space heating in Alberta's temperate climate, while cooking represents a small portion of residential fuel requirement. Despite almost universal access to natural gas, 90 per cent of Alberta homes use electricity for cooking.
12 An excellent survey of clean cooking technologies is provided in USAID/Winrock International (2017).
13 Note the columns are in descending order, and not in quite the same sequence as in Figure 11.
14 See the University of Texas at Austin (2018). Note that powerlines and pipelines are very capital-intensive investments, and their costs are not likely to differ greatly in different countries, regardless of different economic circumstances and level of development of those countries.
15 In 2019, oil, gas and coal provided 84.3 per cent of global primary energy, according to the BP Statistical Review of World Energy 2020.
16 This author is from Alberta, Canada's major oil and gas production area, and an economy largely based on this industry. Many Albertans remain skeptical, fearful and deeply resistant to energy transition and any disruption of the traditional economy.
17 The Post-COVID Recovery: An agenda for resilence, developmnet and equality (irena.org).

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