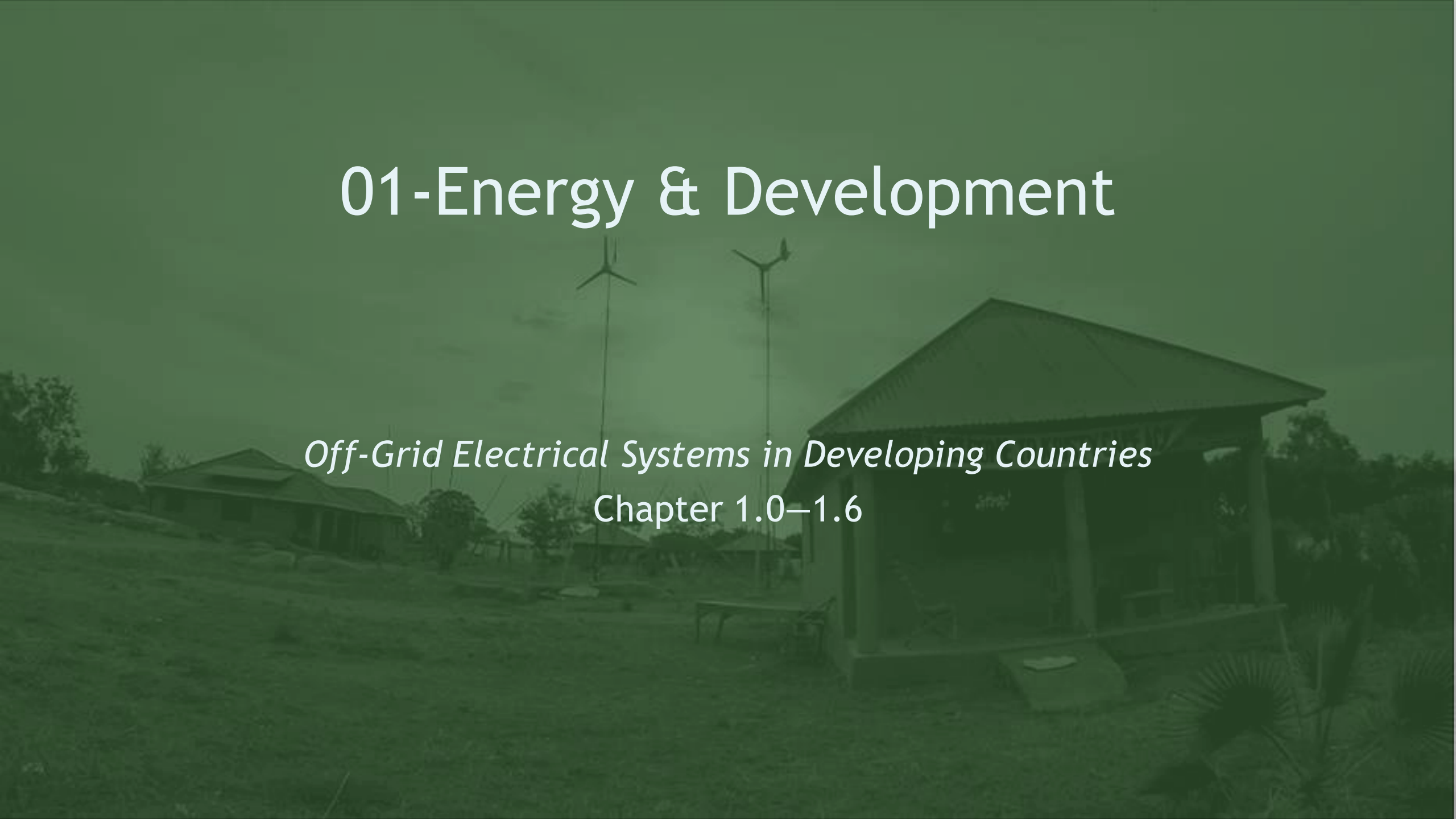


# 01-Energy & Development

*Off-Grid Electrical Systems in Developing Countries*

Chapter 1.0—1.6





# Learning Outcomes

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

- ✓ define “electrification” and describe the motivations for studying it
- ✓ articulate the basic descriptors of rural off-grid communities
- ✓ describe the present and historical trends of energy and electricity consumption
- ✓ describe the various approaches to providing off-grid electricity access

# Off-Grid Electrification

Off-Grid Electrification: *providing electricity to an unserved population by a means other than a connection to the existing centralized grid*

# Why Study Off-Grid Electrification?



## Humanitarian/social justice

- rural poor most likely to be energy impoverished
- access to electricity improves lives and livelihoods



## Business opportunity

- >100,000 mini-grids needed
- >100 million solar lanterns and solar home systems sold



## Intellectual merit

- intersection of technology & society
- dynamic and growing space---need for innovation and problem solvers
- technical principles are widely applicable

# “Third World” Countries

- Antiquated way of classifying countries based on political ideology
  - First World: United States, Western Europe, etc. (capitalist countries)
  - Second World: USSR, (communist countries)
  - Third World: the other countries
- “Third world” should be avoided

# “Developing” Countries

- No universal definition of a “developing” country
  - United Nations does not have a definition of developing country
- “Development” is often based on per person Gross Domestic Product
- Also used:
  - Global South
  - Emerging Markets/Frontier Markets
  - Least Developed Countries
  - Less Economically Developed Countries
- Associated Press recommends using “Developing Country”

See <https://unstats.un.org/unsd/methodology/m49/>

|                                  |  |                                       |                                  |                                  |                                  |  |                                      |
|----------------------------------|--|---------------------------------------|----------------------------------|----------------------------------|----------------------------------|--|--------------------------------------|
| Afghanistan                      | British Indian Ocean Territory                 | Democratic People's Republic of Korea | Guam                             | Madagascar                       | Nigeria                          | Samoa  | Tokelau                              |
| Algeria                          | British Virgin Islands                         | Democratic Republic of the Congo      | Guatemala                        | Malawi                           | Niue                             | Sao Tome and Principe                        | Tonga                                |
| American Samoa                   | Brunei Darussalam                              | Djibouti                              | Guinea                           | Malaysia                         | Northern Mariana Islands         | Saudi Arabia                                 | Trinidad and Tobago                  |
| Angola                           | Burkina Faso                                   | Dominica                              | Guinea-Bissau                    | Maldives                         | Oman                             | Senegal                                      | Tunisia                              |
| Anguilla                         | Burundi  | Dominican Republic                    | Guyana                           | Mali                             | Pakistan                         | Seychelles                                   | Turkey                               |
| Antarctica                       | Cabo Verde                                     | Ecuador                               | Haiti                            | Marshall Islands                 | Palau                            | Sierra Leone                                 | Turkmenistan                         |
| Antigua and Barbuda              | Cambodia                                       | Egypt                                 | Honduras                         | Martinique                       | Panama                           | Singapore                                    | Turks and Caicos Islands             |
| Argentina                        | Cameroon                                       | El Salvador                           | India                            | Mauritania                       | Papua New Guinea                 | Sint Maarten (Dutch part)                    | Tuvalu                               |
| Armenia                          | Cayman Islands                                 | Equatorial Guinea                     | Indonesia                        | Mauritius                        | Paraguay                         | Solomon Islands                              | Uganda                               |
| Aruba                            | Central African Republic                       | Eritrea                               | Iran (Islamic Republic of)       | Mayotte                          | Peru                             | Somalia                                      | United Arab Emirates                 |
| Azerbaijan                       | Chad   | Eswatini                              | Iraq                             | Mexico                           | Philippines                      | South Africa                                 | United Republic of Tanzania          |
| Bahamas                          | Chile  | Ethiopia                              | Jamaica                          | Micronesia (Federated States of) | Pitcairn                         | South Georgia and the South Sandwich Islands | United States Minor Outlying Islands |
| Bahrain                          | China  | Falkland Islands (Malvinas)           | Jordan                           | Mongolia                         | Puerto Rico                      | South Sudan                                  | United States Virgin Islands         |
| Bangladesh                       | China, Hong Kong Special Administrative Region | Fiji                                  | Kazakhstan                       | Montserrat                       | Qatar                            | Sri Lanka                                    | Uruguay                              |
| Barbados                         | China, Macao Special Administrative Region     | French Guiana                         | Kenya                            | Morocco                          | Republic of Korea                | State of Palestine                           | Uzbekistan                           |
| Belize                           | Colombia                                       | French Polynesia                      | Kiribati                         | Mozambique                       | Réunion                          | Sudan  | Vanuatu                              |
| Benin                            | Comoros  | French Southern Territories           | Kuwait                           | Myanmar                          | Rwanda                           | Suriname                                     | Venezuela (Bolivarian Republic of)   |
| Bhutan                           | Congo  | Gabon                                 | Kyrgyzstan                       | Namibia                          | Saint Barthélemy                 |  | Viet Nam                             |
| Bolivia (Plurinational State of) | Cook Islands                                   | Gambia                                | Lao People's Democratic Republic | Nauru                            | Saint Helena                     | Syrian Arab Republic                         | Wallis and Futuna Islands            |
| Bonaire, Sint Eustatius and Saba | Costa Rica                                     | Georgia                               | Lebanon                          | Nepal                            | Saint Kitts and Nevis            | Tajikistan                                   | Western Sahara                       |
| Botswana                         | Côte d'Ivoire                                  | Ghana                                 | Lesotho                          | New Caledonia                    | Saint Lucia                      | Thailand                                     | Yemen                                |
| Bouvet Island                    | Cuba   | Grenada                               | Liberia                          | Nicaragua                        | Saint Martin (French Part)       | Timor-Leste                                  | Zambia                               |
| Brazil                           | Curaçao  | Guadeloupe                            | Libya                            | Niger                            | Saint Vincent and the Grenadines | Togo   | Zimbabwe                             |

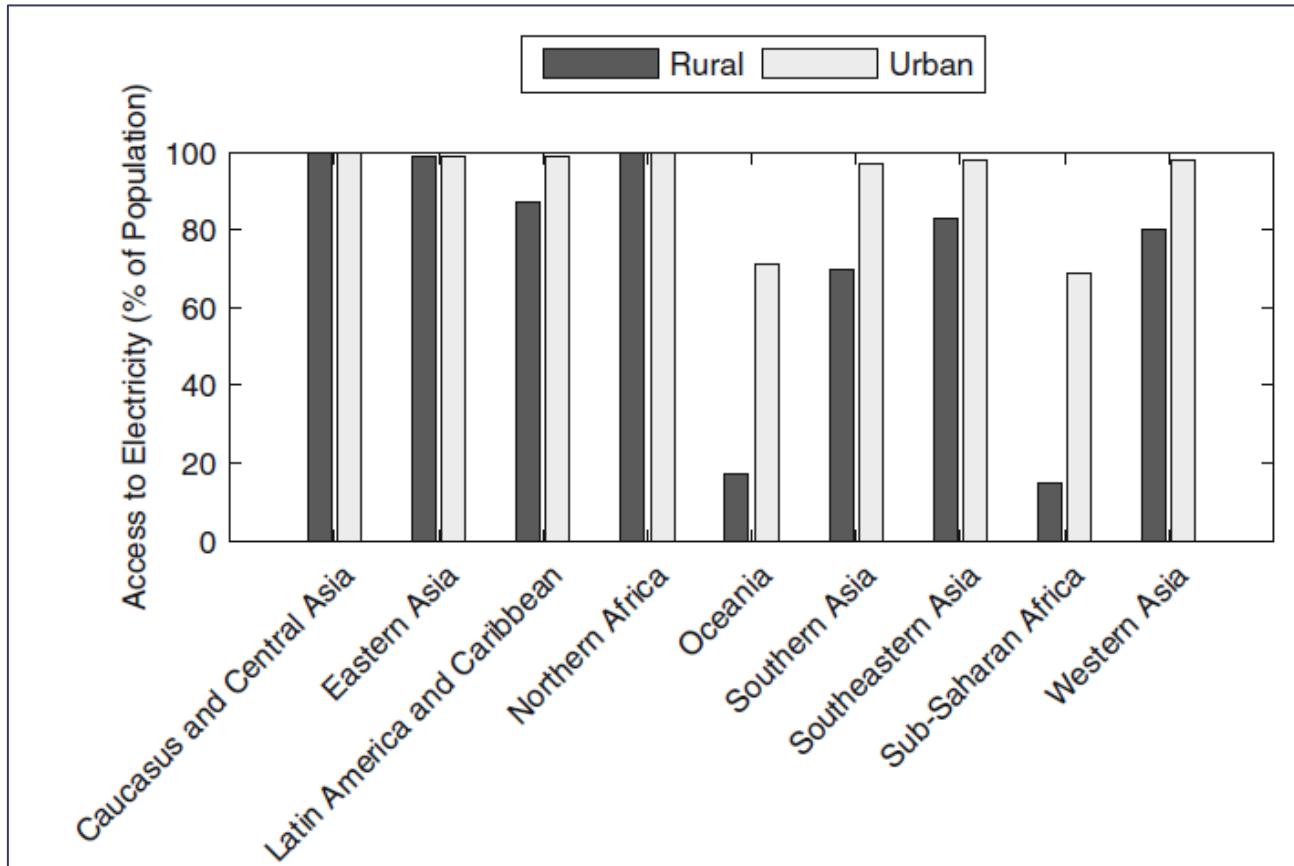
UN-designated  
developing  
countries/regions

See also “Least  
Developed Country”

# General Developing Country Characteristics

- High levels of poverty
- Poor nutrition, healthcare, education
- Vulnerable to external threats





## Rural Penalty

- Rural communities much more likely to be un-electrified
- >100 million urban residents are not connected
- Many are “under the grid” (within 200m of the grid) but are not connected



(courtesy P. Dauenhauer)



# Rural Communities

## Common Characteristics

- decentralized population
- geographic isolation
- underserved in terms of healthcare, education, clean water, sanitation, and other infrastructure
- unable to participate in regional and national markets

# Energy & Human Development

Access to energy underpins all human activities



food



transportation



healthcare



education



business



entertainment



information/  
communication

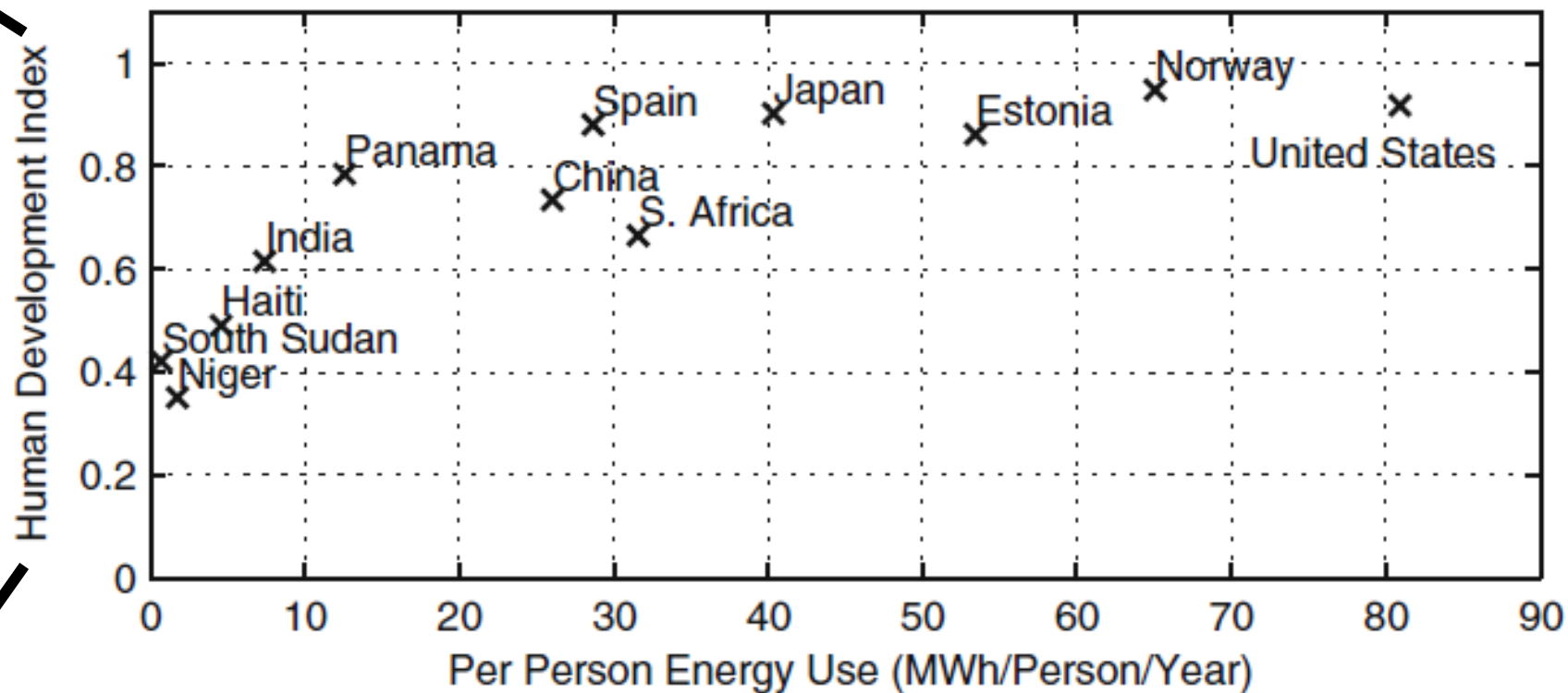
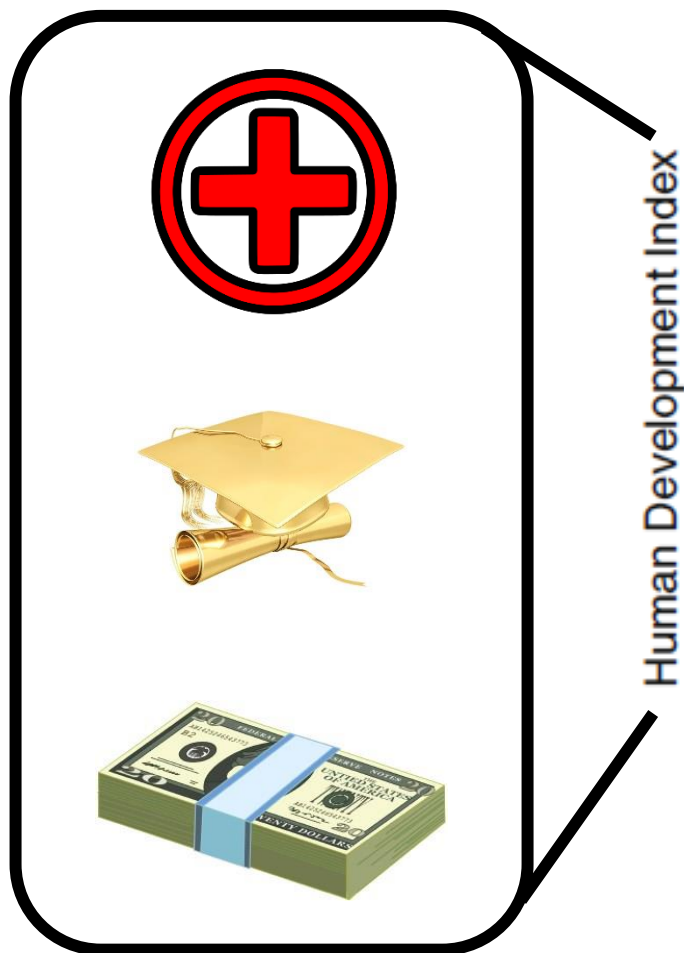


# SUSTAINABLE DEVELOPMENT GOALS



Which other SDG are enabled by access to electricity?

# Human Development Index



See supplemental slides on HDI calculation

# Units of Energy

| Unit                             | Joules                   |
|----------------------------------|--------------------------|
| Joule (J)                        | 1                        |
| Calorie (cal)                    | 4.1868                   |
| British Thermal Unit (BTU)       | 1055.87                  |
| Watt hour (Wh)                   | 3600                     |
| Kilocalorie (C, kcal)            | 4186.8                   |
| Kilowatt hour (kWh)              | $3.6 \times 10^6$        |
| Kilogram of oil equivalent (koe) | $41.868 \times 10^6$     |
| Megawatt hour (MWh)              | $3.6 \times 10^9$        |
| Tonne of oil equivalent (toe)    | $41.868 \times 10^9$     |
| Quad (quad)                      | $1055.87 \times 10^{15}$ |
| Gigajoule (GJ)                   | $1 \times 10^9$          |
| Terawatt hour (TWh)              | $3.6 \times 10^{15}$     |

Electrical energy is commonly expressed in watt hours (Wh) (or kWh, MWh, TWh) rather than joules

The average house in the U.S. consumes 30 kWh of electricity each day

# Exercise

The 2013 average annual per person energy consumption in Zambia was 26.6 GJ. Compute the average daily consumption in kilowatthours per day.

# Exercise

The 2013 average annual per person energy consumption in Zambia was 26.6 GJ. Compute the average daily consumption in kilowatthours per day.

$$26.6 \text{ GJ/yr} = \frac{26.6 \text{ GJ/yr}}{365 \text{ day/yr}} = 72.8 \text{ MJ/day}$$

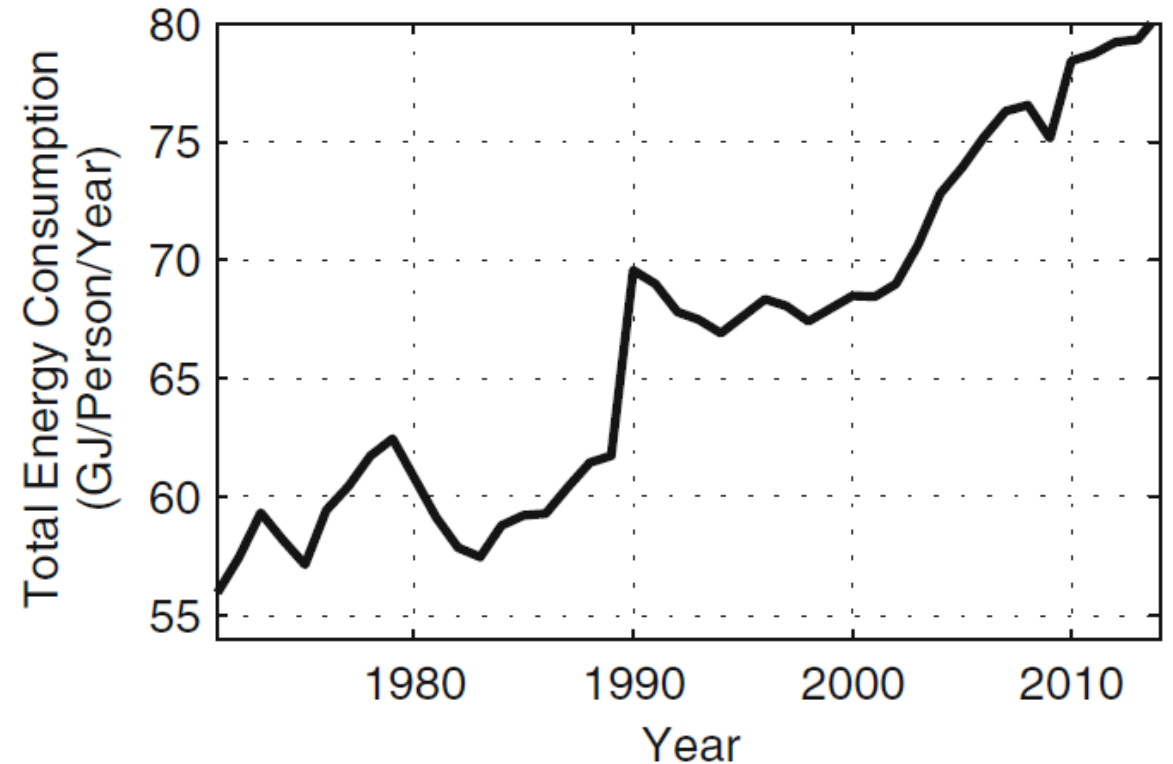
$$72.8 \text{ MJ/day} = \frac{72.87 \text{ MJ/day}}{3.6 \text{ MJ/kWh}} = 20.24 \text{ kWh/day}$$



# Total Energy Consumption

Global per person consumption has shown an increasing trend

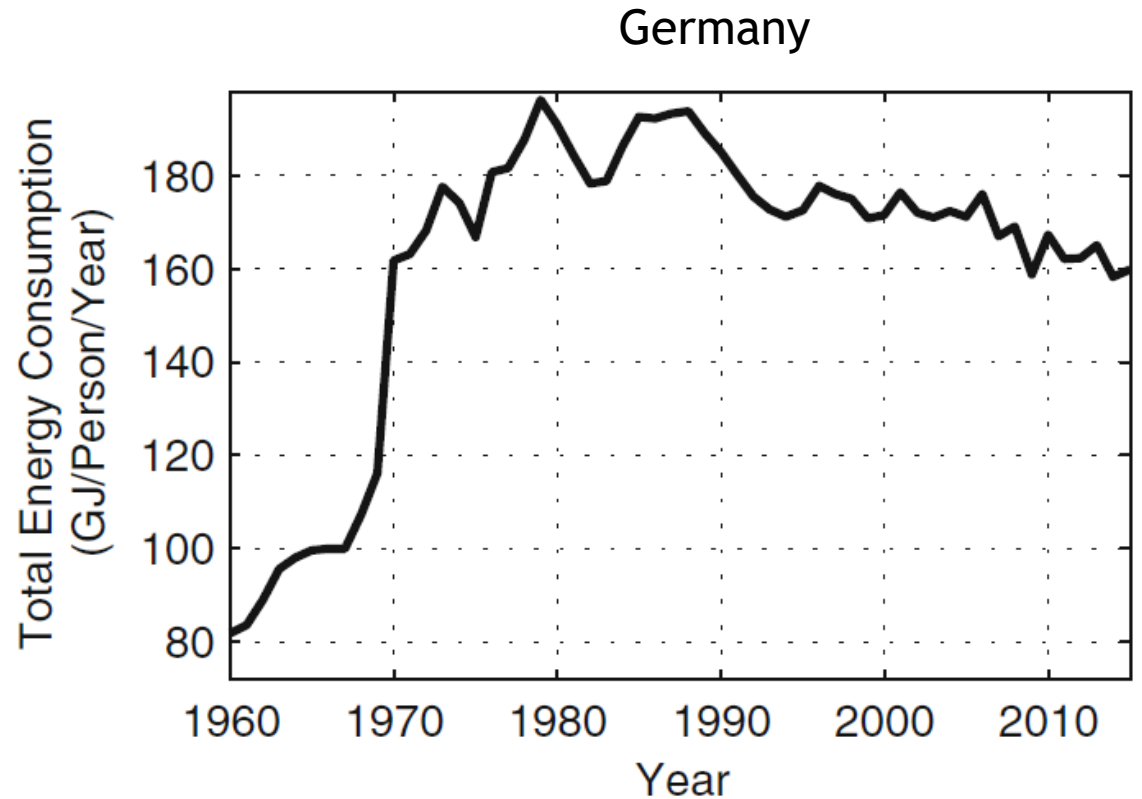
What caused the temporary dip in consumption in 2008-2009?



# Energy Consumption Trends

- Increasing trend in consumption is not universal
- Several developed countries have stagnant or declining per person consumption

What do you think caused the decline in energy consumption?



# Energy Inequality

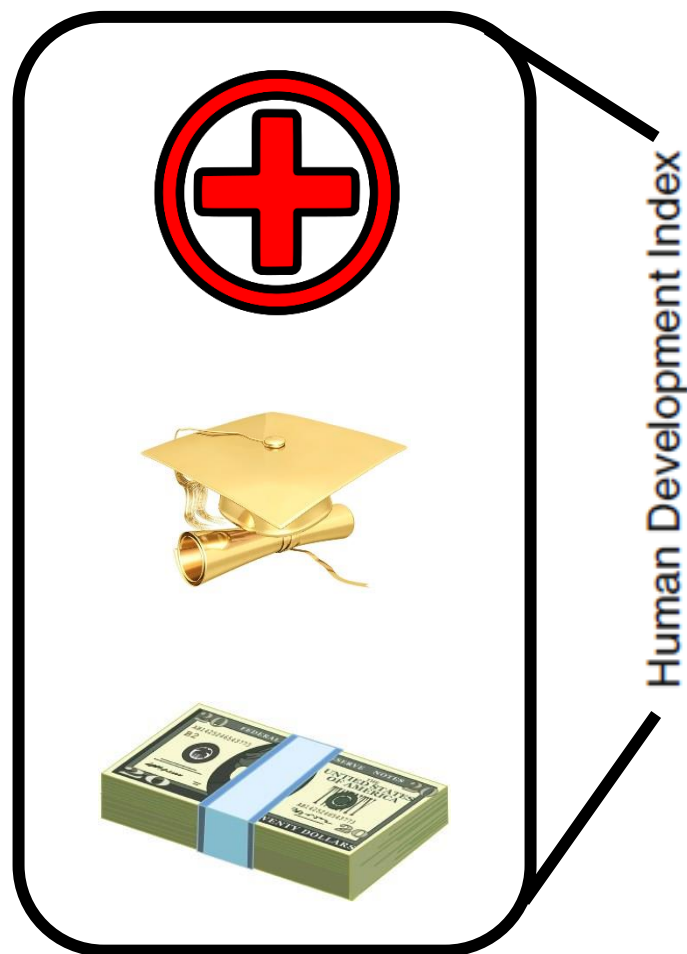
- World average per person energy consumption is 80 GJ/person/year
- Vast inequality in consumption
  - Canada: 318 GJ/person/year
  - Sub-Saharan Africa (average): 29 GJ/person/year

The over 1 billion people in Africa consume less than 4% of the world's energy

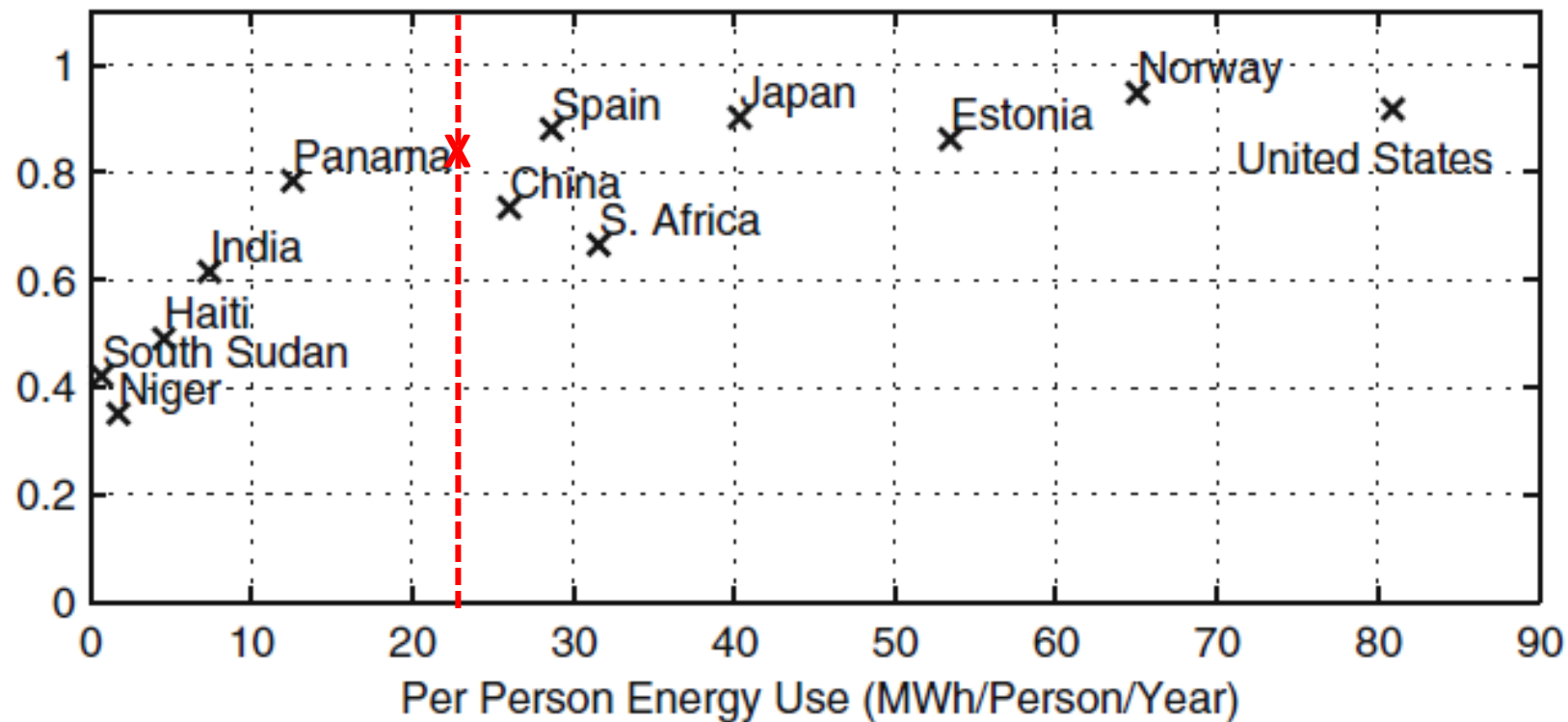
# Energy Inequality

Real problem is equitable distribution of energy

Global Average Energy Use

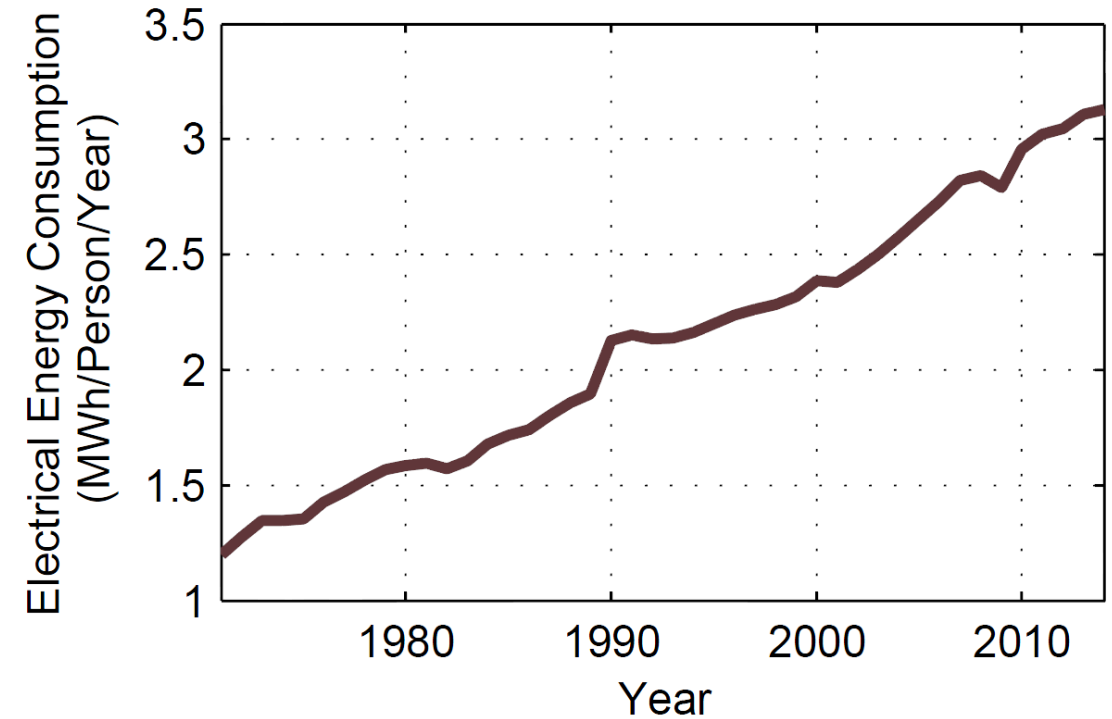


Human Development Index



# Global Electricity Consumption

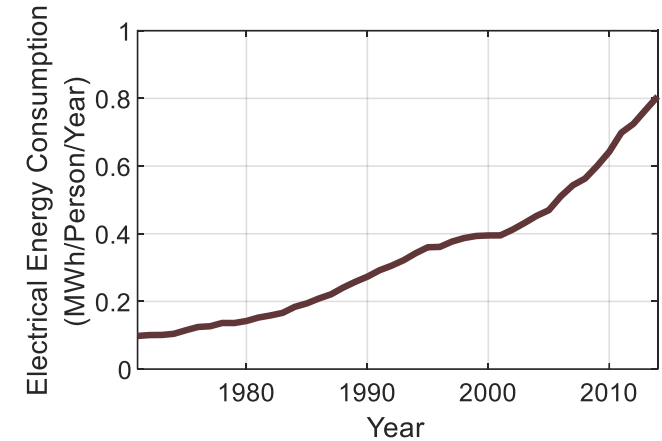
- Global per person electricity consumption has steadily increased 260% from 1972 to 2015 (2.3% per year)
- Total electricity consumption increased by 505%



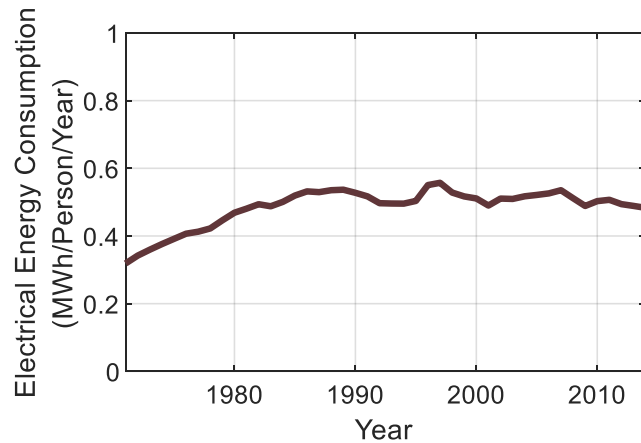
# Match the country/region to its electricity consumption

China  
India  
Sub-Saharan Africa  
United States

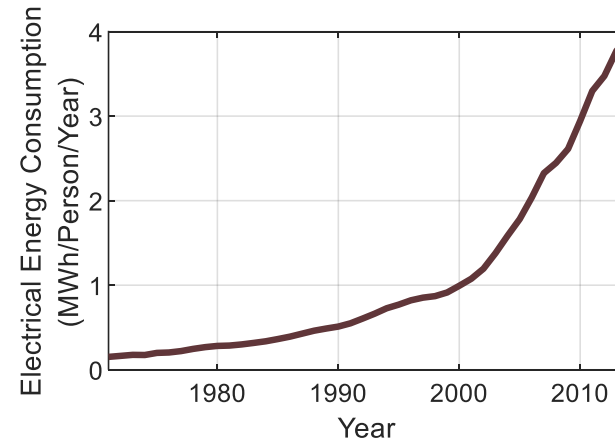
Country/Region: \_\_\_\_\_



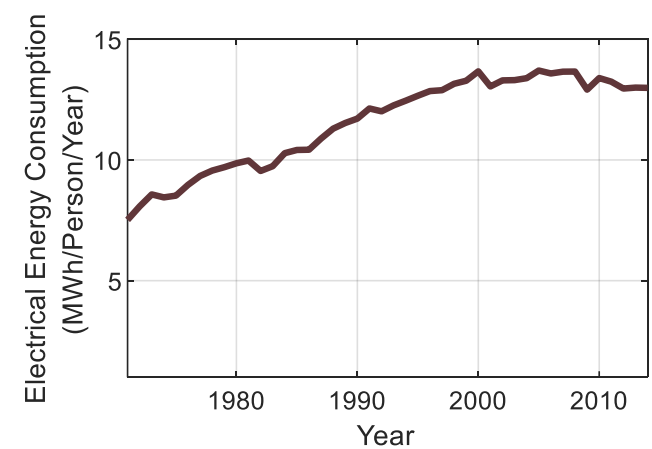
Country/Region: \_\_\_\_\_



Country/Region: \_\_\_\_\_



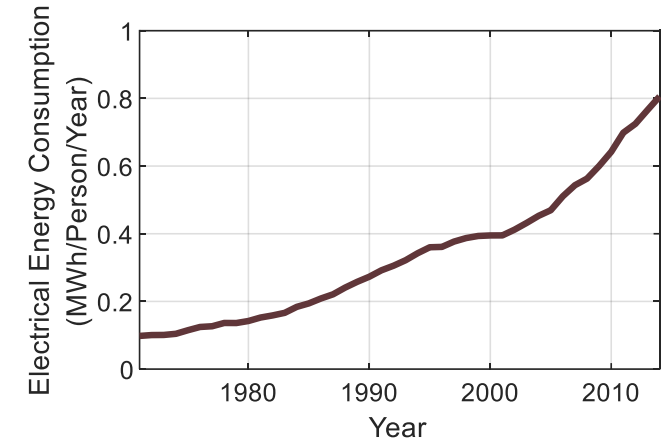
Country/Region: \_\_\_\_\_



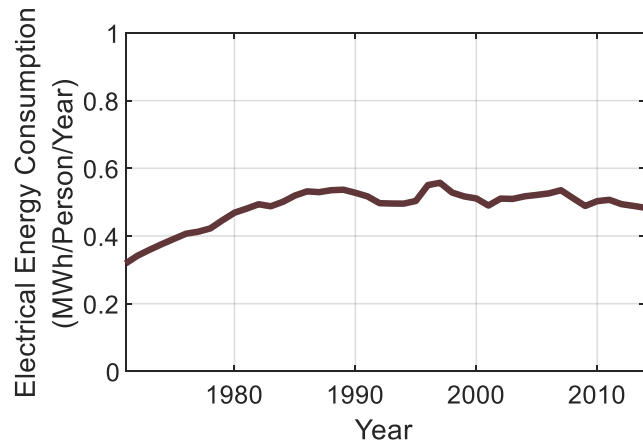
# Match the country/region to its electricity consumption

China  
India  
Sub-Saharan Africa  
United States

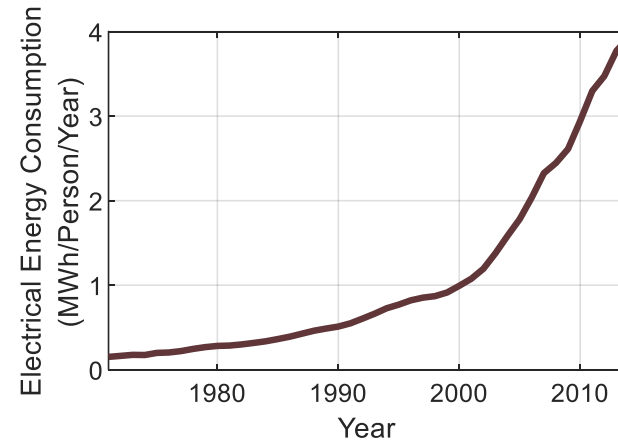
Country/Region: India



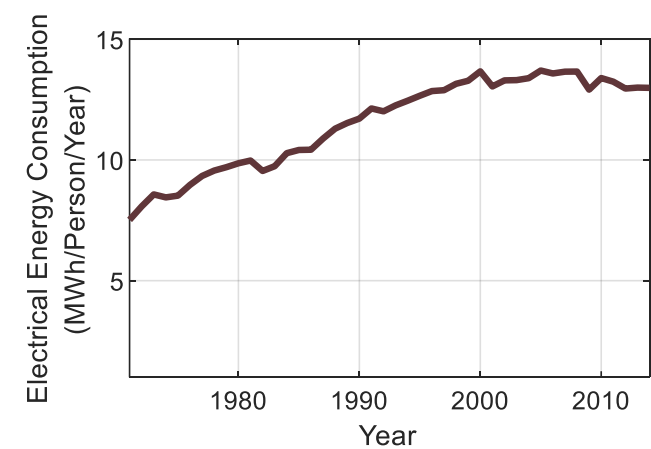
Country/Region: SSA



Country/Region: China



Country/Region: USA



# Electrification Approaches

Solar Lanterns



*(courtesy of d.Light)*

Solar Home Systems



*(courtesy of BBOXX)*

Energy Kiosks



*(courtesy of KiloWatts for Humanity)*

Mini-Grids

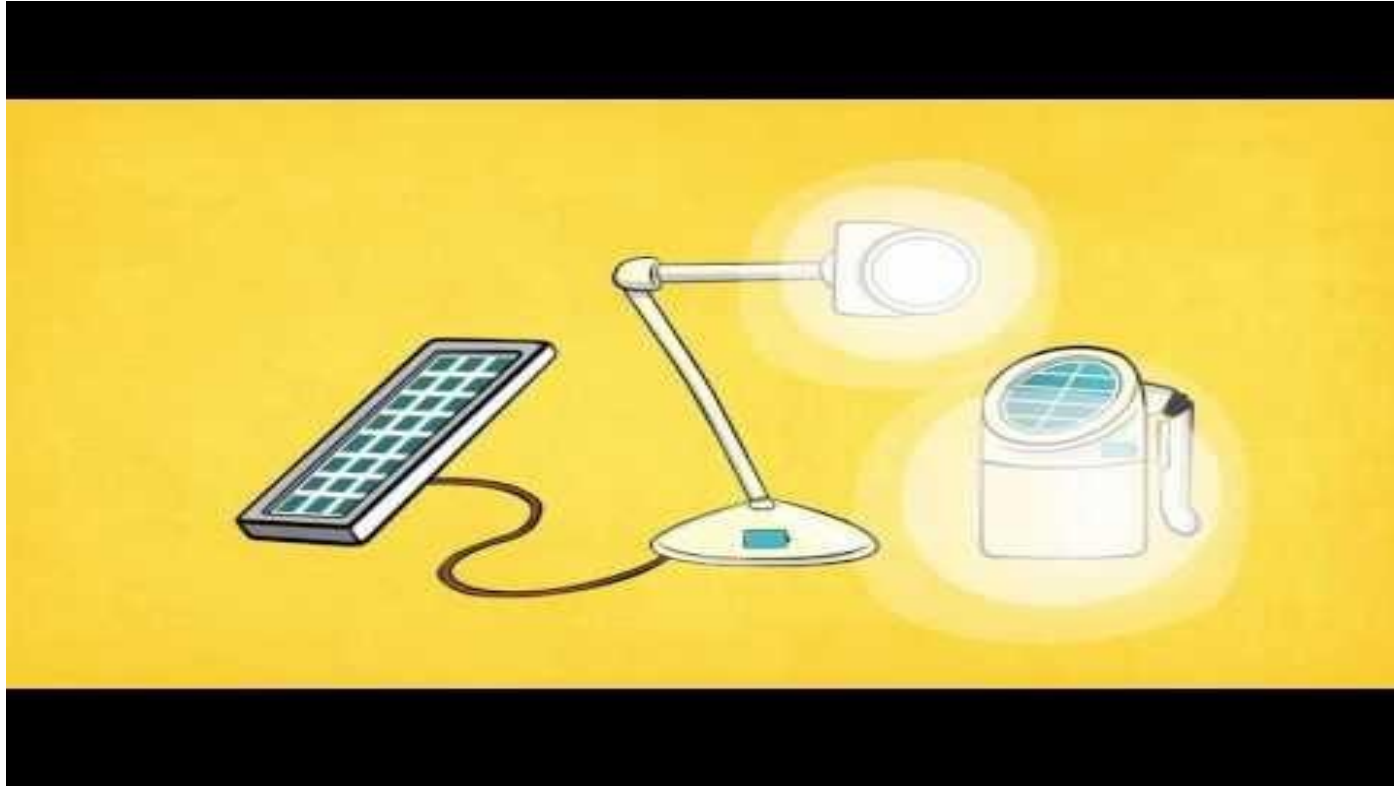


*(courtesy of PowerGen)*

**Increasing Energy Access**



# Solar Lanterns & Solar Home Systems



Source: Lighting Africa

# Solar Lanterns (“pico solar”)

- “Entry level” electricity access
- Components
  - small (<10W) photovoltaic (PV) panel
  - Battery (usually <20Wh)
  - LED light(s)
  - USB port for charging (on larger systems)
- Designed for portability
- Low-cost \$5-\$20



d.Light S30



Sun King Pro 2000



M-KOPA 4



forsera Group  
PSHS 3000

# Solar Home Systems (SHS)

- Higher-tier electricity access
- Components
  - Larger PV panel (usually 20W to 60W)
  - Battery (100Wh-300Wh)
  - LED lights
  - USB ports
  - Inverter (larger systems)
  - Appliances (DC TVs, fans)



BBOX



d.light X850

# Energy Kiosks (Charging Stations)

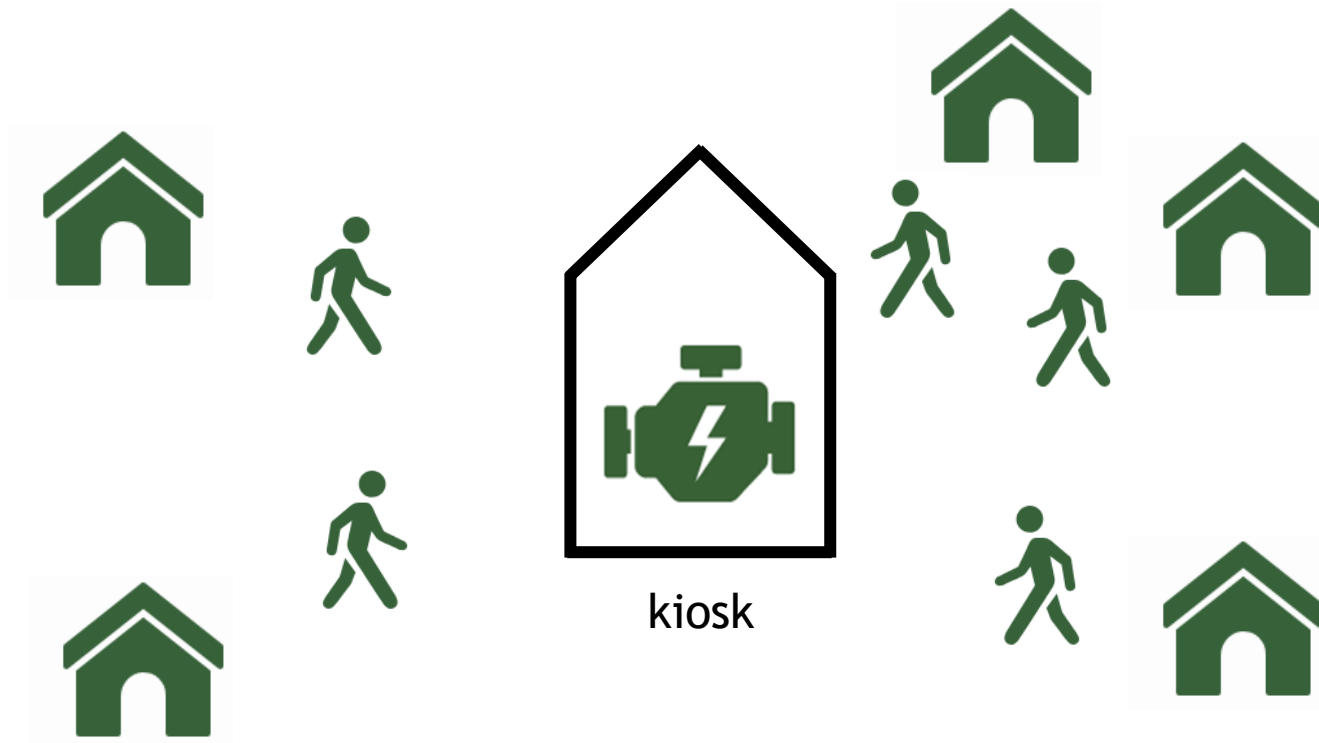
- High tier electricity access
- Can supply high-power loads
  - refrigerators
  - pumps
  - mills
- Walk-up retail service model
  - phone/battery recharging
- No or limited distribution system



# Energy Kiosk

People carry phones and batteries to the kiosk for recharging

Kiosk powers high-power loads



# Mini-Grids (also “micro-grid”)

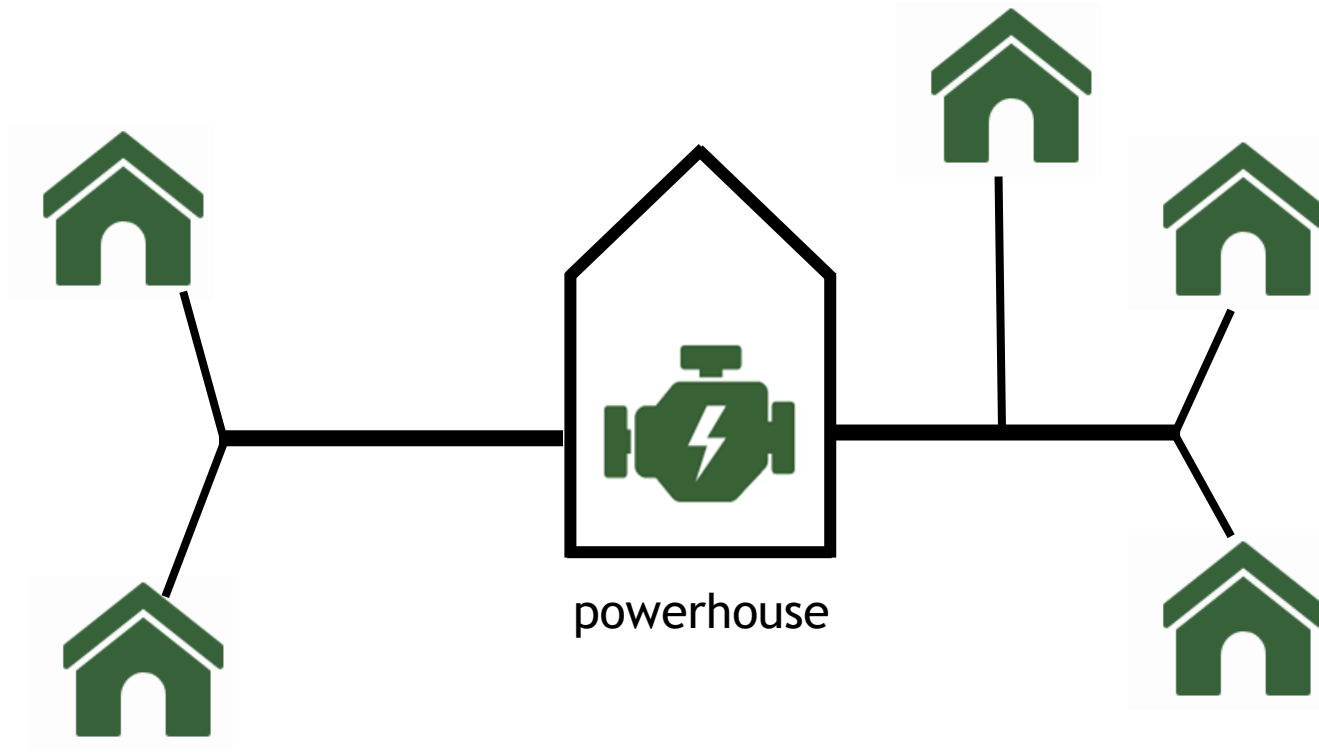
- High tier electricity access
- Replicates grid connection
- Distribution system



*(courtesy of PowerGen)*

# Mini-Grid

Distribution lines  
supply electricity to  
users




# Contact Information

Henry Louie, PhD

Professor

Seattle University

 @henrylouie

[hlouie@ieee.org](mailto:hlouie@ieee.org)

Office: +1-206-398-4619