Klerk, Kyle de; Balchin, Neil; Zhuawu, Collin

Book

Exploring the renewable energy landscape in least developed countries : generation, trade and endowments

Reference: Klerk, Kyle de/Balchin, Neil et. al. (2024). Exploring the renewable energy landscape in least developed countries : generation, trade and endowments. London : Commonwealth Secretariat.
https://www.thecommonwealth-ilibrary.org/index.php/comsec/catalog/download/1131/1228/9813.
doi:10.14217/comsec.1131.

This Version is available at:
http://hdl.handle.net/11159/703208

ISSN 2413-3175
2024/02

INTERNATIONAL TRADE WORKING PAPER

Exploring the Renewable Energy Landscape in Least Developed Countries: Generation, Trade and Endowments

Kyle de Klerk, Neil Balchin and Collin Zhuawu

The Commonwealth

International Trade Working Paper 2024/02

ISSN 2413-3175

By Kyle de Klerk, Neil Balchin and Collin Zhuawu

Kyle de Klerk is an Assistant Research Officer, International Trade Policy in the Trade, Oceans and Natural Resources Directorate at the Commonwealth Secretariat.

Neil Balchin is an Economic Adviser (Trade Policy Analysis) in the Trade, Oceans and Natural Resources Directorate at the Commonwealth Secretariat.

Collin Zhuawu is an Economic Adviser (Multilateral Trade) in the Trade, Oceans and Natural Resources Directorate at the Commonwealth Secretariat.

Please cite this paper as: de Klerk, K., N. Balchin and C. Zhuawu (2024), 'Exploring the Renewable Energy Landscape in Least Developed Countries: Generation, Trade and Endowments', *International Trade Working Paper* 2024/02, Commonwealth Secretariat, London.

Abstract

This paper, the first of a two-part series, examines the renewable energy landscape in least developed countries (LDCs) and explores the scope to expand renewable energy generation and trade in these countries by maximising the potential of their renewable energy endowments. It begins with a detailed overview of existing renewable energy generation capacity across the group of LDCs, paying particular attention to Commonwealth LDC solar, wind, hydro and bioenergy generation. Thereafter, Section 3 examines the state of energy trade involving Commonwealth LDCs and explores opportunities for them to increase their exports of renewable energy. Section 4 assesses the renewable energy generation *potential* in LDCs through an analysis of their raw solar and wind resource endowments. The paper concludes by highlighting practical considerations for LDCs to accelerate their renewable energy transitions and maximise the trade, growth and economic development potential of their renewable energy resource endowments.

Contents

Acknowledgments

The authors gratefully acknowledge comments and suggestions on an earlier draft of this paper made by Brendan Vickers, Salamat Ali and Kartikeya Garg (International Trade Policy Section, Commonwealth Secretariat).

1. Introduction

The heavy reliance on fossil fuels to produce energy in many parts of the world is a major driver of climate change and a significant impediment to sustainable development. A successful clean energy transition requires a shift away from fossil fuel dependency in favour of greater use of renewable energy sources. Recent estimates suggest as much of 60 per cent of the power generated worldwide will need to come from renewable sources by 2030 to achieve the goal of net-zero emissions from the global energy sector by 2050 (United Nations, 2023).

Least developed countries (LDCs) have demonstrated strong commitment to the renewable energy transition. The Least Developed Countries Renewable Energy and Energy Efficiency Initiative for Sustainable Development,[1] endorsed by all LDCs, seeks to ensure citizens of all LDCs have access to sufficient, affordable and modern renewable energy by 2030, with the ultimate goal of generating 100 per cent of electricity in all LDCs from renewable energy sources by 2050. Many LDCs are well positioned – with abundant renewable energy resources – to achieve these objectives, even though their renewable energy generation potential is yet to be fully exploited.

A successful renewable energy transition could bring considerable developmental benefits for LDCs. It has the potential to support the development of new industrial sectors and green value chains, in the process creating new employment opportunities. It could also significantly enhance energy access in remote areas and strengthen their overall energy security. This would make a major contribution to achieving the Sustainable Development Goals (SDGs), especially SDG 7 targeting access to affordable, reliable, sustainable and modern energy for all. Access to an abundant clean energy supply may also open up new trade and investment opportunities for LDCs, particularly given the increasing prevalence of climate-focused trade measures (such as the European Union's [EU's] Carbon Border Adjustment Mechanism) and greater consideration of environmental factors in investment decisions.

This paper, the first of a two-part series,[2] examines the renewable energy landscape in LDCs[3] and explores the scope to expand renewable energy generation and trade in these countries by maximising the potential of their renewable energy endowments. It begins with a detailed overview of existing renewable energy generation capacity across the group of LDCs, paying particular attention to Commonwealth LDC solar, wind, hydro and bioenergy generation. Thereafter, Section 3 examines the state of energy trade involving Commonwealth LDCs and explores opportunities for them to increase their exports of renewable energy. Section 4 assesses the renewable energy generation *potential* in LDCs through an analysis of their raw solar and wind resource endowments. The paper concludes by highlighting practical considerations for LDCs to accelerate their renewable energy transitions and maximise the trade, growth and economic development potential of their renewable energy resource endowments.

2. Renewable energy generation in LDCs

Despite the challenges they face in terms of technological capacity to support a clean energy transition, LDCs have a complex and somewhat surprising renewable energy landscape. Their relative lack of legacy fossil fuel-based energy infrastructure has given many of them a head start in the energy transition, with 51.6 per cent of their total energy generated from renewables in 2020 compared to 27.7 per cent globally (see Table 2.1). This section unpacks the LDC renewable energy landscape, with particular focus on solar, wind, hydro and bioenergy generation.[4] A full table with a breakdown by individual LDC can be found in Annex 1.

While a high percentage of total LDC energy generation is sourced from renewables, it varies widely by country. Figure 2.1 shows the top five

Table 2.1 A snapshot of LDC renewable energy generation by select technologies (2020)

	Total renewable generation (TWh)	Renewables as share of total generation (%)	Renewable generation by select technologies (GWh)			
			Solar	Wind	Hydro	Bioenergy
Global	7,468.1	27.7	843,854.9	1,588,586.0	4,476,230.5	957.5
All LDCs	154.3	51.6	2,918.0	765.0	149,253.7	1,473.5
Commonwealth LDCs*	29.6	23.3	977.3	5.2	27,981.3	626.6
Other LDCs**	124.7	72.4	1,940.7	759.8	121,272.3	846.9

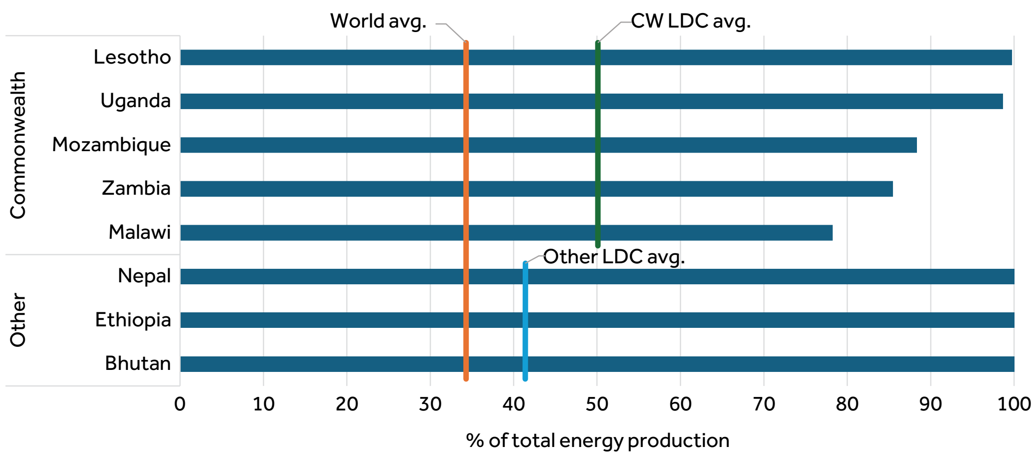
Source: Commonwealth Secretariat, using data from IRENAStat and Emberclimate.org.
*The 14 LDCs that are members of the Commonwealth.
**The 32 LDCs that are not Commonwealth members.

Commonwealth LDCs by share of renewables, as well as Nepal, Ethiopia and Bhutan (which graduated from the LDC category in December 2023) as the three LDCs that already generate 100 per cent of their energy from renewable sources. Lesotho (99.8 per cent) and Uganda (98.7 per cent) are the two Commonwealth LDCs that generate more than 90 per cent of their energy from renewable sources, followed by Mozambique (88.4 per cent), Zambia (85.5 per cent) and Malawi (78.2 per cent).[5] While Table 2.1 shows that the collective share of renewables in Commonwealth LDCs (23.3 per cent) is significantly lower than the non-Commonwealth equivalent (72.4 per cent), Figure 2.1 reveals that when averaged across countries, Commonwealth LDCs generally have a higher share of renewables (50.1 per cent) than their non-Commonwealth counterparts (41.4 per cent). This discrepancy is due to the outsized impact of Bangladesh, an outlier Commonwealth LDC both in terms of its share of total Commonwealth LDC energy generation and its fossil fuel dependence.

Figure 2.2 provides a breakdown of the energy mix for each country grouping. It shows that LDCs rely on fossil fuels for 47.6 per cent of total energy generation, compared to 68.3 per cent globally. While, as a group, Commonwealth LDCs lag both the LDC and global share, if Bangladesh is excluded, only 28.4 per cent of the other Commonwealth LDCs' energy generation depends on fossil fuels (a figure lower than that for non-Commonwealth LDCs).[6] See Annex 2 for a similar energy composition breakdown by individual LDC.

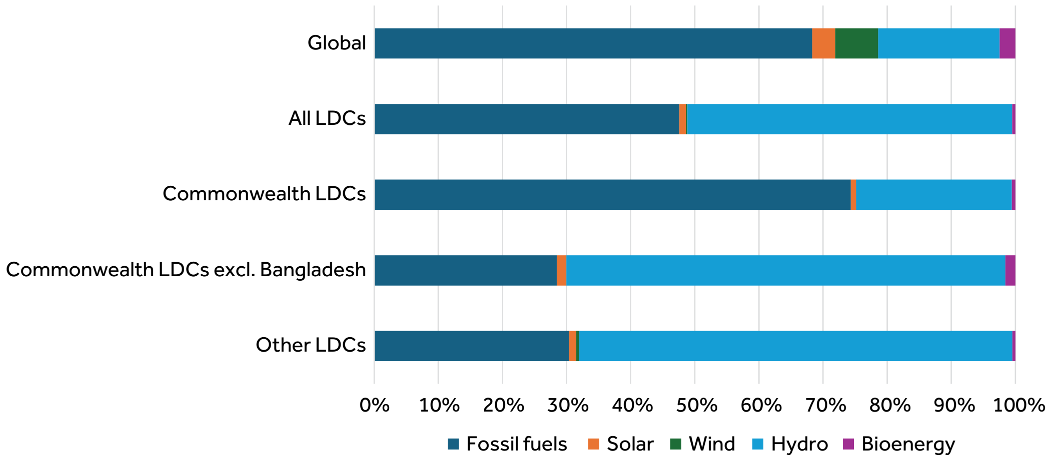
While the contemporary data are encouraging, consideration of the historical trend provides greater nuance. Figure 2.3A shows that total LDC renewable energy generation has more than doubled from 74.14 terawatt hours (TWh) in 2010 to 154.41 TWh in 2020, a steeper growth rate than the global equivalent. However, growth in renewable energy

Figure 2.1 LDCs with largest share of renewables in total energy generation (2020)



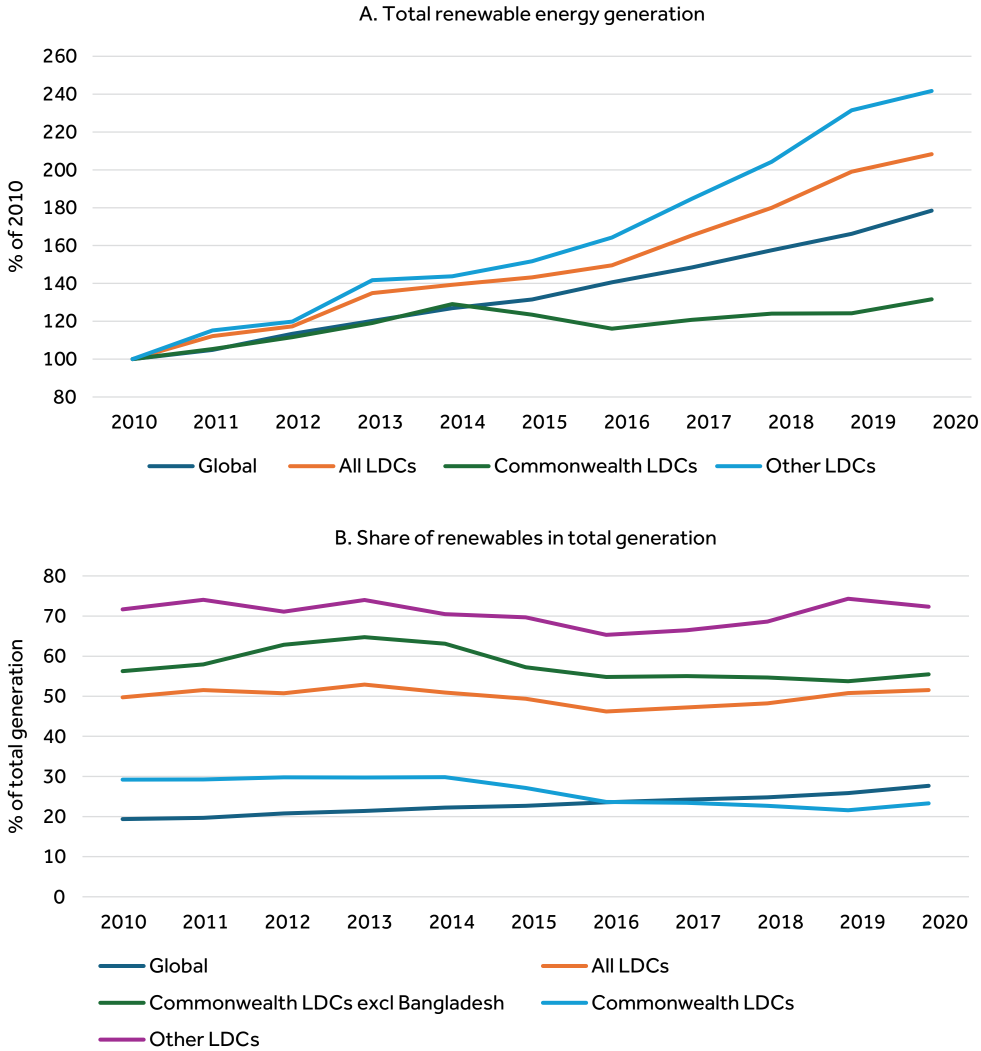
Source: Commonwealth Secretariat, using data from IRENAStat.

Figure 2.2 The composition of energy generation by source (2020)



Source: Commonwealth Secretariat, using data from IRENAStat.

Figure 2.3 Growth of renewable energy generation (2010 = 100 baseline, %)



Source: Commonwealth Secretariat, using data from IRENAStat and Emberclimate.org.

generation in Commonwealth LDCs lags both total LDC and global growth rates, increasing from 22.49 TWh in 2010 to 29.59 TWh in 2020. This discrepancy, and the high collective LDC growth rate, is due to the outstanding growth of several non-Commonwealth LDCs including Angola, Cambodia, Ethiopia and Lao PDR (People's Democratic Republic), all of which have more than tripled their renewable energy generation over this period and now account for more than a third of all renewable energy produced by LDCs.

However, Figure 2.3B shows that the share of renewables in total energy generation in LDCs has remained stable since 2010 at around 50 per cent, while the same share for Commonwealth LDCs has declined from 29.3 per cent in 2010 to 23.3 per cent in 2020. This decline is due to the expansion of fossil fuel energy generation in Bangladesh, as, when excluded from the Commonwealth LDC category, the share of renewables remains consistent at around 55 per cent. While the share of renewables has stagnated in LDCs, globally it has increased from 19.4 per cent in 2010 to 27.7 per cent in 2020. This demonstrates that LDCs are proportionally investing more heavily in fossil fuels than renewables when compared to the global trend and highlights the need for greater investment (see Box 2.1) into and technology transfer of renewable energy technologies for LDCs. This is particularly pertinent when considering that only 56.25 percent of the collective population of LDCs have access to electricity,[7] and thus that their demand for energy will continue to grow significantly as they develop and rural electrification expands. The following sections provide a deeper dive into LDC energy generation from the perspective of individual renewable energy technologies.

2.1 Hydro energy

As mentioned above, hydro is the dominant renewable energy technology, accounting for around 60 per cent of global renewable energy generation. In LDCs, hydro has a near monopoly, accounting for over 96 per cent of total renewable energy generation (see Table 2.2). Additionally, this high share of hydro is consistent when disaggregated by country: among the 32 LDCs that generate some energy from hydro, 25 generate over 90 per cent of their overall renewable energy output from this source (see Annex 1), while hydro accounts for over 50 per cent of *total* energy generation in 17 LDCs (see Annex 2).

Figure 2.6 shows the five largest Commonwealth LDC hydro energy generators, both in terms of gross hydro energy (Figure 2.6B) produced and the share of hydro in total (fossil fuel plus renewable) energy produced (Figure 2.6A). Note that four of the five LDCs in Figure 2.6A are also found in Figure 2.1, again demonstrating the dominance of hydro in LDC renewable energy generation. The LDCs in Figure 2.6B are the largest Commonwealth LDC producers of hydro energy, collectively accounting for over 92 per cent of all hydro energy generated by Commonwealth LDCs. Mozambique

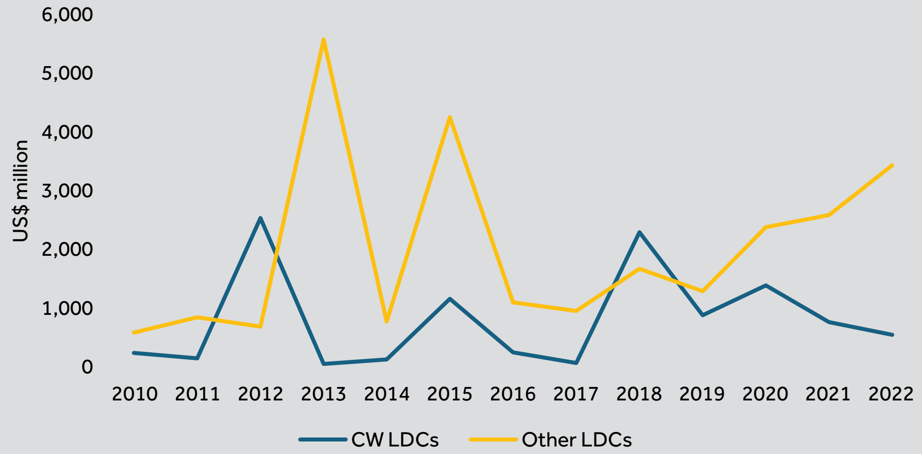
Box 2.1 Greenfield investment in renewable energy in Commonwealth LDCs

Greenfield foreign direct investment (FDI) can play a significant role in expanding renewable energy capacity, but there remain major investment shortfalls. Some estimates suggest as much as US$4 trillion in greenfield renewable energy investments will be required worldwide each year to achieve the goal of net-zero emissions by 2050 (Klein and Tinkler, 2023). Encouragingly, these investments in Commonwealth and non-Commonwealth LDCs have generally increased since 2010, albeit with considerable volatility (Figure 2.4). Commonwealth LDCs collectively attracted capital investments for renewable energy projects worth nearly US$10.4 billion between 2010 and 2022. These accounted for 7.6 per cent of their overall greenfield FDI inflows, compared with 10.7 per cent for all LDCs.

Despite this, Commonwealth LDCs – and LDCs more generally – only account for very small shares of global greenfield FDI in renewable energy, which amounted to US$357 billion between 2010 and 2022. Commonwealth LDCs attracted just 2.9 per cent of these global inflows, while 7.3 per cent was directed to non-Commonwealth LDCs. This is consistent with wider global disparities. In 2022, 85 per cent of worldwide investments in renewable energy benefited less than half of the world's population, with comparatively little flowing to developing countries (IRENA, 2023).

Moreover, greenfield renewable energy investments remain highly concentrated in Commonwealth LDCs. Four countries – Mozambique, Uganda, Zambia and Bangladesh – have attracted the bulk of the capital invested in this area since 2010. New greenfield projects have mostly focused on solar electric power, along with major investments in biomass power in Mozambique and Uganda (Figure 2.5). These two categories accounted for

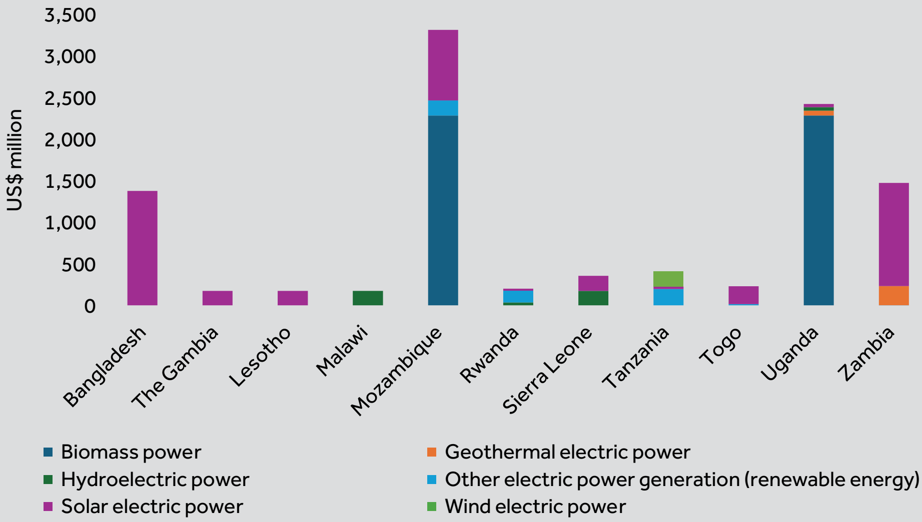
Figure 2.4 Greenfield FDI inflows to renewable energy sectors in LDCs (2010–2022)



Source: Commonwealth Secretariat (calculated using fDi Markets data from the Financial Times Ltd, 2023).

more than 85 per cent of the capital invested in greenfield renewable energy projects across all Commonwealth LDCs between 2010 and 2022. Malawi, Rwanda, Sierra Leone and Uganda welcomed greenfield investments in hydroelectric power during this period; however, there was very limited capital invested in geothermal (only in Uganda and Zambia) and wind (only in Tanzania) electric power across the Commonwealth's LDC members.

Figure 2.5 Greenfield FDI in Commonwealth LDCs by type of renewable energy, (2010–2022, cumulative totals)



Source: Commonwealth Secretariat (calculated using fDi Markets data from the Financial Times Ltd, 2023).

and Tanzania are the only two LDCs not also found in Figure 2.6B on account of their relatively high reliance on fossil fuels. While Zambia is by far the largest producer of hydro energy in Commonwealth LDCs (12.8 TWh), Lesotho has the highest share of hydro in its total energy mix, accounting for 99.8 per cent of energy generation (see the annexes for detailed data).

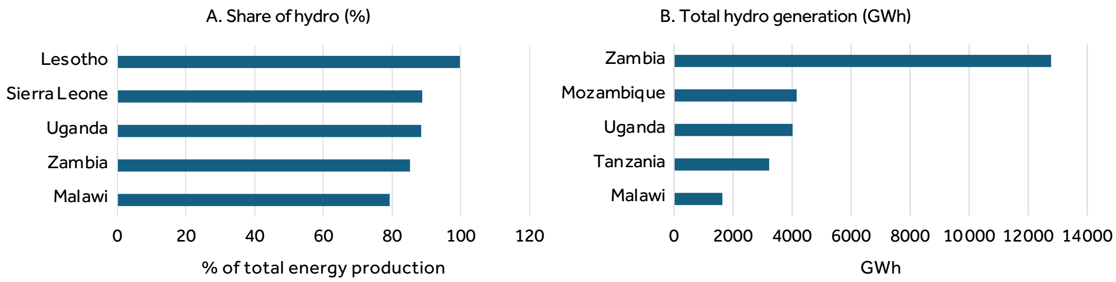
Figure 2.7 charts the growth in hydro energy generation from 2010. In a similar fashion to the trend analysed in Figure 2.3, LDC hydro energy generation has grown much faster than the global rate, from 73.15 TWh in 2010 to 149.25 TWh in 2020, an increase of 104 per cent. This growth has primarily been driven by Lao PDR, Ethiopia, Angola and Myanmar, which collectively increased their hydro energy generation from 23.27 TWh in 2010 to over 70 TWh in 2020, an increase of over 200 per cent. Growth in hydro energy generation in Commonwealth LDCs has been slower, largely keeping pace with the global rate of 27 per cent,

Table 2.2 Share of hydropower in total renewable energy generation (2020, %)

	% of renewable energy generation
Global	59.9
All LDCs	96.8
Commonwealth LDCs	94.6
Non-Commonwealth LDCs	97.3

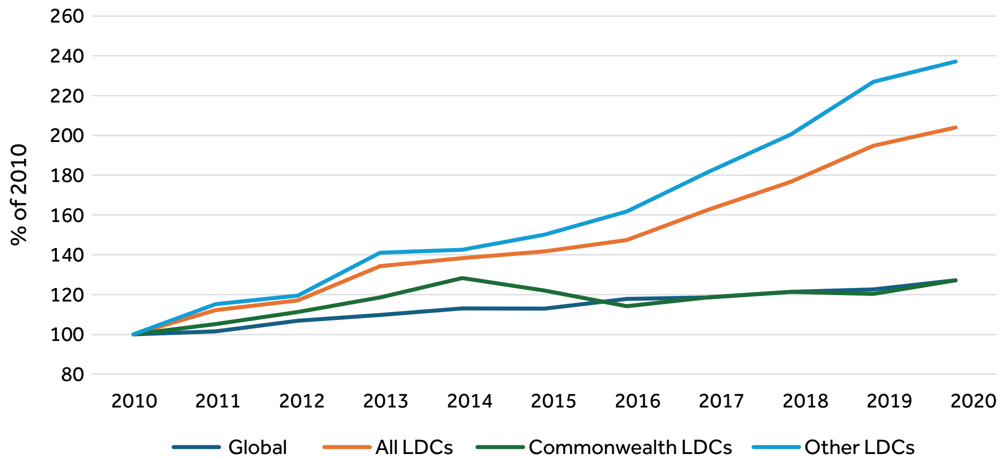
Source: Commonwealth Secretariat, using data from IRENAStat.

Figure 2.6 Commonwealth LDCs generating the most energy from hydro (2020)



Source: Commonwealth Secretariat, using data from IRENAStat and Emberclimate.org.

Figure 2.7 Growth in hydro energy generation (2010 baseline)



Source: Commonwealth Secretariat, using data from IRENAStat.

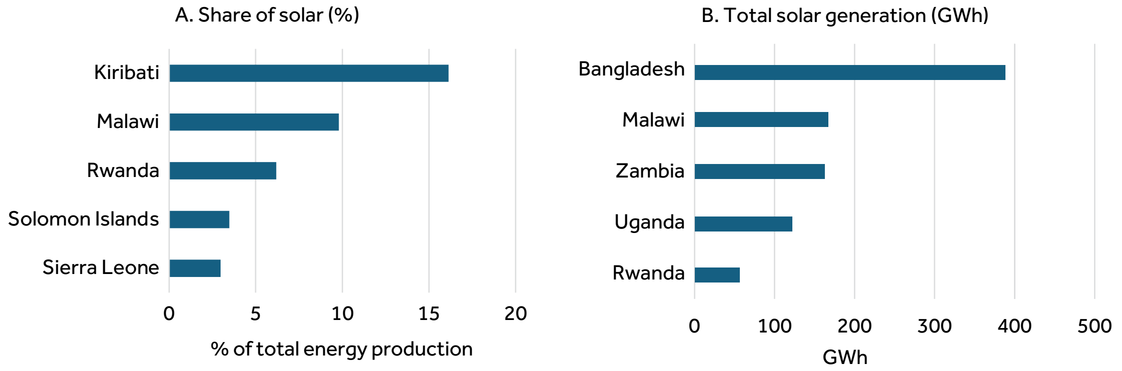
expanding from 22 TWh in 2010 to 28 TWh in 2020. This has mainly been driven by Zambia and Uganda, which increased their collective hydro energy generation by 4.7 TWh and account for 79 per cent of total Commonwealth LDC hydro energy generation growth.

2.2 Solar energy

Solar is the second largest source of renewable energy in LDCs, accounting for 2.92 TWh or 1.9 per cent of their total renewable energy generation. This a significantly smaller share than the global renewable energy mix, where solar accounts for 12.2 per cent. Solar accounts for a marginally higher share of 3.3 per cent in Commonwealth LDCs, reflecting their lower dependence on hydro energy than their non-Commonwealth counterparts. Interestingly, while only 32 LDCs generate energy from hydro, all LDCs other than the Comoros – including the 14 Commonwealth LDCs – generate solar energy, making it the most widely used renewable energy technology among LDCs.

Figure 2.8 shows the largest Commonwealth LDC solar energy producers. Figure 2.8A reflects the modest contribution of solar relative to hydro energy, with solar only accounting for 16.1 per cent of Kiribati's total energy generation, the

Figure 2.8 Commonwealth LDCs generating the most energy from solar (2020)



Source: Commonwealth Secretariat, using data from IRENAStat and Emberclimate.org.

highest share of any Commonwealth and non-Commonwealth LDC. The LDCs in Figure 2.8B collectively account for 91.9 per cent of total Commonwealth LDC solar energy generation, with Bangladesh leading Commonwealth LDCs having produced 389 gigawatt hours (GWh) in 2020. However, as Bangladesh relies on fossil fuels for 98.6 per cent of its energy generation, solar only accounts for 0.5 per cent of its total energy generation (and it is thus not among the countries with the largest shares in Figure 2.8A).

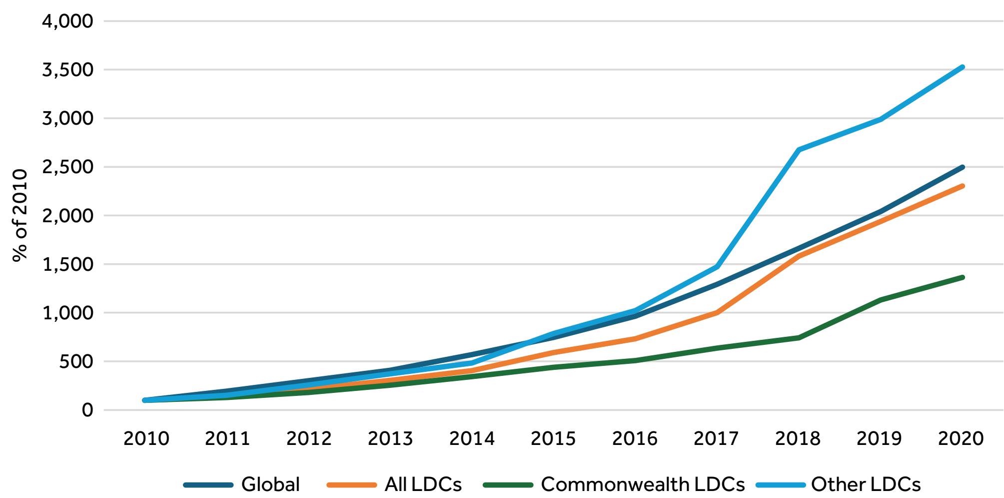
The growth in LDC solar energy generation since 2010 is particularly encouraging. Figure 2.9 shows that solar energy generation in LDCs has increased from 126.7 GWh in 2010 to 2,918 GWh in 2020, an astonishing 2,203 per cent increase. This overall growth is largely due to the contribution of the largest LDC solar energy producers (Yemen, Bangladesh, Cambodia, Senegal and Malawi), which collectively account for 56.7 per cent of total LDC solar generation. These five countries have increased their generation from 56.5 GWh in 2010 to 1,653.3 GWh in 2020, an increase of over 2,827 per cent.

Commonwealth LDC solar energy generation growth is comparatively modest yet still impressive, having increased from 71.7 GWh in 2010 to 977.3 GWh in 2020, a rate of 1,263 per cent. This growth has been driven by the LDCs listed in Figure 2.8B, which collectively increased generation by 830 GWh over this period. Zambia's recent growth is particularly impressive, having gone from generating only 1.3 GWh of solar energy in 2018 to over 163.1 GWh in 2020.

2.3 Bioenergy

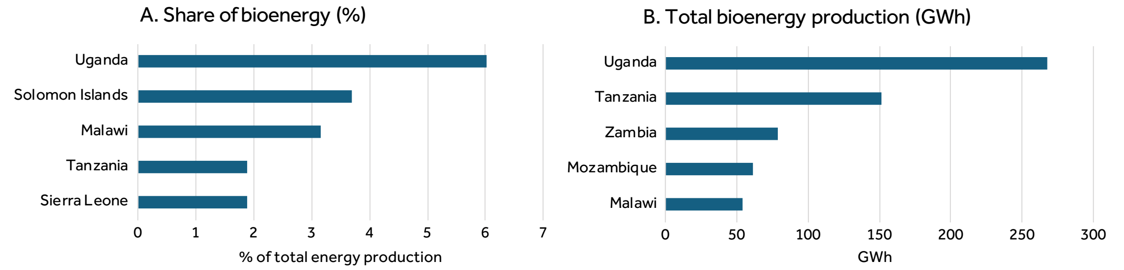
Bioenergy, generated from the combustion of organic materials, is the third largest source of renewable energy in LDCs, accounting for 1.47

Figure 2.9 Growth in solar energy generation (2010 baseline)



Source: Commonwealth Secretariat, using data from IRENAStat.

Figure 2.10 Commonwealth LDCs generating the most energy from bioenergy (2020)



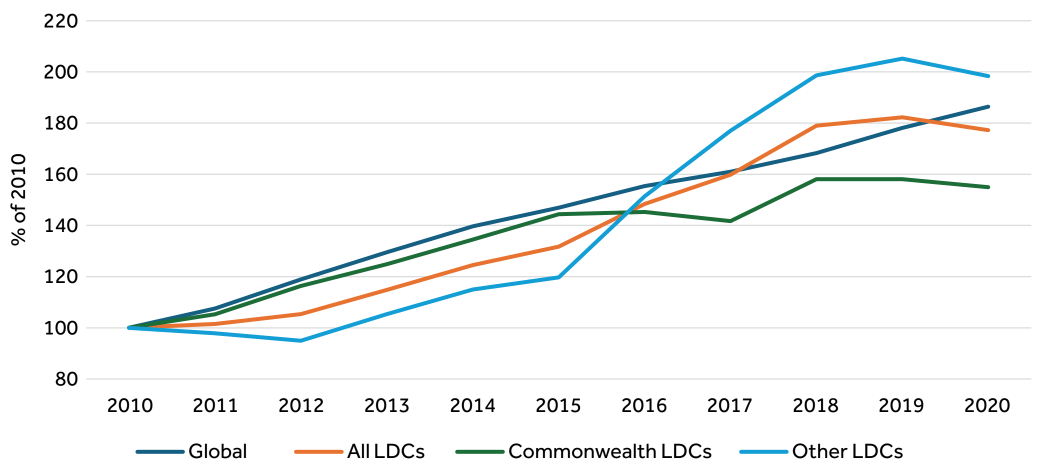
Source: Commonwealth Secretariat, using data from IRENAStat and Emberclimate.org.

TWh or 0.96 per cent of total renewable energy generation. While this is seemingly small, it far exceeds the global equivalent share of bioenergy, which stands at only 0.01 per cent of total renewable energy generation. This may reflect its lower capital and infrastructural requirements in comparison to other renewable energy sources, making it more feasible for LDCs. Its relatively low share in the global energy mix may be a result of its high land use-to-energy generation ratio, given the amount of land needed to farm biofuel crops. Biofuel cultivation may also have potentially negative impacts, through displacing food production, increasing food prices, deforestation and biodiversity loss (Pogson et al., 2013). Commonwealth LDCs exhibit a greater share of bioenergy (2.1 per cent) in their renewable energy mix in comparison to their non-Commonwealth counterparts (0.68 per cent), as well as a higher rate of utilisation of the technology – with 9 out of 14 Commonwealth LDCs generating bioenergy compared to 15 out of the 32 non-Commonwealth LDCs.

This asymmetry is reflected in Figure 2.10A, as Uganda and Solomon Islands have the highest and second highest shares of bioenergy for both Commonwealth and non-Commonwealth LDCs, while Malawi has the fourth highest share of all LDCs. Uganda in Figure 2.10B is also the largest bioenergy generator of all Commonwealth and non-Commonwealth LDCs, producing 267.8 GWh. The LDCs in Figure 2.10B collectively account for 97.8 per cent of bioenergy generation in Commonwealth LDCs, while Zambia and Mozambique are excluded from Figure 2.10A on account of the former's proportionally higher share of hydro energy and the latter's dependence on fossil fuels.

Figure 2.11 shows that the growth in bioenergy generation in LDCs has generally followed the global trend, surpassing it briefly from 2017 to 2019. LDC bioenergy generation has increased from 831.3 GWh in 2010 to 1473.5 GWh in 2020, an expansion of 77.3 per cent. This lags the growth of hydro and solar energy generation over this period. Growth in

Figure 2.11 Growth in bioenergy generation (2010 baseline)



Source: Commonwealth Secretariat, using data from IRENAStat.

bioenergy generation by LDCs, and particularly its intersection with the global growth rate in 2017, has been driven primarily by Angola. Angola only began generating bioenergy in 2014, but has since become the third largest LDC producer with 200 GWh in 2020. As with the previous hydro and solar energy growth figures, bioenergy growth in Commonwealth LDCs falls below both global and non-Commonwealth LDC rates, having increased from 404.3 GWh in 2010 to 626.6 GWh in 2020.

2.4 Wind energy

Wind is the least common source of renewable energy in LDCs, both in terms of total generation measured in GWh and the number of LDCs with generation capacity. In 2020, LDCs collectively generated 0.77 TWh (765 GWh) of wind energy. Only 17 of the world's 46 LDCs have installed wind generation capacity. This accounts for only 0.05 per cent of total renewable energy generated by LDCs, below the global contribution of 2.1 per cent. Just two Commonwealth LDCs (Bangladesh and The Gambia) generate a small amount of wind energy, totalling 5.18 GWh – or less than 0.04 per cent of their respective energy mixes. Despite these small shares, wind energy does play an important part in the energy mix of several non-Commonwealth LDCs, as shown in Figure 2.12.

What is immediately apparent from Figure 2.12B is the quantity of wind energy generated by Ethiopia, totalling GWh 609.1 or 79.6 per cent of all wind energy generated by LDCs (See Box 2.2). When combined with Mauritania, the second largest LDC generator (131.2 GWh), these two countries account for over 96.8 per cent of total LDC wind energy generation. The order of these two countries is reversed in Figure 2.12A, with Mauritania producing 7.4 per cent of its energy from wind, followed by 4.3 per cent in Ethiopia. This inversion is due to the lack of hydro energy in Mauritania's energy mix, while Ethiopia produces 14.4 TWh of hydro energy, 20 times its wind energy generation.

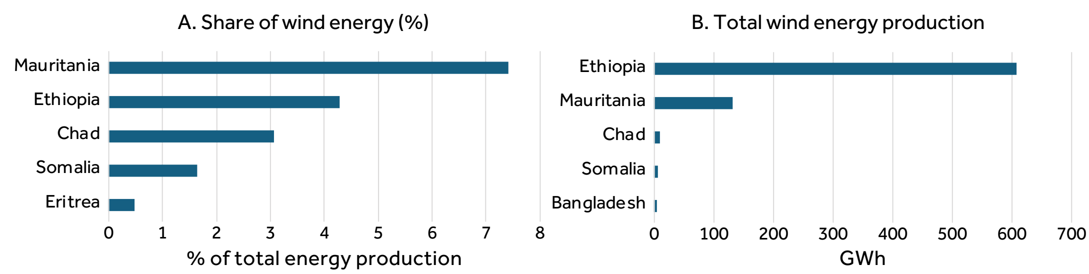
The outsized share of these two countries in LDC wind energy generation is even more apparent when referring to the wind energy generation growth rates found in Figure 2.13. Considering that neither country generated wind energy in 2010, LDC wind energy generation has grown from 8.1 GWh to 765 GWh in 2020, an increase of 9,320.8 per cent. For reference, global wind energy generation has increased by 363.4 per cent, while Commonwealth LDC (Bangladesh and The Gambia) generation has decreased by 3.5 per cent.

Box 2.2 The growth of wind energy in Ethiopia

In 2011, the Ethiopian Government launched the Climate-Resilient Green Economy strategy, which laid out a low-carbon development pathway towards middle-income status by 2025. It called for US$2 billion of annual investment in renewable energy, particularly in hydro, geothermal and wind, with the latter expected to make up 4 per cent (or 3320 GWh) of Ethiopia's 100 per cent renewable energy mix by 2030.

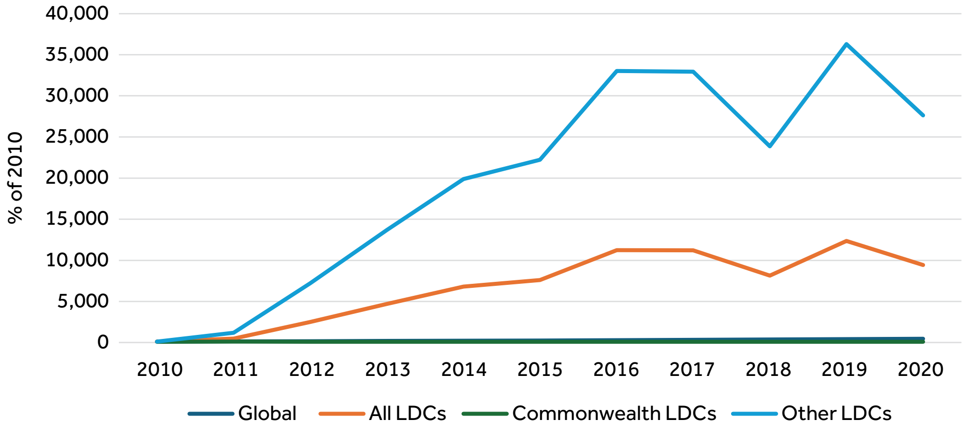
Ethiopia has since invested heavily in wind energy generation capacity, relying on a mix of loans and development finance to construct more than 420 MW of wind farm capacity since 2012, with another 150 MW expected to be brought online by 2025.

Figure 2.12 LDCs generating the most energy from wind



Source: Commonwealth Secretariat, using data from IRENAStat and Emberclimate.org.

Figure 2.13 Growth in wind energy generation (2010 baseline)



Source: Commonwealth Secretariat, using data from IRENAStat.

3. Energy trade involving Commonwealth LDCs and opportunities to boost their renewable energy exports

3.1 Commonwealth LDCs' trade in electricity

While most LDCs produce electricity principally for domestic consumption, often supplemented significantly by imports, half of the 14 Commonwealth LDCs exported some quantity of electricity in recent years, with all of them located in Africa. Among these, Mozambique was the largest exporter by volume between 2015 and 2020 (Table 3.1), averaging 11,659 GWh in exports annually, and is a net exporter of electricity to countries in the Southern African Power Pool (US International Trade Administration, 2022). Mozambique's electricity exports were equivalent to nearly two-thirds of its net electricity production over this period. Zambia, where hydro accounts for 85 per cent of installed electricity generation capacity, also exported relatively large quantities of electricity, averaging more than 1,000 kWh annually, mainly to neighbouring countries in Southern Africa as well as Tanzania and the Democratic Republic of Congo. Electricity is Zambia's highest non-agricultural export earner and its fifth most exported product (OEC, 2021; Lusaka Times, 2023).

Uganda, which also produces the bulk of its electricity from hydroelectric plants and enjoys a surplus of installed capacity relative to consumption, exported comparatively smaller quantities of electricity, mainly to Kenya and Tanzania, averaging 226 GWh each year. Togo, for which natural gas and hydro are the principal sources of electricity generation, exported 138 GWh of electricity annually, on average, between 2015 and 2020, primarily to neighbouring Burkina Faso. Malawi, Rwanda and Lesotho, all of which generate significant shares of power via hydro, also exported small quantities of electricity over this period. Among these, Lesotho, which relies primarily on renewable energy resources, particularly hydropower through the Lesotho Highlands Water Project (LHWP) but also increasingly through emerging solar energy initiatives via the Lesotho Solar Energy Project (launched in 2018), boasts significant potential to expand its exports of renewable energy. Currently, Lesotho exports surplus electricity exclusively to South Africa through a trading agreement with South Africa's national power utility, Eskom.

Despite exporting electricity in varying quantities, a number of these countries have very low rates of electrification domestically. Just 31.5 per cent of the population has access to electricity in Mozambique and more than half of the populations of Uganda and Zambia are without electricity.[8] These countries face significant challenges in distributing electricity, particularly to their rural populations.

Table 3.1 Commonwealth LDC electricity exporters (average values for 2015–2020)

Country	Electricity exports (GWh)	Electricity exports relative to net production (%)
Mozambique	11,659.0	63.5
Zambia	1,095.8	7.8
Uganda	226.3	5.7
Togo	138.0	10.7
Malawi	20.7	1.1
Rwanda	4.7	0.6
Lesotho	2.2	0.4

Note: Figures are average annual values over the period from 2015 to 2020. No electricity exports were reported for Bangladesh, The Gambia, Kiribati, Sierra Leone, Solomon Islands, Tanzania or Tuvalu (data were either not available or not applicable). 'Net production' represents gross production minus the consumption of electricity for direct use in electricity, combined heat and power, and heat plants.
Source: Commonwealth Secretariat (calculated using data from United Nations, 2022).

Boosting renewable energy generation capacity, alongside improvements to electricity distribution and transmission infrastructure, could help to enhance electrification rates in these countries, while also accelerating the transition to cleaner energy and enabling them to expand their electricity exports, in the process providing additional revenue. Such export expansion needs to be backed by the development of physical cross-border transmission infrastructure and systems, as well as greater coherence in policy, legal and regulatory frameworks – including those governing grid connectivity, access to transmission and distribution networks, energy accounting, payment and dispute resolution – to facilitate cross-border trading (Pollitt and McKenna, 2014; Singh et al., 2016).

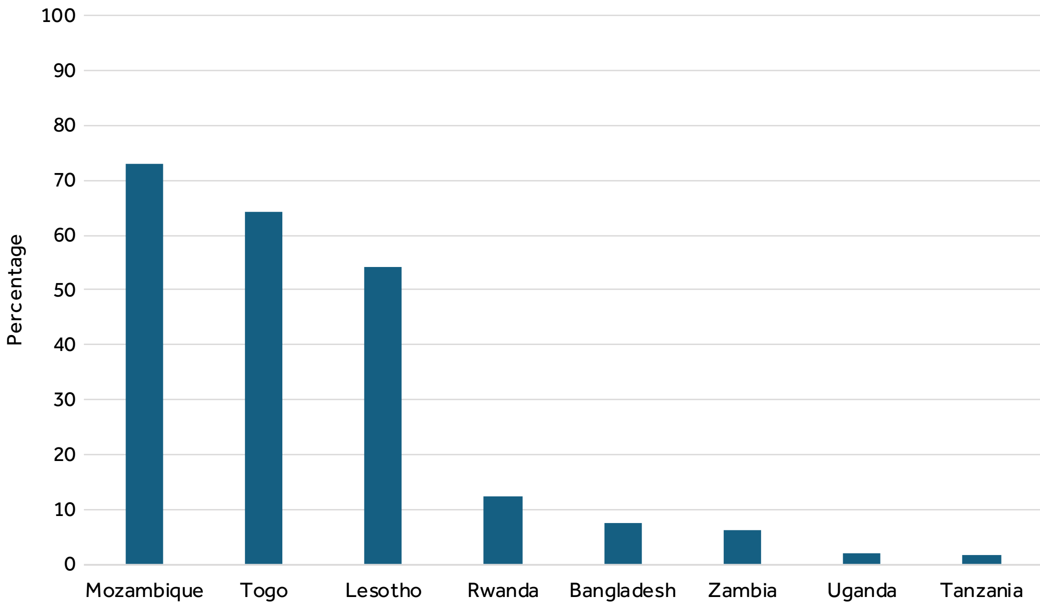
Commonwealth LDCs that import large quantities of electricity can also reduce their reliance on electricity imports by expanding renewable energy capacity domestically. Even though some of these countries export electricity in varying quantities, they also import power in significant quantities to meet local demand, suggesting they currently have only limited capacity to generate surplus electricity for export. Mozambique imported nearly 9,000 GWh of electricity each year, on average, between 2015 and 2020, whereas Bangladesh imported more than 5,000 GWh, and Togo, Zambia and Lesotho (the latter importing from Mozambique and South Africa) imported 813,700 and 400 GWh, respectively over this period (Table 3.2). In several countries, these imports are equivalent to very high shares of their net electricity production: more than 130 per cent for Togo, 86 per cent for Lesotho and almost 50 per cent for Mozambique. They are also significant when measured as

Table 3.2 Electricity imports by Commonwealth LDCs (average 2015–2020)

Country	Electricity Imports (GWh)	Electricity imports relative to net production (%)
Mozambique	8,940.5	48.8
Bangladesh	5,182.7	7.2
Togo	813.2	131.3
Zambia	700.5	5.6
Lesotho	400.3	86.4
Tanzania	104.0	1.4
Rwanda	76.7	11.1
Uganda	62.8	1.6

Note: Figures are average annual values over the period from 2015 to 2020. No electricity imports were reported for The Gambia, Kiribati, Malawi, Sierra Leone, Solomon Islands and Tuvalu (data were either not available or not applicable). 'Net production' represents gross production minus the consumption of electricity for direct use in electricity, combined heat and power, and heat plants.
Source: Commonwealth Secretariat (calculated using data from United Nations, 2022).

Figure 3.1 Ratio of imports to electricity consumption in Commonwealth LDCs importing electricity (average 2015–2020)



Source: Commonwealth Secretariat (calculated using data from United Nations, 2022).

a share of overall electricity consumption in several Commonwealth LDCs, particularly Mozambique (73 per cent), Togo (64 per cent) and Lesotho (54 per cent) (Figure 3.1).

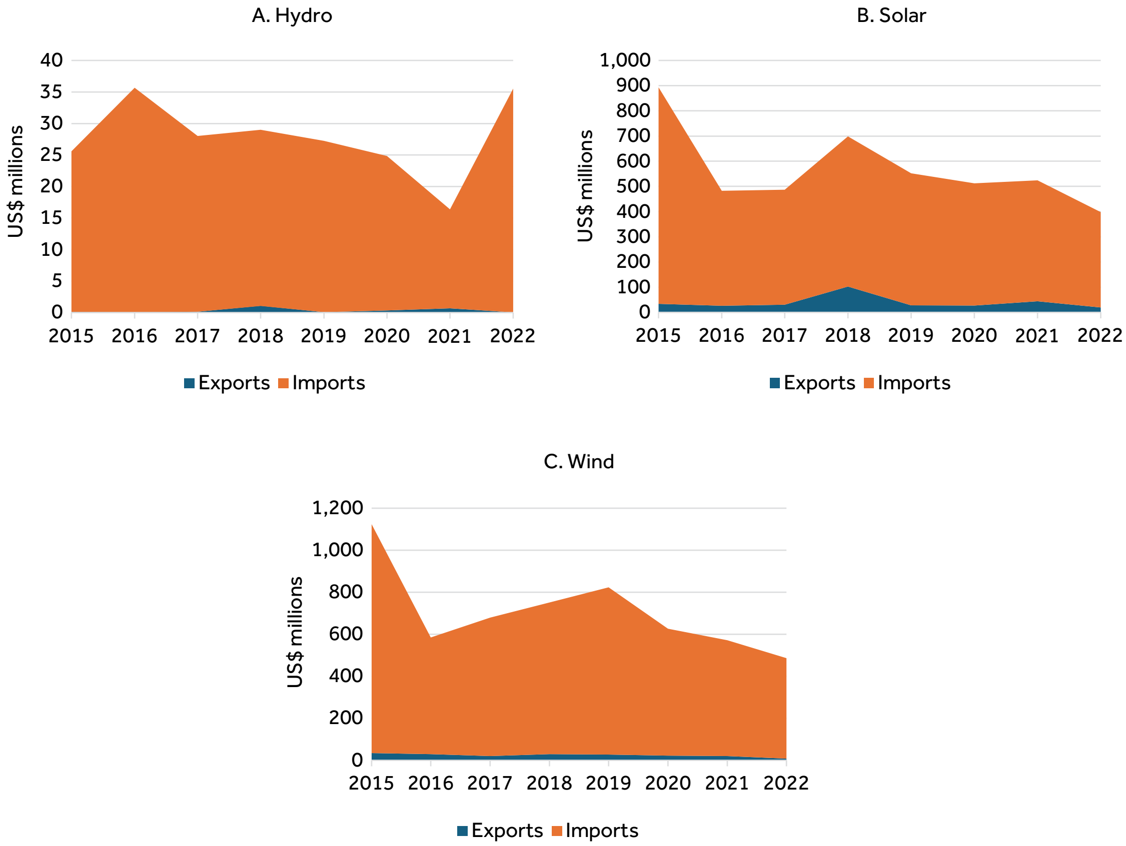
3.2 Commonwealth LDCs' trade in renewable energy components and technologies

Trade can be an important conduit for increasing renewable energy generation capacity in LDCs. Using the classifications in Pueyo and Linares (2012), Bridle and Bellman (2021), and WTO and IRENA (2021), panels A, B and C in Figure 3.2 show recent trends in Commonwealth LDCs' exports and imports of a selection of components typically used in large-scale hydro, solar and wind energy projects. Like many low-income and lower middle-income countries, Commonwealth LDCs are currently net importers of these technologies. In 2022, Commonwealth LDCs collectively exported just US$8,104 in hydraulic turbines, water wheels and associated parts typically used for hydropower, while their imports of these components totalled $35.5 million. They exported $19.6 million in generators, solar modules, inverters, cells and structural components for solar projects compared with imports of $378.4 million; and $8 million in exports of turbines, rotor blades, towers and transformers for wind energy projects versus $478 million in imports.

The same holds across individual Commonwealth LDCs (Table 3.3) and most of the specific components used in these projects, with few exceptions. Between 2015 and 2022, all Commonwealth LDCs were net importers of the components typically used in hydropower projects, except for Lesotho and Uganda, both of which were net exporters of hydraulic turbines and water wheels with power exceeding 10,000 kW (HS 8401013). The same goes for large-scale solar projects, except for Sierra Leone, which was a net exporter of PV generators (HS 850131, HS 850132) and Tanzania, a net exporter of parts of inverters (HS 850490). Similarly for large-scale wind projects, only Solomon Islands and Togo were net exporters of transformers (HS 850422) and rotor blades (HS 841290), respectively. In all cases, they exported these technologies in only limited quantities.

This analysis highlights the major role played by imports in enabling the generation of renewable energy in LDCs. They can provide ready access to components and technologies that would otherwise require substantial

Figure 3.2 Aggregate trade by Commonwealth LDCs in selected components for large-scale hydro, solar and wind projects (2015–2022)



Notes: Calculated as aggregate values across 13 Commonwealth LDCs (no data for Tuvalu). Hydro components are (with HS (Harmonized System) Codes in parenthesis): hydraulic turbines and water wheels (841011; 841012; 841013), parts of hydraulic turbines and water wheels (841090), and non-electric, instantaneous or storage water heaters (841919). Solar comprises solar modules (854129; 854140; 854190), inverters (850440; 850490), structural elements (racking and mounting) (700510; 700719; 100991; 7610), electrical items, including insulated wire, cable and other insulated electric conductors (8544), and generators (850131; 850132; 850161). Wind includes wind turbines (850161; 850163; 850164), rotor blades (841290; 848210; 848230), towers (7308; 7326) and transformers (850421; 850422; 850434; 850440).
Source: Commonwealth Secretariat (using UN Comtrade data).

investment and technical expertise to develop locally.[9] Imports also present a potential channel for technology transfer, particularly if LDCs can develop the necessary enabling factors and absorptive capacity – in terms of knowledge base, skills, and local scientific and innovation capabilities – to ensure effective adoption and diffusion of renewable energy technologies (Acharya and Keller, 2010; Mani, 2010; Pueyo and Linares, 2012; Weko and Goldthau, 2022). In this way, imports can complement other channels – such as FDI (see Box 2.1), licensing, collaborative research and development (R&D) and sub-contracting – facilitating the flow of foreign clean energy technologies to LDCs and other developing countries (Pueyo and Linares, 2012).

On the other end of the trade spectrum, the analysis above indicates that Commonwealth LDCs currently export very limited quantities of key components used in the production of hydro, solar and wind energy. Yet, for those with scope to develop the capacity and technological capabilities to manufacture renewable energy components to internationally competitive standards, there may be opportunities to significantly expand their exports – either regionally or globally – and, in the process, benefit from positive economy of scale effects.

Table 3.3 Commonwealth LDCs' trade in selected components and technologies for large-scale hydro, solar and wind projects (2015–2022, cumulative values, US$ million)

Country	Hydro			Solar			Wind		
	Exports	Imports	Net trade	Exports	Imports	Net trade	Exports	Imports	Net trade
Bangladesh	0.0	1.9	−1.8	4.8	239.9	−235.1	9.1	260.2	−251.2
The Gambia		0.7	−0.7	0.0	18.2	−18.2	0.1	63.7	−63.6
Kiribati		0.1	−0.1	0.0	8.7	−8.7	0.1	8.3	−8.2
Lesotho	0.0	0.8	−0.8	3.1	58.3	−55.2	2.9	222.2	−219.2
Malawi	0.7	30.3	−29.6	2.1	233.8	−231.7	4.0	271.4	−267.3
Mozambique	0.0	8.7	−8.7	9.9	854.7	−844.8	21.3	1,016.7	−995.5
Rwanda	0.1	40.1	−40.0	10.9	433.6	−422.8	5.7	476.1	−470.4
Sierra Leone	0.0	0.1	−0.1	2.4	81.8	−79.4	3.5	89.7	−86.2
Solomon Islands	0.0	0.8	−0.8	0.1	21.8	−21.7	0.2	20.3	−20.1
Tanzania	1.2	56.1	−54.8	103.7	985.6	−881.9	38.3	1,303.7	−208.3
Togo	0.0	0.5	−0.5	5.4	260.3	−254.9	8.4	216.7	−300.2
Uganda	0.2	56.6	−56.4	21.5	478.5	−457.0	22.5	322.7	−1,265.4
Zambia	0.1	23.1	−23.1	147.4	560.6	−413.3	72.5	1,185.6	−1,113.0

Notes: No data for Tuvalu. Solar exports and imports are calculated as aggregate values for the components listed in the notes for Figure 3.2.
Source: Commonwealth Secretariat (using UN Comtrade data).

4. Towards expanding LDC renewable energy generation: a look at solar and wind energy endowments

While the preceding sections have sought to provide an overview of existing LDC renewable energy generation from hydro, solar, bio and wind and their trade in these types of renewable energy and associated technologies, this section explores LDC renewable energy generation *potential* by looking at raw solar and wind resource endowments.[10] This analysis is useful to identify those LDCs where technology transfer may have the largest impact and investment the greatest returns. A breakdown of solar and wind energy endowments by LDC is available in Annex 3.

Solar is the most widely used renewable energy generation technology in LDCs, which indicates that it may be the most appropriate target of mass technology transfer considering that almost all LDCs have some degree of technical expertise and capacity to utilise the technology. LDCs generally enjoy an abundance of solar radiation, particularly those located in Central Africa and the Middle East with relative proximity to the equator. As a group they receive an average of 5.46 kWh per square meter per day (kWh/m^2/day) in global horizontal solar irradiation compared to an average of 5.29 kWh/m^2/day for other developing countries (Table 4.1). Commonwealth LDCs have a lower average (measured in the same terms) of 5.38 kWh/m^2/day compared to the non-Commonwealth average of 5.50 kWh/m^2/day, largely due to the high number of non-Commonwealth LDCs located in Central and North Africa.

What LDCs enjoy in high solar resource endowments relative to other developing countries they generally lack in wind energy endowments, partially due to the high number that are landlocked. When measuring the 10 per cent windiest areas in each LDC, they collectively average a wind power density of 6.58 kWh/m^2/day at a height of 50 meters, compared to an

Table 4.1 Renewable energy endowments (kWh/m²/day)

	Solar (average global horizontal radiation)	Wind (average of 10% windiest areas)
All LDCs	5.46	6.58
Other developing countries	5.29	8.63
Commonwealth LDCs	5.38	4.64
Other LDCs	5.50	7.43

Source: Commonwealth Secretariat, using data from Global Solar Atlas 2.0, Global Wind Atlas and the World Bank.

average of 8.63 kWh/m²/day for other developing countries (Table 4.1). Commonwealth LDCs also average a lower power density compared to their non-Commonwealth counterparts: 4.64 kWh/m²/day compared to 7.43 kWh/m²/day, respectively.

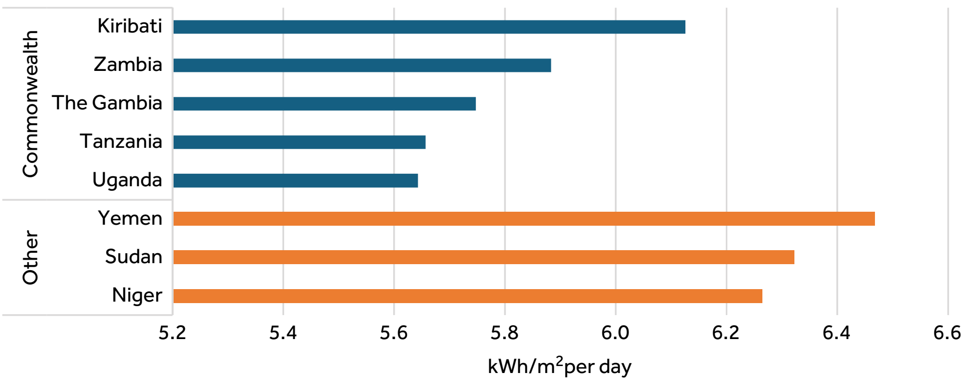
Figure 4.1 shows the Commonwealth and non-Commonwealth LDCs with the greatest solar energy potential and generally reflects the geographic concentration mentioned above. Yemen has the highest solar energy potential, receiving an average of 6.47 kWh/m²/day, followed by Sudan (6.32 kWh/m²/day) and Niger (6.26 kWh/m²/day). Kiribati is the only Commonwealth LDC in the overall top ten, receiving 6.13 kWh/m²/day.

With respect to wind resource endowments, while LDCs generally lag other developing countries, there are several outliers - as depicted in Figure 4.2. Lesotho, a Commonwealth member, has the highest wind energy potential of all LDCs at an average of 19.7 kWh/m²/day, which is also the third highest potential of all developing countries behind Chile (72 kWh/m²/day) and Argentina (33.4 kWh/m²/day). This is followed by Afghanistan at 17.8 kWh/m²/day and Chad at 16.30 kWh/m²/day.

These data on solar and wind energy endowments can be used to calculate the approximate area of new solar and wind farms required to replace fossil fuel energy generation in LDCs (see Annex 4 for the methodology). Figure 4.3 shows that LDCs would require approximately 3,665 km² of new solar farms for this purpose compared to 3,800 km² of wind farms,[11] and that Commonwealth LDCs require a significantly smaller area of installed solar (1,850 km²) than wind (2,758 km²) to displace fossil fuels in their energy mix. This higher solar efficiency holds true for individual Commonwealth LDCs too: only two LDCs, Malawi and Tanzania, require a smaller area of new wind than solar to offset their fossil fuel energy generation (see Annex 3 for country-level data).

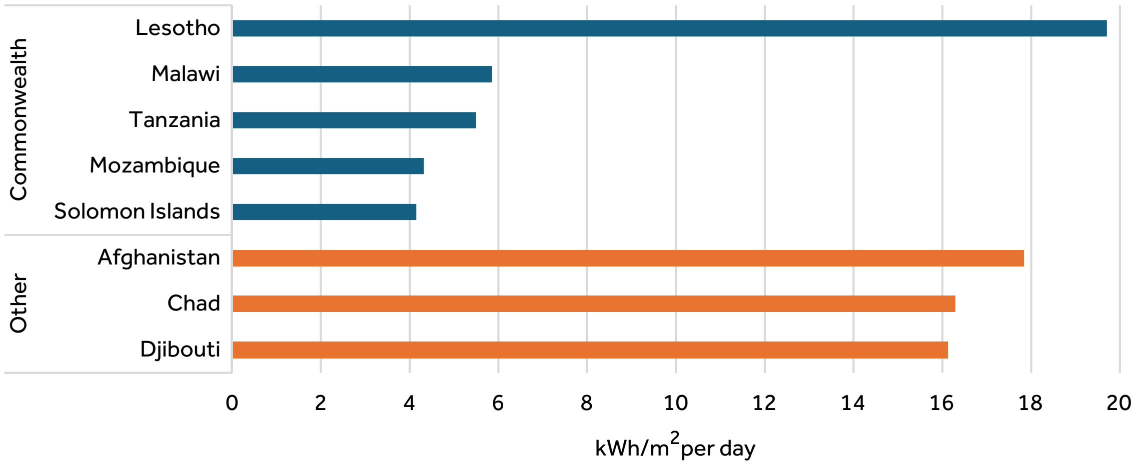
This trend is somewhat inverted when looking to non-Commonwealth LDCs, which collectively require a smaller total area of new wind farms (1,041 km²) than solar farms (1,057 km²) to replace fossil fuels. Fifteen (15) of the 29 non-Commonwealth LDCs that contain fossil

Figure 4.1 LDCs with highest solar energy generation potential (average global horizontal irradiation, kWh/m²/day)



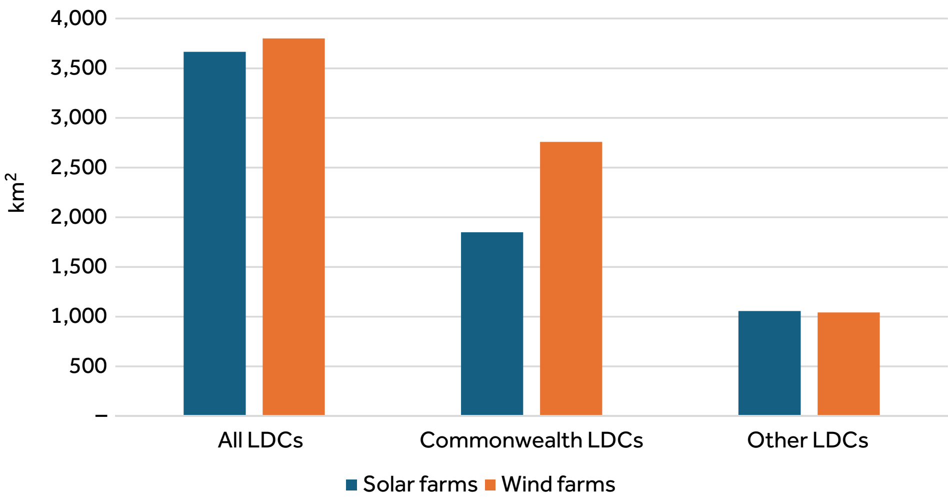
Source: Commonwealth Secretariat, using data from Global Solar Atlas 2.0 and the World Bank.

Figure 4.2 LDCs with highest wind energy generation potential (average power density of 10 per cent windiest areas, 50 meters height, kWh/m²/day)



Source: Commonwealth Secretariat, using data from Global Wind Atlas and the World Bank.

Figure 4.3 Required installed area of new solar and wind farms to displace fossil fuel energy generation (2020, km²)



Source: Commonwealth Secretariat, using data from Global Solar Atlas 2.0, Global Wind Atlas, the World Bank and Emberclimate.org.

fuels in their energy mix also require a smaller area of wind than solar for a similar offset.

While these figures are approximations, they provide an indication of where the technology transfer of – and the investment into – solar or wind energy in different LDCs may be more productive to reduce respective fossil fuel dependencies. Twenty-two (22) LDCs require the construction of less than 5 km² of solar or wind farms to displace fossil fuels in their energy mixes, after which they could look to leverage high endowments to potentially become net exporters of green energy and players in enabling the global energy transition. This will not be possible if LDCs continue to face infrastructure financing deficits and high levels of public debt, which inhibit the utilisation of these endowments, as well as a failure of development partners to abide by their technology transfer obligations. Without this international support, LDCs in the short term may be forced to rely more heavily on fossil fuels to meet growing energy demand, as well as continuing to lack the technology bases needed to navigate their longer-term energy transitions.

5. Conclusion and way forward

Renewable energy sources such as solar, wind and hydroelectricity produce low or zero greenhouse gas emissions and can make an important contribution to mitigating climate change and supporting more sustainable production and trade. Access to affordable, renewable energy should support the development of wealth-generating economic activities, improve living standards by reducing the national energy bill and stimulating job creation, and provide the necessary platform to accelerate the clean energy transition in the world's LDCs (WTO, 2017). Ramping up renewable energy generation can also provide opportunities for these countries to expand their exports of green energy.

However, many LDCs have yet to maximise the potential presented through their sizeable renewable energy resource endowments. Greater investment, especially in supporting infrastructure and technologies, will be required to fully realise the gains available to LDCs that can successfully navigate the renewable energy transition. At present, among the Commonwealth LDCs, investments in renewable energy sectors – including via new greenfield FDI – remain highly concentrated.

Leveraging FDI and other forms of private investment can provide the financial impetus necessary to develop renewable energy infrastructure and associated technologies at scale in LDCs. Dedicated access to existing climate-related funding facilities – including through the Climate Investment Platform and the Energy Transition Accelerator Financing Platform – should also be secured for renewable energy projects in these countries.

Besides financing and investment, LDCs need to overcome major challenges related to accessing the technologies necessary to produce renewable energy efficiently and at scale. This is crucial to ensure they make better use of their existing resource endowments and accelerate their energy transitions. Special attention should be paid to how emerging technologies, appropriately adapted to local contexts in LDCs, can help deliver clean energy that is affordable, cost competitive and accessible to all, including marginalised communities and those living in remote areas. In the second paper of this two-part series (see Zhuawu et al., 2024), we examine the role of trade and investment in enabling the diffusion of green technologies to LDCs to aid their renewable energy transitions.

With suitable levels of investment, access to key technologies and skills, there is scope to significantly expand renewable energy generation capacity in LDCs. In many parts of the world, it is now cheaper to build wind and solar energy infrastructure compared to power plants that run on fossil fuels (United Nations, 2023). Estimates from the Carbon Tracker Initiative suggest new wind and solar energy will be 96 per cent cheaper than existing coal power by 2030.[12]

Delivering a complete, inclusive and equitable renewable energy transition will require structural transformations to the energy sector in many LDCs. For policy-makers seeking to facilitate these transformations and deliver an inclusive, equitable and sustainable energy transition, the greatest emphasis should be placed on ensuring energy generated from renewable sources is accessible and affordable for all.

Notes

1 www.ldc-climate.org/wp-content/uploads/2019/09/LDC-REEEI.pdf

2 The second paper focuses on the role of trade and investment in enabling the diffusion of green technologies to LDCs to help their transition to renewable energy (see Zhuawu et al., 2024).

3 As the analysis for this paper was undertaken before Bhutan graduated from the LDC category in December 2023, it is included in the calculations and estimates as part of a group of 46 LDCs.

4 The data do not reflect LDC energy generation from any other renewable energy sources, either due to a lack of data or LDC generating capacity.

5 It is worth noting that these countries likely supplement domestic generation with imported electricity (such as Lesotho importing electricity from South Africa),

altering the energy consumption mix. LDC trade in renewable energy is further explored in Section 3.

6 While Bangladesh has been excluded as an outlier for this analysis, the remainder of this section will include Bangladesh in further analysis.

7 Data for 2021 from the World Bank's World Development Indicators database.

8 Data for 2021 from the World Bank's World Development Indicators database. The electrification rate in Uganda is 45.2 per cent, while 46.7 per cent of the population has access to electricity in Zambia.

9 But heavy reliance on imports, coupled with limited domestic manufacturing capabilities, also means many LDCs are vulnerable to shortages in the supply of, or disruptions to, trade in key renewable energy components and technologies, especially amid rapidly accelerating demand for clean energy inputs and technologies globally.

10 Data were not available for hydro and bioenergy endowments in LDCs.

11 When comparing solar and wind endowment data, it is important to note that solar endowment data are based on average solar irradiation, while wind endowment data are based on the average of the 10 per cent windiest areas per individual LDC. This is due to: (a) a lack of data on the 10 per cent areas that receive the highest solar irradiation per LDC; and (b) solar irradiation being much more consistent across landmasses compared to wind, making the utilisation of the average of the latter misleading when comparing endowments.

12 https://carbontracker.org/reports/carbon-tracker-annual-review-2018-2019/

13 https://emp.lbl.gov/sites/default/files/2_tracking_the_sun_2021_report.pdf

14 https://documents1.worldbank.org/curated/en/466331592817725242/pdf/Global-Photovoltaic-Power-Potential-by-Country.pdf

15 https://documents1.worldbank.org/curated/en/466331592817725242/pdf/Global-Photovoltaic-Power-Potential-by-Country.pdf

16 https://files.bregroup.com/solar/NSC_-Guid_Agricultural-good-practice-for-SFs_0914.pdf

17 www.epa.gov/sites/default/files/2019-08/documents/wind_turbines_fact_sheet_p100il8k.pdf

18 https://energyfollower.com/wind-turbine-spacing/

References

Acharya, R.C. and W. Keller (2010) 'Technology Transfer through Imports'. NBER Working Paper 13086. Cambridge, MA: National Bureau of Economic Research.

Bridle, R. and C. Bellman (2021) 'How Can Trade Policy Maximise the Benefits from Clean Energy Investment?' *International Institute for Sustainable Development Report,* July.

IRENA (International Renewable Energy Agency) (2023) 'Investment Needs of USD 35 trillion by 2030 for Successful Energy Transition', 28 March. www.irena.org/News/pressreleases/2023/Mar/Investment-Needs-of-USD-35-trillion-by-2030-for-Successful-Energy-Transition

Klein, J. and E. Tinkler (2023) 'Capturing the true value of greenfield renewables'. *Infrastructure Investor,* 13 February. www.infrastructureinvestor.com/capturing-the-true-value-of-greenfield renewables/#:~:text=The%20UN%20estimates%20that%20at,of%20additional%20renewable%20energy%20capacity.

Lusaka Times (2023) 'Government Justifies Export of Power to Neighbouring Countries', 14 January. www.lusakatimes.com/2023/01/14/government-justifies-export-of-power-to-neighboring-countries/

Mani, M. (2010) 'Creating incentives for clean technology trade, transfer, and diffusion: The role of non-distorting policies'. Background paper for the conference on Climate Change, Trade and Competitiveness: Issues for the WTO, 16–18 June 2010.

OEC (2021) 'Electricity in Zambia'. https://oec.world/en/profile/bilateral-product/electricity/reporter/zmb

Pogson, M., A. Hastings and P. Smith (2013) 'How Does Bioenergy Compare with Other Land-Based Renewable Energy Sources Globally?' *GCB Bioenergy* 5(5): 513–24. https://doi.org/10.1111/gcbb.12013.

Pollitt, M. and M. McKenna (2014) 'Power Pools: How Cross-Border Trade in Electricity Can Help Meet Development Goals'. World Bank Blog, 1 October. https://blogs.worldbank.org/trade/power-pools-how-cross-border-trade-electricity-can-help-meet-development-goals

Pueyo, A. and P. Linares (2012) 'Renewable Technology Transfer to Developing Countries: One Size Does Not Fit All'. *Institute of Development Studies Working Paper* 412, November.

Singh, A., P. Wijayatunga and P.N. Fernando (2016) 'Improving Regulatory Environment for a Regional Power Market in South Asia'. *Asian Development Bank South Asia Working Paper Series No*. 45, August.

United Nations (2022) '2020 Electricity Profiles', Department of Economic and Social Affairs, Statistics Division, New York: United Nations.

United Nations (2023) 'Sustainable Renewable Energy Key to Unlocking Developing Countries' Potential, Achieving Global Goals, Speakers Tell High-Level Political Forum'. High-Level Political Forum, 5th and 6th meetings, 12 July. https://press.un.org/en/2023/ecosoc7136.doc.htm

United States International Trade Administration (2022) 'Mozambique – Country Commercial Guide: Power Generation, Transmission and Distribution', 30 November. www.trade.gov/country-commercial-guides/mozambique-power-generation-transmission-distribution

Weko, S. and A. Goldthau (2022) 'Bridging the low-carbon technology gap? Assessing energy initiatives for the Global South'. *Energy Policy*, 169.

WTO (World Trade Organization) (2017) *Report on the Implementation of Article 66.2 of the TRIPS Agreement: European Union*. Document IP/C/W/616/Add.7, 21 April.

WTO and IRENA (2021) 'Trading into a bright energy future: The case for open, high-quality solar photovoltaic markets'. Geneva and Abu Dhabi: WTO Publications and IRENA.

Zhuawu, C., N. Balchin and K. de Klerk (2024) 'Challenges and Opportunities for Renewable Energy Technology Transfer in Least Developed Countries'. International Trade Working Paper 2024/03, Commonwealth Secretariat, London.

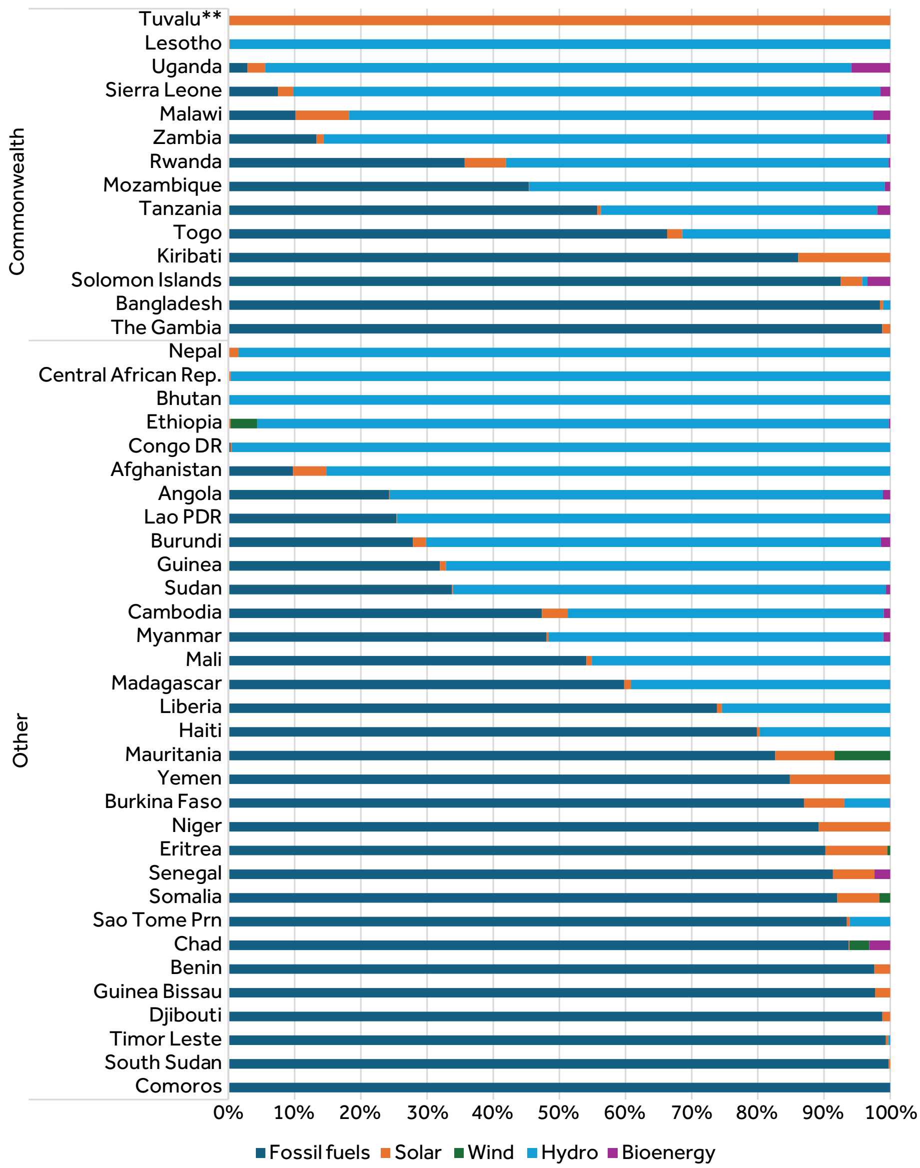
Annex 1. LDC renewable energy profiles

	Total renewable generation (TWh)	Renewable generation by select technologies (GWh)			
		Solar	Wind	Hydro	Bioenergy
Global	**7,468.06**	**843,854.86**	**1,588,586.04**	**4,476,230.46**	**957.47**
All LDCs	**154.27**	**2,918.03**	**764.97**	**149,253.65**	**1,473.48**
Commonwealth LDCs	**29.59**	**977.33**	**5.18**	**27,981.31**	**626.61**
Bangladesh	1.17	389.13	5.08	776.69	3.86
The Gambia	0.00	3.47	0.10	..	..
Kiribati	0.00	4.84	..	..	..
Lesotho	0.42	0.76	..	416.73	..
Malawi	1.86	167.64	..	1,641.55	53.85
Mozambique	4.20	1.65	..	4,137.89	61.46
Rwanda	0.58	56.31	..	518.78	2.33
Sierra Leone	0.25	6.23	..	238.12	3.94
Solomon Islands	0.01	3.48	..	0.89	3.70
Tanzania	3.42	42.36	0	3,223.58	151.34
Togo	0.22	14.84	..	204.00	..
Tuvalu	0.00	1.53	..	..	..
Uganda	4.42	122.04	..	4,028.12	267.82
Zambia	13.04	163.05	..	12,794.96	78.31
Other LDCs	**124.68**	**1,940.70**	**759.79**	**121,272.34**	**846.87**
Afghanistan	1.12	62.66	0.12	1,052.61	..
Angola	14.02	18.27	..	13,801.67	200.00
Benin	0.01	5.34	..	0.07	..
Bhutan	11.37	0.39	1.11	11,369.73	..
Burkina Faso	0.21	100.85	..	112.39	1.30
Burundi	0.29	7.93	..	271.58	5.55
Cambodia	4.26	316.20	0.30	3,860.03	78.88
Central African Rep.		0.43	..	135.60	..
Chad	0.02	0.38	8.90	..	9.50
Comoros	0.00	..	..	0	..
Dem. Rep. of the Congo	11.92	28.14	..	11,890.77	0
Djibouti	0.00	0.60	0	..	..
Eritrea	0.04	42.49	2.00	..	..
Ethiopia	15.08	32.30	609.04	14,403.70	29.98
Guinea	1.51	20.59	..	1,493.44	..
Guinea-Bissau	0.00	1.89	..	..	..
Haiti	0.20	4.23	0.07	200.00	..
Lao P.D.R.	29.90	43.47	..	29,812.95	45.83
Liberia	0.13	3.62	..	124.00	..
Madagascar	0.87	22.56	0.47	844.45	0.62
Mali	1.73	31.70	..	1,702.17	0
Mauritania	0.27	140.01	131.19	0	..
Myanmar	13.24	79.45	0.02	12,897.20	261.06
Nepal	6.38	95.65	0.35	6,284.59	0

	Total renewable generation (TWh)	Renewable generation by select technologies (GWh)			
		Solar	Wind	Hydro	Bioenergy
Niger	0.05	46.09	..	..	..
Sao Tome and Principe	0.01	0.42	..	5.89	..
Senegal	0.40	290.65	0	0	110.30
Somalia	0.03	24.24	6.22	..	..
South Sudan	0.00	1.25	..	..	..
Sudan	11.14	27.51	..	11,008.00	103.85
Timor-Leste	0.00	1.72	..	1.50	..
Yemen	0.49	489.67	..	..	0

Source: Commonwealth Secretariat, using data from IRENAStat and Emberclimate.org.

Annex 2. Composition of LDC energy generation (2020)*



Source: Commonwealth Secretariat (calculated using IRENAStat and Emberclimate.org data).
*****Note that there may be discrepancies between the cumulative share of renewables displayed in this figure and official IRENAStat share of renewables data. This is likely due to the exclusion of non-solar, wind, hydro or bioenergy generation from the analysis in this paper.
******Data are unavailable for Tuvalu's fossil fuel energy generation. As a result, Tuvalu's energy composition in this annex reflects that 100 per cent of its renewable energy is generated by solar.

Annex 3. Renewable energy endowments

	Energy endowments (kWh/m^2 per day)		Installed area to displace annual fossil fuel energy generation (km^2)	
	Solar (average global horizontal radiation)	Wind (average of 10% windiest areas)	Solar farms	Wind farms
All LDCs	**5.46**	**6.58**	**3,664.85**	**3,799.72**
Other developing countries	**5.29**	**8.63**	**..**	**..**
Commonwealth LDCs	**5.38**	**4.64**	**1,849.67**	**2,758.25**
Bangladesh	4.60	2.90	1,643.02	2,496.03
The Gambia	5.75	3.58	5.12	7.90
Kiribati	6.13	3.43	0.50	0.85
Lesotho	5.54	19.70	0.00	0.00
Malawi	5.59	5.86	3.81	3.49
Mozambique	5.38	4.32	65.80	78.70
Rwanda	5.08	1.78	6.40	17.55
Sierra Leone	5.12	1.61	0.40	1.21
Solomon Islands	4.40	4.15	2.31	2.35
Tanzania	5.66	5.50	77.13	76.21
Togo	5.22	2.76	8.36	15.18
Tuvalu	5.34	3.26	..	..
Uganda	5.64	2.52	2.34	5.03
Zambia	5.88	3.62	34.49	53.76
Other LDCs	**5.50**	**7.43**	**1,056.86**	**1,041.47**
Afghanistan	5.49	17.83	2.22	0.66
Angola	5.75	3.34	79.28	131.11
Benin	5.33	3.17	4.19	6.76
Bhutan	3.94	6.84	0.00	0.00
Burkina Faso	5.81	4.34	24.99	32.07
Burundi	5.19	2.50	2.15	4.29
Cambodia	5.09	3.62	76.33	102.95
Central African Rep.	5.70	2.23	0.00	0.00
Chad	6.26	16.30	4.54	1.67
Comoros	5.05	3.86	2.61	3.28
Dem. Rep. of the Congo	5.19	1.99	0.59	1.47
Djibouti	6.06	16.13	0.84	0.30
Eritrea	6.07	13.10	6.85	3.05
Ethiopia	5.85	6.65	0.17	0.15
Guinea	5.57	2.18	12.93	31.67
Guinea-Bissau	5.60	2.33	1.45	3.35
Haiti	5.54	10.15	14.85	7.77
Lao P.D.R.	4.48	8.06	229.88	122.73
Liberia	4.88	1.20	7.49	29.22
Madagascar	5.63	10.75	23.27	11.69
Mali	6.02	8.35	34.40	23.79
Mauritania	6.04	11.76	21.68	10.69

	Energy endowments (kWh/m^2 per day)		Installed area to displace annual fossil fuel energy generation (km^2)	
	Solar (average global horizontal radiation)	Wind (average of 10% windiest areas)	Solar farms	Wind farms
Myanmar	4.69	3.84	264.79	310.76
Nepal	4.53	13.01	0.00	0.00
Niger	6.26	10.87	6.15	3.40
Sao Tome and Principe	4.30	1.70	2.12	5.15
Senegal	5.80	4.22	74.03	97.55
Somalia	6.03	13.94	5.89	2.45
South Sudan	5.68	3.72	9.47	13.88
Sudan	6.32	12.00	91.16	46.11
Timor-Leste	5.32	7.87	9.54	6.19
Yemen	6.47	9.77	42.99	27.32

Source: Commonwealth Secretariat, using data from Global Solar Atlas 2.0, Global Wind Atlas, the World Bank and Emberclimate.org.

Annex 4. Methodology for calculating the area required for the displacement of fossil fuels by renewable energy technologies

The methodology used to calculate the area of wind and solar farms required to displace annual fossil fuel energy generation differs slightly between technologies. For solar, the average theoretical potential expressed as kWh/m^2/day was converted to kWh/km^2/year. To derive practical solar potential, the converted theoretical potential was discounted by the efficiency of solar panel technology (assumed at 20 per cent[13]), losses due to soiling (−3.5 per cent[14]) and cumulative conversion losses (−7.5 per cent[15]) for an overall conversion rate of 9 per cent. These assumptions align with established industry standards and the assumptions made by Global Solar Atlas 2.0, as found in the footnotes. The final figure for installed area of solar farms was derived by dividing annual fossil fuel generation (expressed in kWh) by practical solar potential, weighted by an assumed 30 per cent[16] coverage of solar panels in total solar farmland use. The impact of temperature and seasonality was excluded, and solar power plant availability was assumed to be 100 per cent.

For wind, a similar methodology was used. The average theoretical potential of the 10 per cent windiest areas was converted to kWh/km^2/year and was discounted by an assumed efficiency of wind turbines (the average industry standard of 30 per cent[17]) and the same cumulative conversion losses (−7.5 per cent) for an overall conversion rate of 22.5 per cent. The final figure of total wind farmland use was derived by assuming a gap of seven rotor blades between wind turbines[18] or a coverage by wind turbines of 12.5 per cent in total wind farmland use. Wind power plant availability was assumed to be 100 per cent.