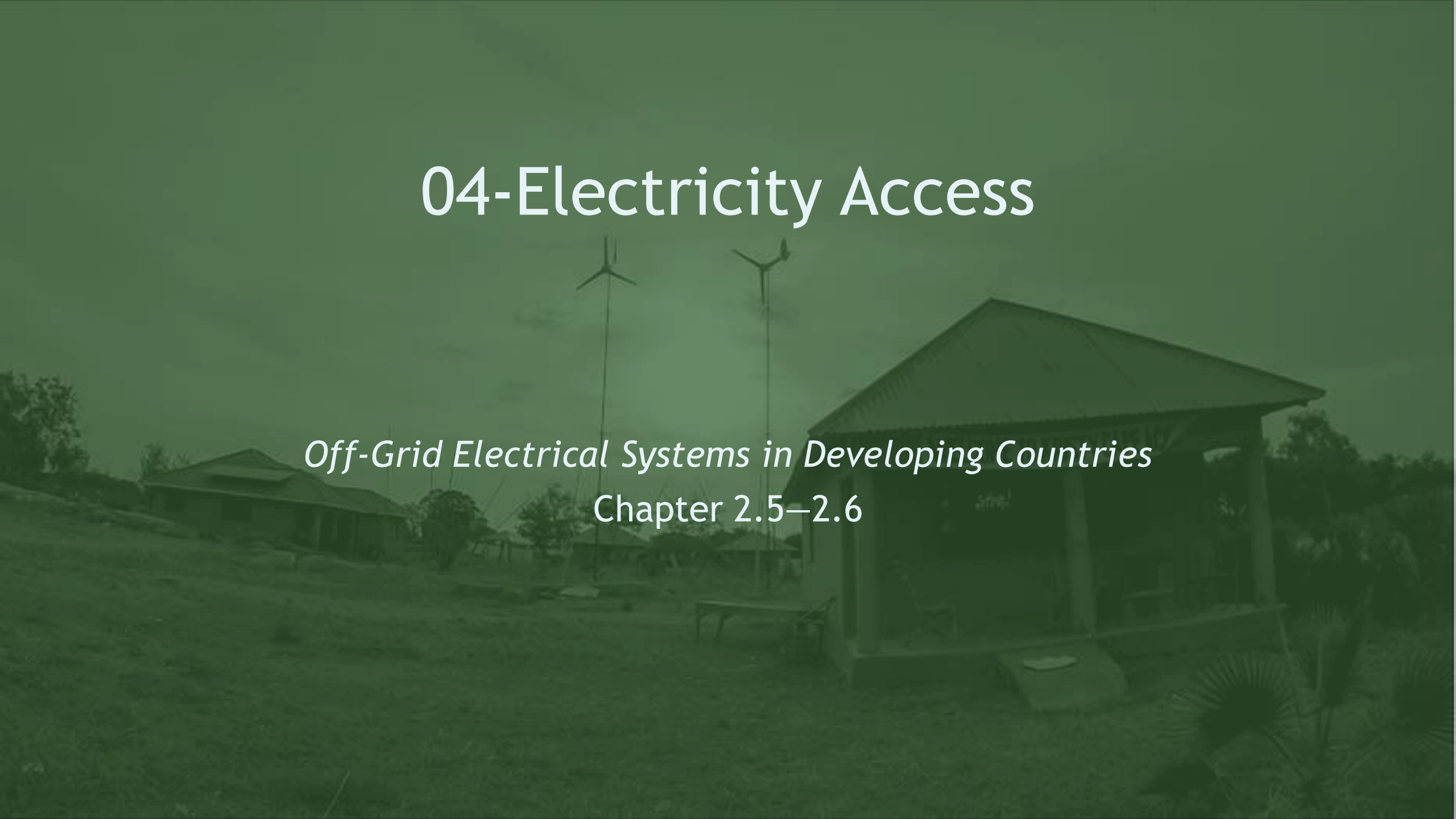
04-Electricity Access

Off-Grid Electrical Systems in Developing Countries

Chapter 2.5—2.6



Learning Outcomes

At the end of this lecture, you will be able to:

- ✓describe the role of electricity in meeting the energy needs of a rural household
- ✓define the terms *universal access*, *electrification rate*, and *Annual Growth Rate*
- ✓compute the electrification rate and Annual Growth Rate for countries and regions

Replace or Complement?

- Off-grid systems can be designed to partially or completely replace traditional fuels, or to complement them by powering devices that traditional fuels cannot supply (e.g. a mobile phone)
- Size, cost, and design of the system depends on the strategy selected

Example

Consider a household whose consumption is 60 GJ (16,667 kWh) per year from fuel wood and kerosene. Of this, 36 GJ from fuel wood is used for cooking and water heating on a cook stove with an efficiency of 12%, and 20 GJ from fuel wood is used for space heating. Kerosene is used for lighting, with an annual consumption of 4 GJ. Compute the annual energy required, in kilowatthours, to replace the fuel with electricity from the national grid. Assume the electric cook stove is 75% efficient and the electric lamps consume 45 kWh per year.

Example---Electric Cookstove Consumption

Of this, 36 GJ from fuel wood is used for cooking and water heating on a cook stove with an efficiency of 12%... Assume the electric cook stove is 75% efficient.

The electric cookstove reduces the consumption from water heating and cooking to:

$$36\ GJ \times 0.12/0.75 = 5.76\ GJ = 1600\ kWh$$

Example---Heating

…20 GJ from fuel wood is used for space heating

Assuming the same energy for heating is required from electricity

20 GJ x (1 kWh/0.0036 GJ) = 5555 kWh

Example: Total

The total electrical energy for complete replacement is:

1600 kWh + 5555 kWh + 45 kWh = 7201 kWh

cooking heating lighting

Exercise

Compute the annual expenditure of the same household if electricity is used to completely replace the traditional fuels, assuming the electricity is $0.15/kWh.

Replace or Complement?

- Complete replacement of traditional fuels is not practical in most situations
- Common strategy:
  - Replace expensive, low-quality, and/or harmful fuels such as kerosene (lighting) and disposable batteries
  - Complement traditional fuels for applications like mobile phone charging, radios, television
  - Retain traditional fuels for heating and cooking

Use traditional fuels for thermal applications (heating, cooking)

How much electricity does a household need?

Household electricity requirements depends on local context and level of service provided

20 to 100 kWh/person/year

365 kWh/household/year
(1 kWh/day)

Electricity Services

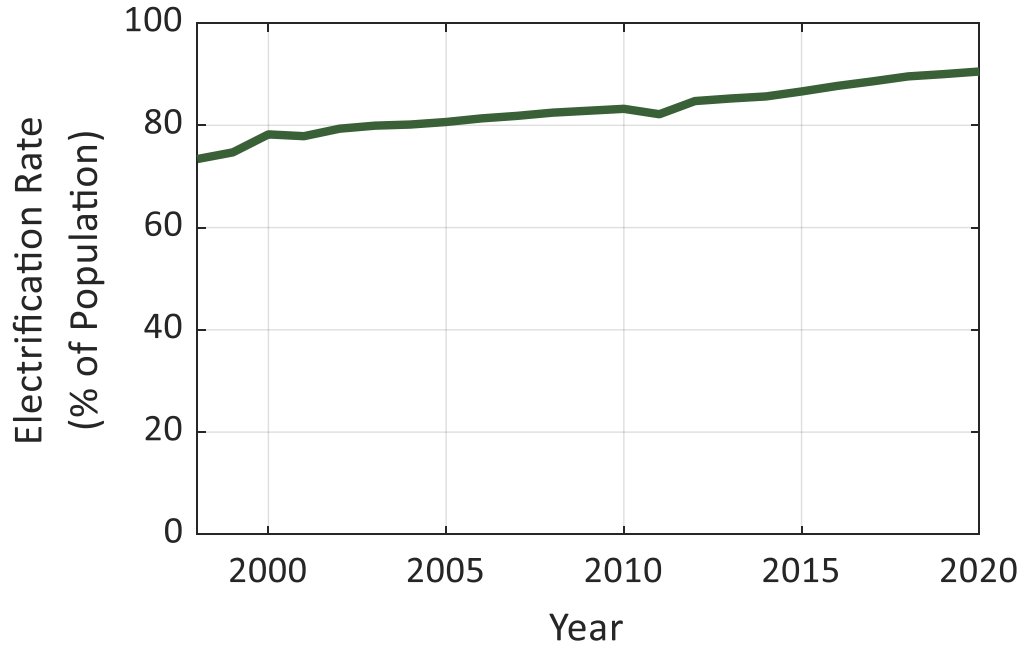
Service	Very-Low Power	Low-Power	Medium-Power	High-Power	Very High-Power
1. Lighting	Task	General	--	--	--
2. Communication & entertainment	Phone charging, radio	TV, computer, printer	--	--	--
3. Space cooling & heating	--	Fan	Air cooler	--	Air conditioner
4. Refrigeration	--	--	Refrigerator, freezer	--	--
5. Mechanical Loads	--	--	Water pump, food processor	Washing machine	Vacuum cleaner
6. Product heating	--	--	--	Iron, hair dryer	Water heater
7. Cooking	--	--	Rice Cooker	Toaster, microwave	Electric range (cooker)

Electricity Services

Services	Consumption (kWh/person/year)
Task lighting	1
Light or TV or radio	2
Light, phone, radio, small TV	22
Light, phone, radio, TV, fan, productive uses	220

Type of technology used also affects consumption (e.g. LED versus compact florescent light)

$$\text{Electrification Rate (\%)}: 100 \times \frac{\text{population whose house is connected to national grid}}{\text{total population}}$$



2020 Electrification rate: 90.5%.
733 million without access to electricity

Calculating Population with and without Access

- Population with access = total population x electrification rate

- Population without access = total population x (100 – electrification rate)

- Electricity access is a binary indicator, so

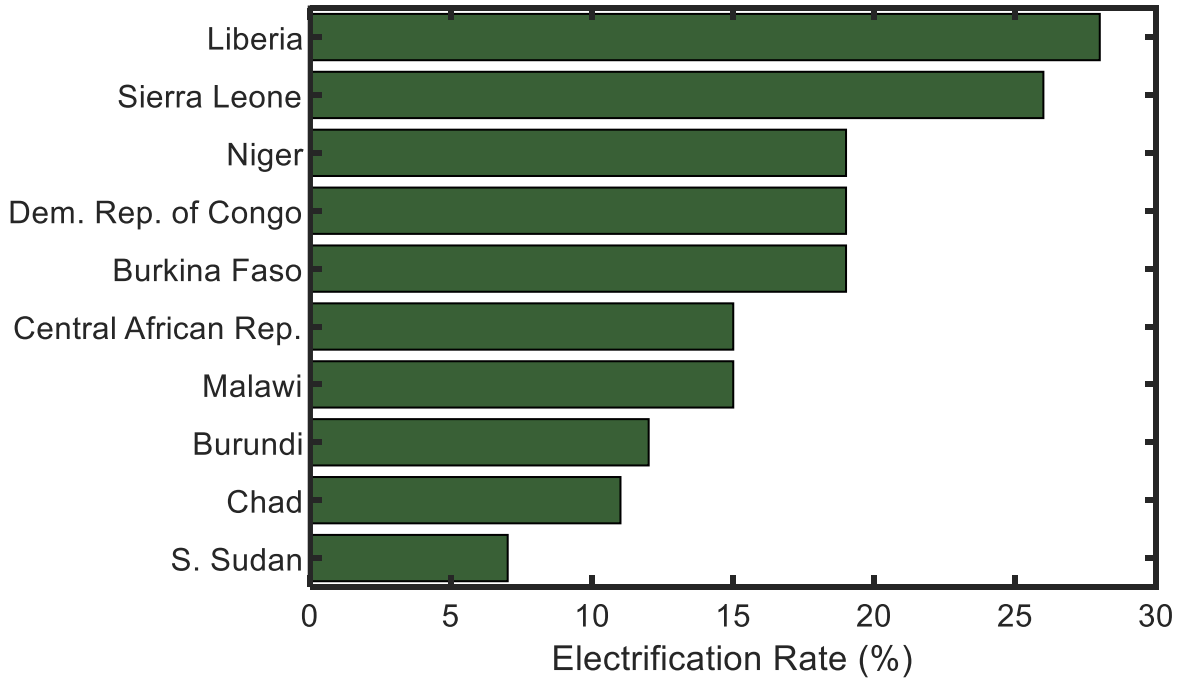
population with access plus population without access = total population

Electricity Access Around the World

Electrification rate of SSA is approx. 48%

Rural penalty

- World urban electrification rate: 97%
- World rural electrification rate: 83%
- SSA urban electrification rate: 78%
- SSA rural electrification rate is 28%



Source: Tracking SDG7, The Energy Progress Report, 2022

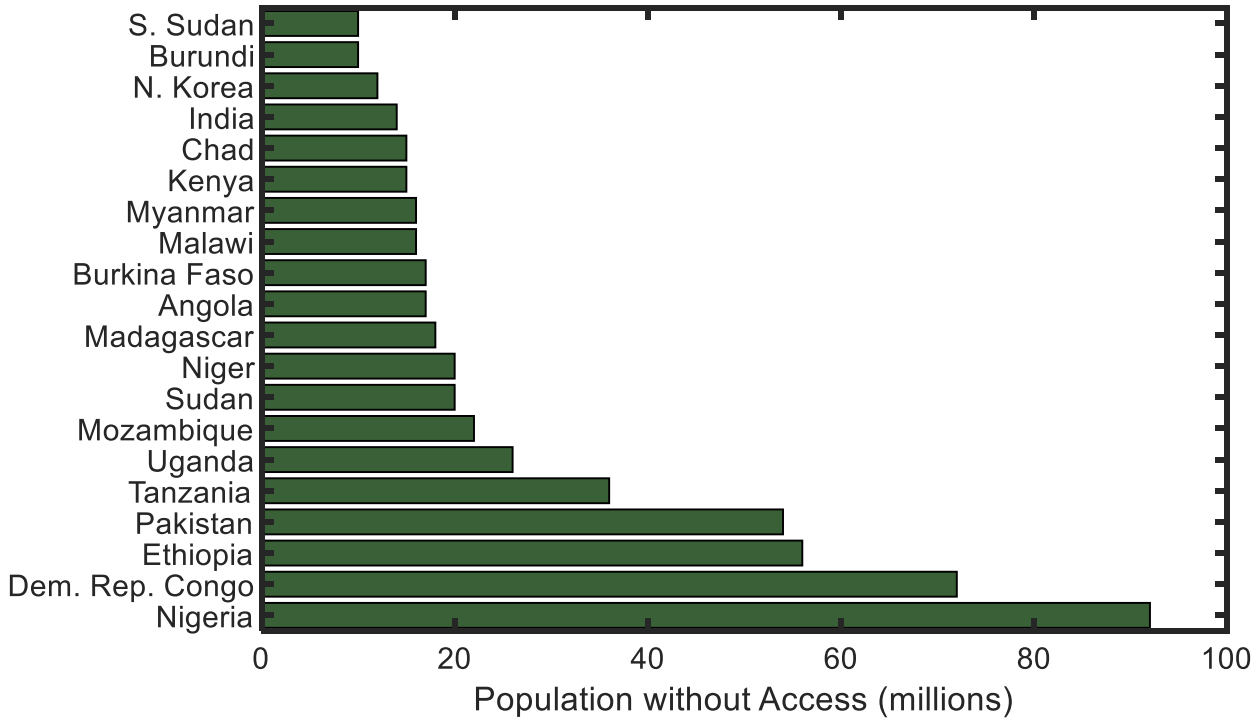
Countries with Largest Populations without Electricity Access

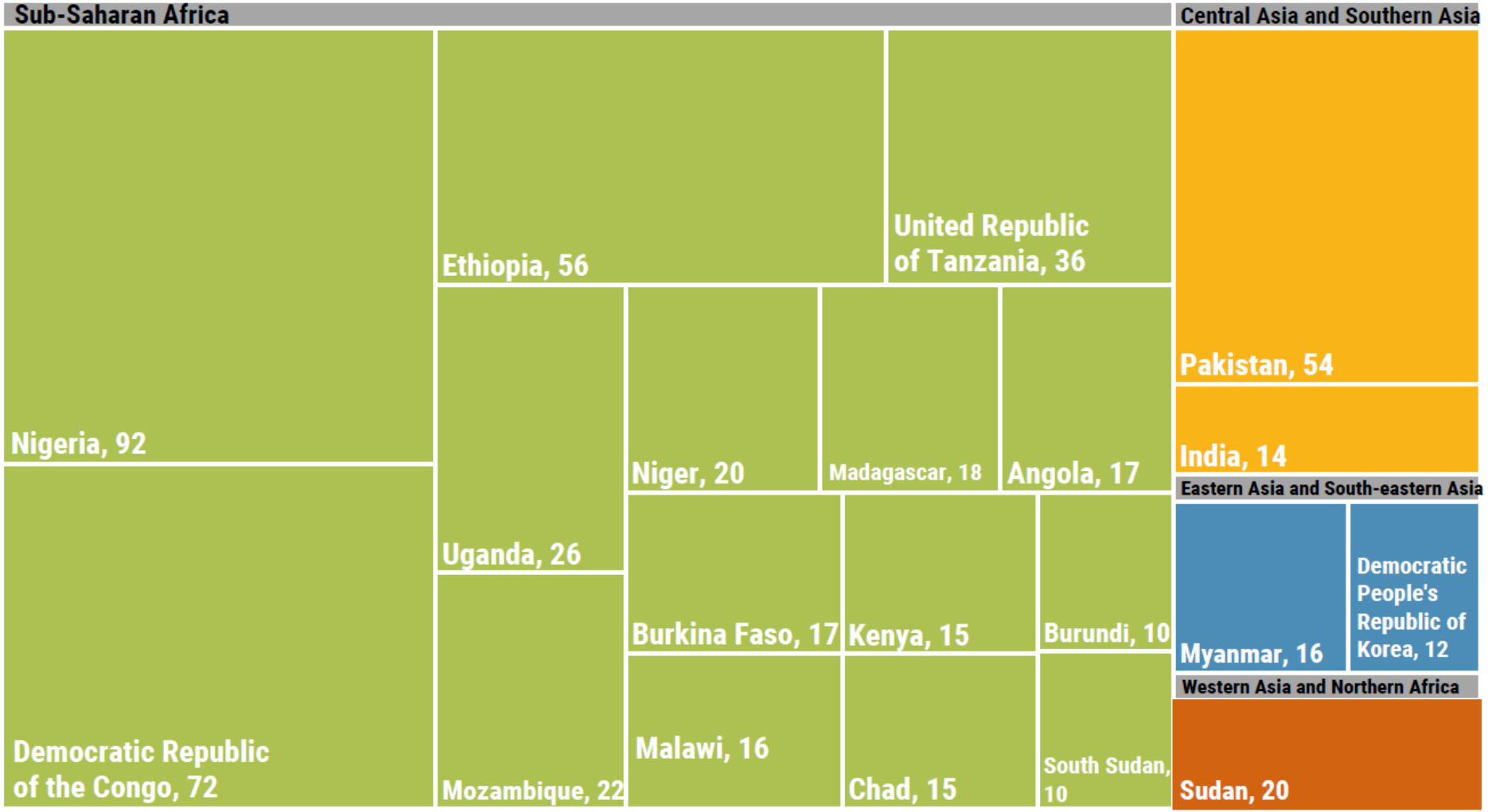
1) Nigeria (92 million*)
2) Democratic Republic of Congo (72 million*)
3) Ethiopia (56 million)
4) Pakistan (54 million)
5) Tanzania (36 million)

*Electricity access did not outpace population growth

Electricity Access Around the World

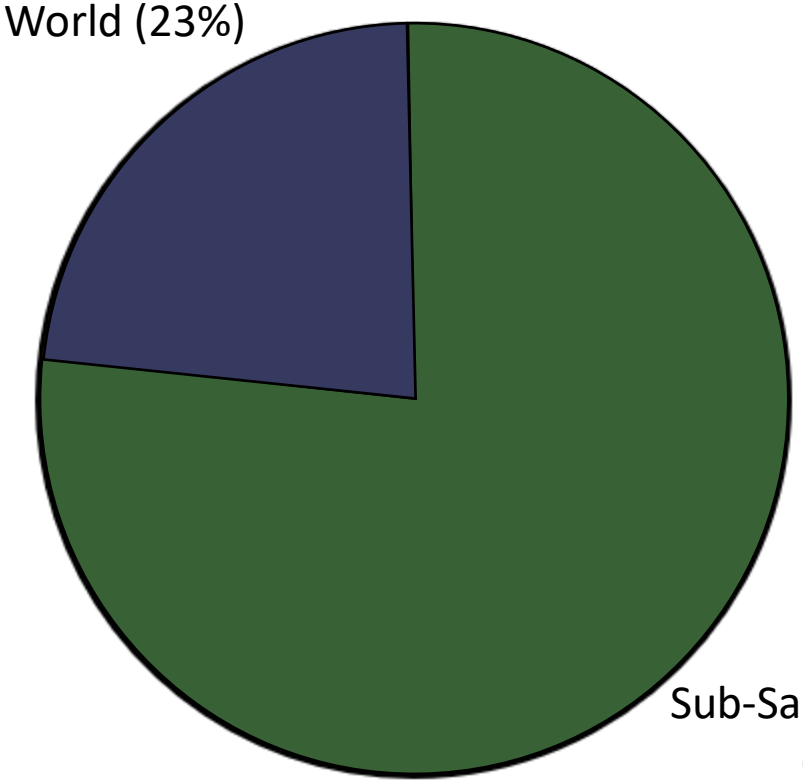
Approximately 76% of un-electrified live in just 20 countries





Source: Tracking SDG7, The Energy Progress Report, 2022

Distribution of Population without Electricity Access

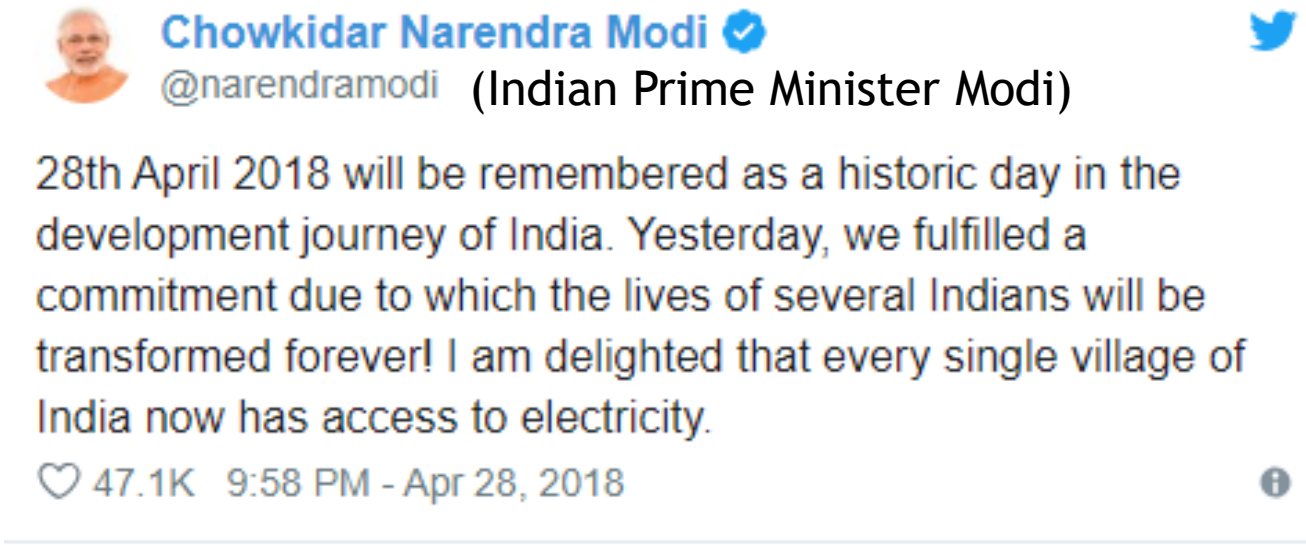


Zambia

Navajo Reservation, United States

(*courtesy D. Terry, Navajo Tribal Utility Authority*)

The headlines



The headlines

Every village in India now has electricity. But millions still live in darkness. --Washington Post

https://www.washingtonpost.com/world/asia_pacific/every-village-in-india-now-has-electricity-but-millions-still-live-in-darkness/2018/04/30/367c1e08-4b1f-11e8-8082-105a446d19b8_story.html?utm_term=.717711e32ff9

Modi Announces '100% Village Electrification', But 31 Million Indian Homes Are Still In The Dark --Forbes

https://www.forbes.com/sites/suparnadutt/2018/05/07/modi-announces-100-village-electrification-but-31-million-homes-are-still-in-the-dark/#64670d0763ba

Achieving Universal Electricity Access

Universal electricity access: global electrification rate of 100%

Time

Realistically, universal access is decades away. (see Problem 2.9)

Investment

Estimated annual investment through 2030 is $45 billion per year.
Present investment is approx. $10 billion per year.

Universal access is technically feasible, with relatively limited environmental impact depending on consumption

Is progress really being made?

Malawi in 2010

- total population: 14.8 million
- electrification rate: 9%

Malawi in 2012

- total population: 15.7 million
- electrification rate: 10%

An increase of 1 percentage point in electrification rate shows progress

Is progress really being made?

Malawi in 2010

- total population: 14.8 million
- electrification rate: 9%
- population without electricity: 13.47 million

Malawi in 2012

- total population: 15.7 million
- electrification rate: 10%
- population without electricity: 14.13 million

Number of people without electricity increased by 600,000!

Discussion

Do you consider Malawi to be making progress on electricity access?

Is progress really being made?

Sub-Saharan Africa in 2013

- total population: 0.952 billion
- electrification rate: 36.5%
- population without electricity: 604.5 million

Sub-Saharan Africa in 2014

- total population: 0.979 billion
- electrification rate: 37.7%
- population without electricity: 609.9 million

More people without access in 2014 than in 2013

Is progress really being made?

Sub-Saharan Africa in 2015

- total population: 1.01 billion
- electrification rate: 38.4%
- population without electricity: 622.2 million

Sub-Saharan Africa in 2016

- total population: 1.03 billion
- electrification rate: 42.8%
- population without electricity: 589.2 million

Electrification rate increasing AND population without access decreasing

Annual Growth Rate (AGR)

- Annual Growth Rate: quantifies the change in electricity access over a period of time
- AGR considers population growth dynamics as well as change in electricity access

$$AGR = \frac{(A[y] - A[y-t]) - (P[y] - P[y-t])}{P[y]} \times \frac{1}{t}$$

$$= \frac{\text{(pop. without access year in year } y-t\text{) - (pop. without access in year } y\text{)}}{P[y]} \times \frac{1}{\Delta t}$$

Annual Growth Rate (AGR)

$$AGR = \frac{(A[y] - A[y-t]) - (P[y] - P[y-t])}{P[y]} \times \frac{1}{t}$$

$$= \frac{\text{(pop. without access in year } y-t\text{) - (pop. without access in year } y\text{)}}{\text{population in year } y} \times \frac{1}{t}$$

$A[y]$: number of people with access to electricity in year y

$P[y]$: population in year y

t: period of time considered, years

Exercise

Compute the AGR of Malawi between 2010 and 2012

Malawi in 2010

- total population: 14.8 million
- electrification rate: 9%
- population without electricity: 13.47 million

Malawi in 2012

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- electrification rate: 10%
- population without electricity: 14.13 million

$$AGR = \frac{\text{(pop. without access in year } y - t\text{) - (pop. without access in year } y\text{)}}{\text{population in year } y} \times \frac{1}{t}$$

$$= \frac{13.47 - 14.13}{15.7} \times \frac{1}{2} = -0.021$$

If population without electricity increases, then the AGR will be negative

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